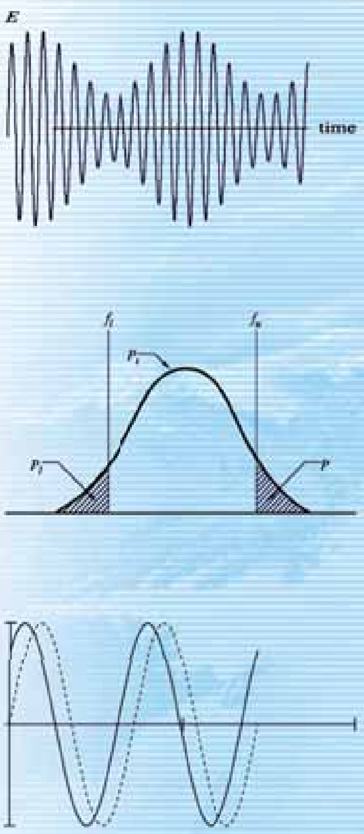
International Telecommunication Union

Handbook

Spectrum Monitoring – Supplement



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FOREWORD

The purpose of this Supplement to the ITU-R Handbook – Spectrum Monitoring, Edition 2002, is to provide, in a timely manner, up-to-date information on several issues before the publication of the next complete edition of the Handbook. Specifically, it provides a complete and self-contained revision of Chapter 3 (Monitoring equipment and automation of monitoring operations), § 5.1 (Spacecraft emission monitoring) of Chapter 5 and Annex 1 (Monitoring system planning and tenders) of the Handbook.

This Supplement was prepared by a Rapporteur Group established for this purpose by Radiocommunication Study Group 1. I convey my great appreciation to the Rapporteur, Chapter Rapporteurs and Co-Rapporteurs, contributors, participants and all those who have provided lots of support and dedication to the work of the Rapporteur Group for the successful development of the Supplement.

Valery Timofeev

Director, Radiocommunication Bureau

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CHAPTER 3

MONITORING EQUIPMENT AND AUTOMATION OF MONITORING OPERATIONS

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3.1 Introduction

3.1.1 General considerations

The equipment available at a radio monitoring station should be suitable to perform the measurements required at that station. The measurements are derived from the tasks that the station has been assigned. These tasks in turn depend on the purpose and goals of radio monitoring within the country as covered in § 1.3 and § 2.3. The nature and quality of the measurements will determine which types of equipment are necessary.

A monitoring station that will take part in the international monitoring system must be able to carry out the measurements with an accuracy that complies with the technical standards for monitoring stations contained within the relevant ITU-R Recommendations. Where applicable, these Recommendations are mentioned in § 3.3 to 3.5. Other characteristics of the equipment should meet the minimum criteria as stated in the relevant parts of § 3.3 to 3.5. Particular attention should be paid to provide recommended linearity for measurement receivers and active antennas as discussed in § 3.1.2 and to take into account the effect of the environment, such as surrounding metallic structures.

For a monitoring station, a minimum set of equipment would be a receiver and an antenna system for the frequency range of interest. A rotatable directional antenna can provide coarse bearing information. Basic frequency and field-strength measurement capability is also required and may be provided by using a calibrated receiver and antenna.

This system could then be supplemented by the addition of a process controller to provide automation of some basic measurement tasks and direction-finding (DF) equipment for azimuth bearing information. Most monitoring stations use automation to relieve the operators from performing time-consuming, long-term measurements such as conducting spectrum occupancy measurements.

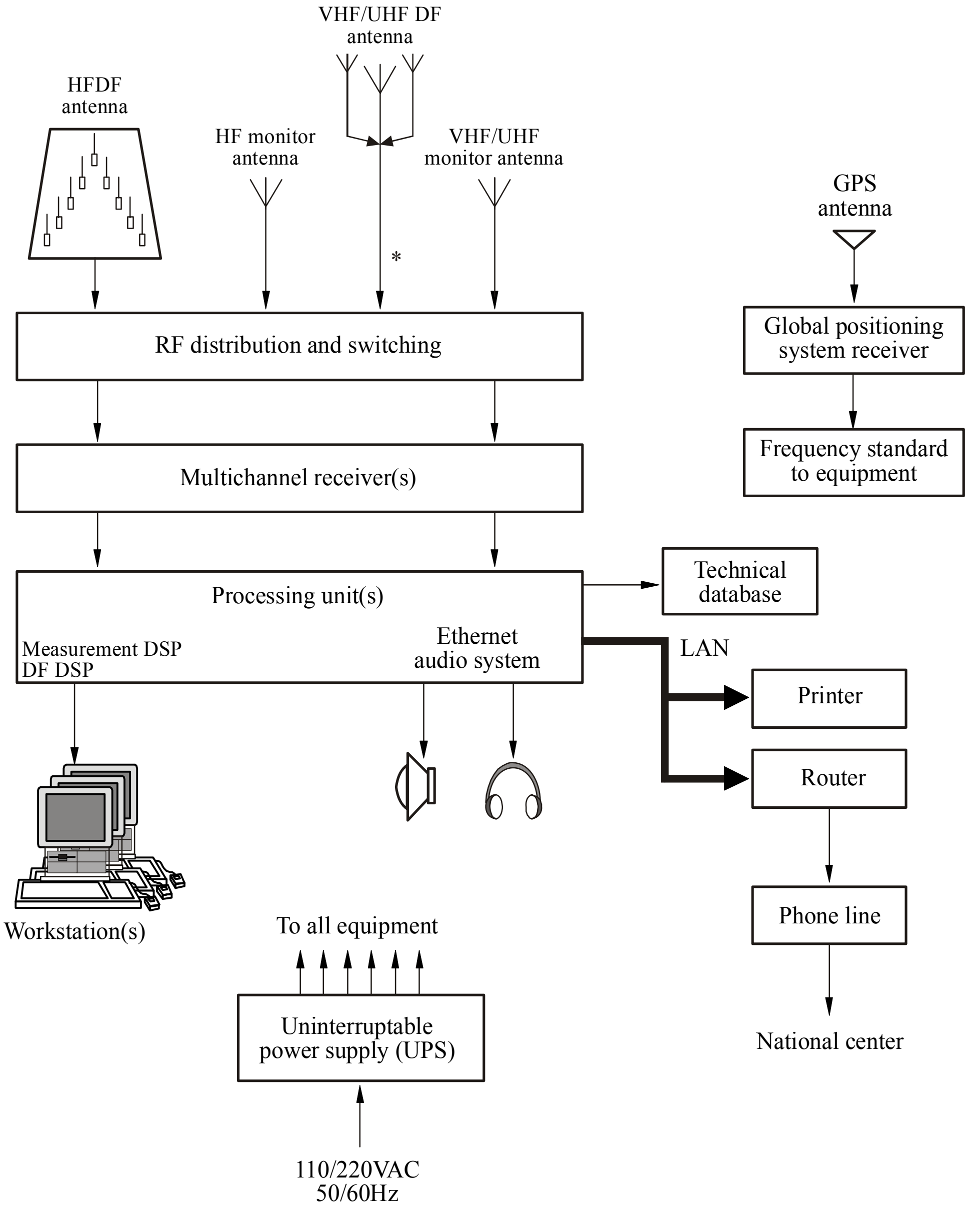
The most sophisticated monitoring systems consist of a hierarchy of national, regional, remote and mobile monitoring stations networked together in real-time to provide integrated control of multiple stations from a single operation console. This type of system is computer-and network-based, using sophisticated software to relieve the operators of tedious tasks and greatly increase measurement speed. It also increases equipment utilization by allowing background tasks, such as searching for unlicensed transmitters, to be automatically executed when the equipment is not required for other purposes.

A block diagram of a modern, integrated monitoring station with minimum equipment is shown in Fig. 3-1. The station uses receivers covering frequencies from 9 kHz to 3 000 MHz to provide basic measurement functionality for frequency, field strength, modulation analysis and DF. The control unit allows measurements such as spectrum occupancy to be made over time. A database containing licensing and technical information or a direct interface to a spectrum management system database is provided. This technical database includes technical information on licensed stations and their parameters, which allows an integrated station to identify frequencies on which there are transmitters that are not included in the database and therefore are presumably unlicensed, and to identify transmitters that are not operating within their licensed parameters.

It should be noted that the overall accuracy of radio monitoring systems depends not only on specifications of individual components such as receivers and antennas. Relevant parameters such as linearity, sensitivity, azimuth accuracy and field strength accuracy may also be influenced by the type and length of the cables between the system components as, well as by environmental conditions.

FIGURE 3-1

Block diagram of an integrated monitoring station



* Can also be connected directly to the processing unit.

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3.1.2 Influence of interference environment

Ideally, monitoring stations should be placed at sites where monitoring is not interfered with by transmitters close by, or by high-voltage lines or microwave links passing across the site. Further, once a site is selected, or more importantly, once monitoring operations have started, the site should be protected by means such as frequency planning.

Since the aforementioned principle cannot always be observed, the antennas and receivers of spectrum monitoring stations generally operate under interference conditions that are generally far more rigorous than those experienced by ordinary communication-receiving antennas and receivers. The working frequency, location, antenna height and azimuth, etc., of a fixed-service receiver are specially selected at the frequency assignment stage such that the receiver in question is adequately protected (by providing an appropriate frequency and a geographical separation between radio stations based, in particular, on the given parameters of the antenna and receiver) from the effects of interference from transmitters of other radio links. Every effort is made therefore to maintain such protection *vis-à-vis* all new frequency assignments.

On the contrary, spectrum monitoring station antennas should ideally be set up on a raised point surrounded by open space to ensure that signals are received from the greatest possible number of monitored transmitters within a wide service area and for all azimuths. It often happens that monitoring stations are located in cities close to powerful transmitters – including those used for sound and television broadcasting – with high antennas, or that such power transmitters are installed close to existing monitoring stations. In such cases, little or no attention is ever paid to the question of observing the frequency and geographical separation requirements that are a fundamental feature of frequency planning for communication radio facilities. As a result, monitoring station antennas and receivers generally have to operate under far more rigorous interference conditions than other radio facilities. This imposes special requirements in terms of the parameters characterizing the intrinsic protection of receivers and active antennas against the effects of potential interference.

First, it concerns such parameters as receiver selectivity and linearity (second-and third-order intercept points), IF and image frequency rejection, receiver dynamic range and linearity (second-and third-order intercept points) of active antennas and their protection from interference (damage threshold). The above, to a large extent, determines the ability of the spectrum monitoring station equipment as a whole to perform measurements and DF under arduous uncontrolled interference conditions. If, as a result of insufficient protection due to a failure to observe the requirements indicated in § 3.2 and 3.3, the antenna and/or receiver is affected by interference, both the measurement of certain (or all) transmitter emission parameters and DF operations can be subject to significant errors; in other words, the data will be unreliable or may simply be unobtainable. Therefore, when antennas and receivers with inadequate characteristics are used, the large sums spent on setting up the spectrum monitoring stations and networks may have been wasted. The influence of interfering signals usually appears as intermodulation and/or blocking. The mechanisms of these phenomena are considered in § 3.3.2.

In the light of the foregoing, it is recommended to avoid the use for spectrum monitoring purposes of standard receivers that do not satisfy the full set of requirements laid down in § 3.2 and 3.3.

Results of measurements and DF at the site are also greatly influenced by other antennas and surrounding metallic structures; this subject is discussed in § 3.2.5.

3.1.3 Man-machine interface

Manual operation of equipment, including receivers and maintenance equipment, and the interactive operation of systems, is often required to conduct monitoring station tasks. Also, for the operation of automated spectrum monitoring systems described in § 3.6, certain guidelines concerning man-machine interface should be observed. General guidance is given by IEC 447/4.93: Man-machine interface (MMI) – Actuating principles.

3.1.3.1 Basic principles

The application of actuating principles, disposition and sequence of actuators should be applied in an unambiguous manner, especially for monitoring stations where operators have to carry out various tasks with equipment of different origin. It should take into account the working speed required, ergonomic aspects and the required level of prevention of unintended operation.

Actuators shall be unambiguously identifiable, it shall be possible to execute a command only through the intended operation of an actuator (this limits the application of double-function actuators), the method of dialogue used should take into account ergonomic aspects relevant to the task.

To avoid operator errors, the application of the following measures is recommended:

– defined command priority, and

– simplification of actuator operating sequence (e.g., through automation).

The arrangement of actuators shall be logically grouped according to their operational or functional correlation. One or more of the following grouping principles can be used:

– by function or interrelationship;

– by sequence of use;

– by frequency of use;

– by priority.

3.1.3.2 Actions and effects

As far as possible, the necessary action of the actuator should be correlated to the required final effects, according to the operating direction or to the relative location of an actuator. Final effects can be classified into increasing effects and decreasing effects.

Principally, there are two different methods to perform opposite actions by using:

– one actuator with two operating directions (e.g., a hand wheel or tuning knob);

– a set of, e.g., two actuators (e.g., push-buttons), each with only one operating direction.

Some operators prefer, especially for the setting of the frequency of a receiver and for volume control, to use tuning knobs. Thus, the correction of the frequency while listening to the audio signal with volume setting at the same time can be done in an easy way. Sufficient separation between the two knobs is required for two-hand operation.

3.1.3.3 Actuator identification and feedback requirements

Visual, audible or tactile information/feedback will help to improve the man-machine interface. The reaction/effect of the actuator action should be immediate, any delay might cause erroneous actions by the user. Examples are:

– A light-emitting diode (LED) may be used to indicate that a switch has been set to ON (LED colour preferably amber or green).

– Each change of a setting (e.g. frequency, bandwidth, attenuation) should be indicated immediately on a display.

– Displays should be easily readable both in sunlight and in a dimmed room.

– In most cases, an audible feedback other than the one coming from the loudspeaker is inadequate, since it may interfere with the audio signal.

– A loudspeaker should preferably be mounted on the front panel of a receiver, since the phone jack may switch it off.

– A panoramic spectrum display helps for frequency tuning and for orientation when interfering effects disturb the reception. Ideally the display should be of the real-time type with the possibility of digital storage for maximum hold. When a minimum hold is added, intermittent signals can easily be discovered among continuous emissions.

– When tuning of the frequency is done in discrete steps using a tuning knob, it has proven to be very useful to have a tuning knob with magnetic locking, which gives a tactile feeling for each step while preventing unintentional detuning caused by e.g., vibrations. On the other hand, magnetic locking combined with a flywheel permits fast tuning.

  Digital processing of the information step should provide acceleration with increasing tuning speed. A combination with a set of keys allows quasi-continuous tuning with the tuning knob and tuning from channel to channel, this by using a combination with two actuators as described above.

– It is advantageous to have an analogue reaction with manual tuning by e.g., a level and a tuning meter, especially when no panoramic spectrum display is available. An analogue meter helps e.g., to direct an antenna to the direction of maximum reception.

3.1.3.4 Computer interface

Instead of each instrument having its own individual user interface, a user interface can be created using computers, software and remote-controlled equipment as discussed further in § 3.6. This user interface allows access to the controls of each instrument in a similar way, reducing operator training. Examples of such user interface, use menus and dialogue boxes, or graphical representation such as icons and symbols. This technique is particularly powerful when the operator for practical tasks can customize it, allowing flexibility in addressing mission and processing methods.

3.2 Monitoring and measurement antennas

3.2.1 General considerations

The purpose of receiving antennas is to extract the maximum possible signal from the environment and to apply this signal to the input of the receiver, while at the same time minimizing the pick-up of noise and interfering signals. The specific characteristics of a monitoring antenna will be determined largely by each particular application. When a monitoring antenna is chosen, consideration must be given to such factors as the properties of the desired signal, the parameters intended for observation, the characteristics of the installation site and any interference that may be present.

For the best reception results, antennas should have a polarization corresponding to the polarization of the arriving signal wavefront and should provide matching of the impedance of the transmission line and receiver input circuits, so as to ensure the maximum transfer of power. Omnidirectional reception patterns have proved useful for general monitoring or for radio-frequency spectrum determinations. For the observation of a particular signal on shared frequencies, it may be desirable to use a directional antenna, which either nulls one or more of the interfering signals, or maximizes the desired signal. A mobile unit is also useful in separating shared frequencies by driving closer to the antenna radiating the signal of interest. For some types of observations, such as studies of field strength, it is considered necessary that the properties of the antenna used be accurately predictable with respect to frequency response and be invariant with time. A mobile unit with calibrated antennas is able to provide a measure of average field strength in a given area. Since no one type of antenna has all the properties necessary for efficient reception of all types of signals, a number of different antennas will generally be required at monitoring stations.

Descriptions of the various types of antennas for specific applications are given in the following paragraphs, categorized by frequency band.

3.2.2 Suitable antenna configurations

The properties of electromagnetic waves, including wavelength, resonance, and signal and noise propagation, help choose antennas in relation to:

– Directivity and gain, which are the main technical parameters of antennas. Antennas may be divided into two groups: omnidirectional antennas (where the azimuth radiation pattern is essentially circular) and directional antennas. Omnidirectional antennas may be used for general tasks of monitoring when the transmitter position is not known (occupancy rates, scanning), while directional antennas may be used for specific tasks (technical measurements) when a better sensitivity is needed.

- VLF, LF, HF, VHF, UHF or SHF frequency bands.
- Size and weight may be considered when choosing an antenna, depending on the type of monitoring station: fixed, mobile, transportable or portable.

3.2.2.1 Monitoring tasks associated with omnidirectional antennas

Omnidirectional antennas are suited for the following monitoring tasks:

- unknown transmitter search,
- spectrum occupancy,
- band or frequency scanning,
- DF,
- automatic missions.

Omnidirectional antennas are also well suited for:

- technical measurements (field strength, bandwidth and frequency measurements), when the antenna factor is known,
- monitoring of a moving transmitter,
- identification and analysis of mobile or cellular networks services.

3.2.2.1.1 VLF/LF/MF/HF bands

For these frequency bands, the wavelength is very long and it is not practical to have antennas of a size of the order of a quarter wavelength, which would give maximum antenna sensitivity. Active antennas could be used, but they have lower linearity due to intermodulation.

Fixed stations:

Fixed radio monitoring equipment has fewer size and weight limitations and therefore can employ higher performance antennas. Fixed monitoring stations should be installed in rural areas away from cities and where adequate land areas are available to accommodate all of the antennas needed.

Fixed VLF/LF/MF/HF monitoring stations are very important for long distance signal analysis and high power transmitter analysis, including monitoring near borders or in large countries, DF, and single station location (SSL), where a single station can measure elevation and azimuth angle and use ionospheric information to locate a transmitter.

Suitable omnidirectional antennas at such stations include:

- An antenna system that will provide omnidirectional vertically-polarized reception over the short-wave frequency range (2 to 30 MHz). This system could consist of one large antenna such as a wideband inverted conical antenna, several conical monopole type antennas that overlap in frequency, or an active antenna.
- At least one omnidirectional active antenna system providing both vertical and horizontal polarization or the possibility of polarization diversity reception and covering the frequency range between 9 kHz and 30 MHz, especially if space and/or economics are limiting factors.
- One long-range, wide-aperture DF array that could be from 50 to 300 m in size, to provide directional bearings. Antennas could be either omnidirectional or directional. Other monitoring stations can provide additional bearings and the transmitter location can be determined by triangulation. (Frequency range from several 100 kHz up to about 30 MHz.)

Mobile stations:

Antenna size is the principal limitation for VLF/LF/MF/HF mobile monitoring stations. Such stations allow for:

– Measurement results when moving near the transmitter. For example, whereas a fixed monitoring station may not be able to perform an accurate measurement because the *S/N* is too low, a mobile monitoring station can be driven near the transmitter to increase the *S/N*.

– An additional line-of-bearing (LoB), in association with a fixed monitoring station, to increase location accuracy.

Size limits considerably the choice of such antennas:

– Short monopole (whip antennas)

– Dipole (centre-fed)

– Magnetic loops

– Active antennas.

3.2.2.1.2 VHF/UHF bands

Antenna size is less critical in these bands (except for the lower VHF band where the dimensions of the antenna have a direct impact on the sensitivity). Fixed and mobile antennas have similar characteristics; the main difference is the position of the antenna and the ability to put it on the top of a mast.

The types of omnidirectional antenna encountered in these bands include dipole, conical or biconical antennas. Directional antennas may also be used, such as those for DF systems.

Fixed stations:

A main advantage of a fixed monitoring station is the possibility to raise the antenna to the top of a high fixed mast in order to increase line-of-sight (LoS) for more distant transmitters than it would be possible from a mobile station. In the use of such antennas in cities, it is important to try to minimize multipath due to building reflections.

Omnidirectional antennas are useful for general monitoring near the fixed station and for coverage of large areas, especially for automatic tasks. Physically larger omnidirectional antennas are also required for a better sensitivity in the lower part of the VHF band.

If a fixed station is located inside or near a metropolitan area, one vertically and one horizontally polarized medium gain omnidirectional general purpose monitoring antenna system can be used. A small improvement in sensitivity can be achieved by using a rotating high-gain log-periodic cross-polarization (vertical and horizontal) antenna system for the frequency range(s) required. It is generally more cost effective to increase the height of an omnidirectional antenna because VHF/UHF propagation is LoS.

Mobile stations:

In the VHF/UHF bands, omnidirectional, conical or biconical antennas are well suited for mobile use:

– Low size and weight, associated with good performance, means they are a good compromise for installation on a vehicle.

– Antennas that allow for monitoring and DF homing while driving.

– Their low weight allows them to be placed on top of an erectable mast, improving coverage area and minimizing influence of low obstacles.

– They can perform monitoring in cooperation with fixed monitoring stations. For example, when fixed monitoring stations intercept a signal with low *S/N*, the mobile monitoring station may give better results by moving near the transmitter.

– They allow monitoring where fixed monitoring stations cannot be deployed. Since propagation for the UHF band is more LoS, coverage with fixed monitoring stations is often impossible.

These monitoring stations are useful for cellular network monitoring:

– small size of cells favours the use of mobile monitoring stations,

– received signal levels do not require high sensitivity antennas.

Portable/transportable stations:

The advantages of such monitoring stations are the same as for mobile monitoring stations. Portable and transportable antennas may also be used in the following tasks:

– monitoring from the top of buildings. Mobile monitoring stations are often disturbed by multipath and portable monitoring stations may provide a solution to lower the effect of multipath;

– monitoring from the countryside, to put the monitoring station at a high level or at a remote point which a mobile vehicle cannot reach;

– for measurement from a specific point or from a building (school, hospital).

3.2.2.1.3 SHF band

In the SHF band, some omnidirectional antennas have very poor gain and the propagation loss requires high gain antennas; so that, in this band, monitoring antennas are usually very directional; omnidirectional antennas and fixed antennas need to be in the main beam of the signal to be useful.

Mobile omnidirectional antennas are usually used only for the lower frequencies of the SHF band (frequencies up to about 6 GHz). However, they are often used for the following tasks:

– to intercept and analyse and perform measurements of the direct beam stream of a microwave link with the monitoring antenna near the transmitter;

– to analyze cellular networks.

3.2.2.2 Monitoring tasks associated with directional antennas

Directional antennas are useful for the following tasks:

– for known transmitter measurements, to allow better gain in the direction of the signal and then to improve monitoring of low level signal or to get better *S/N*;

– for technical measurements, where directivity is required, to get better measurements by improving *S/N* and lowering multipath or interference;

– for SHF monitoring, where propagation requires high gain antennas.

Rotators for directional antennas must be very accurate for SHF antenna. The rotation of the antenna requires time to steer the antenna to the direction of arrival. Therefore, directional antennas are not adapted to fast scanning and for occupation rate measurement.

3.2.2.2.1 VLF/LF/HF bands

Large size directional antennas are required in these bands and are only useful at fixed sites where large installation areas are available.

Fixed stations:

A main objective of directional antenna in these bands is to increase either the sensitivity or the received *S/N*. A main use is to monitor international or national signals.

Suitable directional antennas at such stations include:

– An antenna system that will provide highly directional, vertically-polarized reception in sectors around all points of the compass over the short-wave frequency range. Alternatives include a single log-periodic star-shaped curtain array with six curtains, or a spoke pattern of bidirectional end fire loop arrays.

– An antenna system that will provide highly directional, horizontally-polarized reception at all azimuths over the short-wave frequency range. Alternatives include a large rotatable, wire-strung horizontally-polarized log-periodic array, which has the disadvantage of requiring up to 60 s or more to rotate in azimuth, or an array of six horizontal curtains that provide 360° azimuth coverage on six 60° beams.

– One long-range, wide aperture DF array that can be from 50 to 300 m in size, to provide directional bearings. Antennas can be either omnidirectional or directional.

3.2.2.2.2 VHF/UHF bands

Directional antennas may improve technical measurement by reducing noise and interference and provide increased coverage and *S/N* for general monitoring and DF tasks. Individual directional antennas may be on a rotator, or may use fixed arrays of directional antennas covering all directions, such as an outward looking circularly disposed antenna array. Fixed arrays with directional or omnidirectional elements are suitable for a VHF/UHF DF system.

Fixed stations:

In a fixed monitoring station, size and weight is less important than in a mobile monitoring station, and directional antennas are a good complement to omnidirectional antennas.

Mobile stations:

Directional antennas on a mobile monitoring station have the same advantage than those of a fixed monitoring station, but have the disadvantage that they need the installation and maintainance of a rotating antenna in a mobile environment. An omnidirectional antenna on a mast which can be raised to improve reception provides an excellent alternative to a rotating antenna. Also, higher sensitivity is not required on a vehicle, which can move to increase *S/N* and improve reception.

3.2.2.2.3 SHF band

Due to propagation loss at these frequencies, directional antennas are well suited for SHF bands, because of their high gain. Their main disadvantage is the directivity of the incidence signal, which means that the measurement must be performed on the main beam of the signals.

Fixed stations:

Fixed monitoring stations have only specific tasks when monitoring SHF signals. They are useless for microwave links, uplink satellite and cellular networks. Fixed monitoring stations are required only for satellite downlink monitoring. Use of large directional antennas in a fixed monitoring station is required when monitoring downlink satellite signals. These antennas may be 10 m diameter dishes, which offer a high level of sensitivity.

Mobile, transportable and portable stations:

Measurements above 3 GHz usually require mobile operation in order to deploy the antenna into or near the antenna beam. Mobile, transportable and portable monitoring stations allows the use of small antennas, with diameters up to 1 m.

Their goal is to:

– intercept and analyze microwave links (direct path or secondary lobs of emission antennas),

– analyze uplink satellites links by moving the monitoring station close to the transmitter antenna,

– DF signals with the directivity of the antenna. On the SHF band, the measurement may give accurate results with a dish antenna.

Two main types of antennas, horn or dish, are used in these bands for mobile monitoring stations:

– Horn antennas have lower gain and as a result, lower sensitivity. However, horn antennas have less directivity, which may be more suitable for unknown signals.

– Dish antennas have the best gain and thus offer better sensitivity. However, the high directivity of such antennas requires that the direction to the transmitter or the source of the signal be well known, or that automated scanning be implemented to localize the source. In conclusion, horn antennas are well suited for general monitoring in the low frequencies of the SHF band (f < 18 GHz). Only dish antennas are suitable for upper frequencies where path loss is high.

3.2.2.3 Antenna selection summary

The selection of antennas should allow for new emerging digital processing techniques, such as smart antennas, which allow omnidirectional antennas to take on directive properties. Table 3-1 gives general guidelines for the selection of antennas for the various monitoring tasks.

TABLE 3-1

Antenna selection according to monitoring task and frequency band

	VLF/MF/HF					
	Monitoring applications				**DF applications**	
	Omni antennas		**Directional antennas**			
	Fixed	**Mobile/ transportable**	**Fixed**	**Mobile/ transportable**	**Fixed**	**Mobile/ transportable**
Loop	X	X	X(1)		X	X
Monopole	X	X	X(1)		X	X(2)
Dipole	X	X	X(1)		X	X
Conical/biconical	X					
Log-periodic by sector	X					
Log-periodic			X			
	VHF/UHF					
	Monitoring applications				**DF applications**	
	Omni antennas		**Directional antennas**			
	Fixed	**Mobile/ transportable**	**Fixed**	**Mobile/ transportable**	**Fixed**	**Mobile/ transportable**
Monopole	X	X	X(1)	X(1)	X	X
Dipole	X	X	X(1)	X(1)	X	X
Conical/biconical	X	X	X(1)	X(1)	X	X
Fan			X	X	X	X
Log-periodic			X	X(3)		

TABLE 3-1 (*end*)

	SHF					
	Monitoring applications				**DF applications**	
	Omni antennas		**Directional antennas**			
	Fixed	**Mobile/ transportable**	**Fixed**	**Mobile/ transportable**	**Fixed**	**Mobile/ transportable**
Dish			X	X		
Horn			X	X		
Log-periodic			X	X	X	X
Slant	X(4)	X				
Dipole					X	X

X(1): Used as an array with analogue or digital beamforming.

X(2): In the MF/HF band only.

X(3): Antenna height is more important than directivity; it is easier to lift higher a smaller omni antenna than a directional antenna, so a transportable log-periodic application is more practical than a mobile one.

X(4): With limited coverage since it is a fixed station.

3.2.3 Antennas for VLF, LF, MF and HF

3.2.3.1 VLF/LF/MF omnidirectional types

In view of the extremely long wavelengths at VLF, LF and MF (e.g., 10 000 m for a frequency of 30 kHz), antennas for these frequencies are necessarily limited to those that are small compared to the wavelength. Since signals in these bands are primarily vertically polarized, vertical antennas are generally used for reception. A simple upright antenna, which represents only a small percentage of a quarter wavelength, has an impedance which is largely reactive and of large magnitude. Such an antenna can generally be made tall enough to provide required sensitivity above atmospheric noise levels.

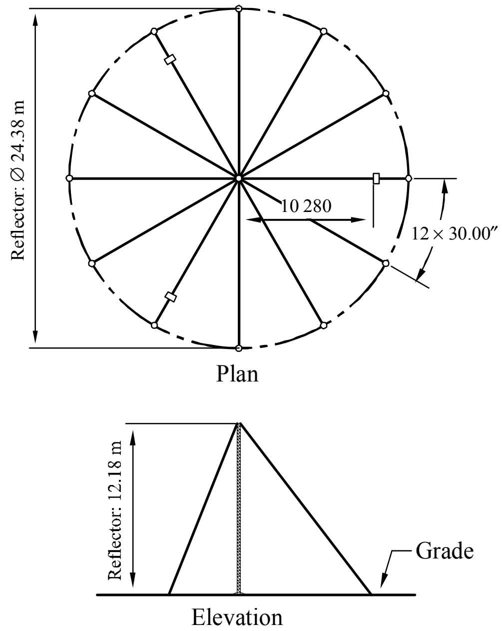
When the size of the antenna element is limited physically to a small part of a wavelength, such as occurs at VLF and LF, an active antenna will generally provide a much greater *S/N* than that obtained by connecting the antenna directly to the receiver without the use of an active device for impedance matching. In order to avoid intermodulation and cross modulation in the active circuits, attention should be paid to the following technical data:

Antenna factor 20 log(E/V) should lie between:	15 dB and 25 dB
Second-order intercept point (antenna output) should be not less than:	50 dBm
Third-order intercept point (antenna output) should be not less than:	25 dBm
Permissible field strength for 10 dB cross modulation should be not less than:	10 V/m
Maximum permissible r.m.s value of the interfering field strength (lightning protection damage threshold) should not be less than:	20 kV/m at 100 kHz and 200 kV/m at 10 kHz

State-of-the-art active antennas fulfilling the above given specifications are offered by several manufacturers. In high local field strengths, which are common in medium wave as well as FM and TV bands, even the above specifications for active antenna are not adequate and one should resort to a passive antenna such as a 12 m tall monopole shown in Fig. 3-2.

FIGURE 3-2

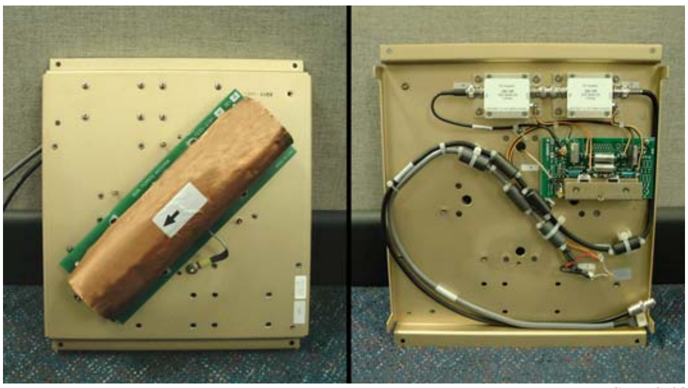
Typical passive receive antenna for VLF/LF/MF/HF, 9 kHz-30 MHz



One example of a compact active antenna, which is useful for both monitoring and DF purposes, is a pair of small active magnetic loops; top and bottom views of one of the pair of loops are illustrated in Fig. 3-3. This antenna can be quite small (box with sides approximately 0.3 × 0.3 m and 0.1 m high) to cover 300 kHz to 30 MHz, but has the sensitivity and azimuth DF accuracy of a much larger antenna (such as an array of 3 m-tall whips).

FIGURE 3-3

Compact active antenna



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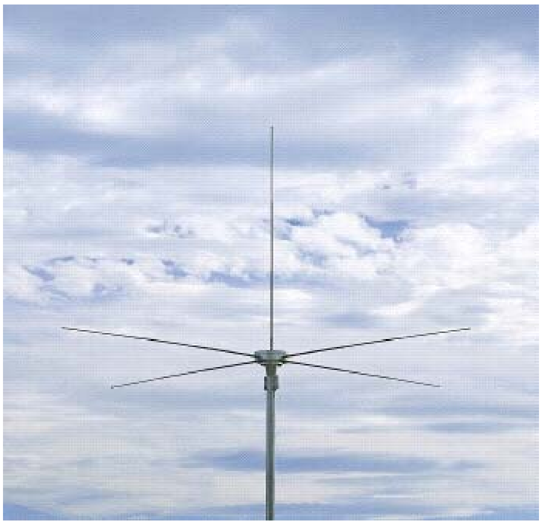
Each loop consists of a high permeability ferrite rod wound with a multiple turn coil. The coil is shielded with an electrostatic shield and the outlet is connected to a transformer –to make the antenna less sensitive to local e-field disturbances and thereby improve DF accuracy. The transformer provides impedance matching, common mode rejection, and balance to unbalance transformation.

Active antennas covering VLF/LF/MF/HF frequencies (9 kHz to 30 MHz) can also be built for horizontal polarization as well as for vertical polarization, as shown in Fig. 3-4. The antenna provides two output connectors, one for vertical polarization and one for horizontal polarization. It covers 9 kHz to 80 MHz vertically polarized and 600 kHz to 40 MHz horizontally polarized.

FIGURE 3-4

Active antenna for vertical and horizontal polarization



Spec-3-04

3.2.3.2 General considerations for HF antennas

At HF, the radio waves reflect off the ionospheric layers that exist from 100 to 300 km above the Earth. The antenna must direct maximum radiation at these ionospheric reflecting layers at the desired elevation and azimuth angles, such that coverage to desired locations will be achieved.

For instance, if a transmitter location is 350 km from a monitoring station, maximum radiation from the antenna should occur at an elevation angle near 60° for reflection off the 300 km-high ionospheric layer. In this case-the ray path from the monitoring station to the ionosphere and then to the transmitter forms an approximate equilateral triangle, including a direct line between the monitoring station and the transmitter; this simple one-reflection path is called a one-hop path. As the distance increases, the elevation angle or take-off-angle for the one-hop path decreases; the take-off-angle of the one-hop ray can get as low as about 3° for the longest paths. Three degrees is typically a minimum take-off-angle, being limited by nearby hills, other obstructions and antenna radiation pattern undercutting at the very low elevation angles. In general, the path to the receiver may consist of several hops; for instance, a two-hop path occurs where there is a ground reflection midway between the transmitter location and the monitoring station and there are two reflections from the ionospheric layer. The one and two hops may exist singly or simultaneously. When two or more paths occur at the same time, this is known as multipath propagation.

A highly efficient receive antenna is generally not needed because of the moderately high levels of man made and atmospheric radio noise at HF. For instance, one might wish to use a vertically-polarized antenna for reasons of radiation pattern coverage and accept a few dB of antenna loss because this antenna loss usually will not have a significant effect on the receive system sensitivity.

For receiving, it is much more important to use antennas with a high directive gain so that the signal level picked by the antenna is enhanced relative to the noise. Under the assumption that equal noise power density is being received from all directions, which is usually the case, the total noise power received by the antenna is independent of the antenna directivity. Thus, the received *S/N* is increased by increasing receive antenna directivity.

A given monitoring station may be able to use several antennas to provide required short- to long-range coverage. Antenna selections may include a short-range omnidirectional high take-off angle antenna combined with several moderate- to long-range directive antennas. Also, a monitoring station may have limited land area available and may need to use a small number of antennas of a single type that provide the best service to all ranges. Several ground station antenna types are presented in this section that may be chosen for use by a monitoring site. All HF-high power transmitters (>1 kW) should be located at least 5 to 10 km from the monitoring station in order to provide high isolation between HF transmitters and HF receivers and to allow a lower radio noise environment at the receive site. Antennas for HF should cover the 2 to 30 MHz frequency band.

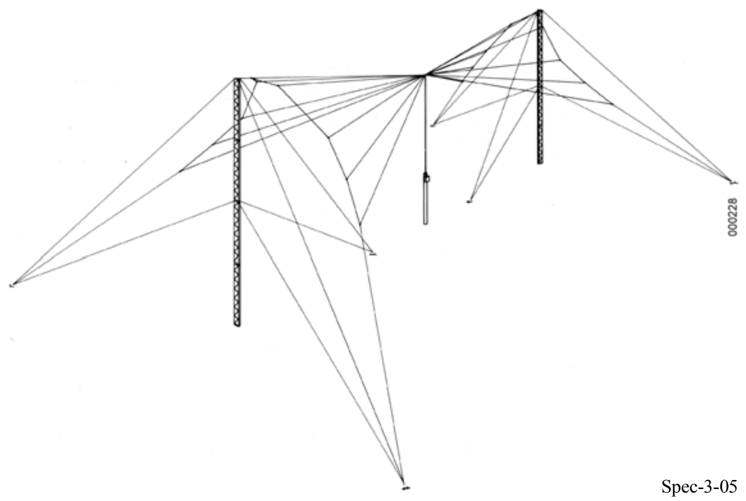
3.2.3.3 HF antenna types

Horizontal broadband dipole (see Fig. 3-5)

The best antenna types for short to moderate range HF coverage are horizontally- or circularly-polarized antennas that have peak radiation near the zenith. The ground wave radiated by a vertically-polarized HF antenna is attenuated by ground losses and generally not received farther than about 100 km over ground and about 300 km over ocean water. All vertically-polarized antennas have a null overhead and are not suitable for very short-range skywave monitoring at HF. The horizontal wideband dipole is an example of an antenna that can provide short-range coverage, from approximately 3 to 12 MHz, with a fairly omnidirectional radiation pattern. These antennas are relatively small; an example of such a horizontally-polarized dipole is mounted on two towers, 22 m tall and requires 66 m x 38 m of land area; this is a good antenna to use on a limited receive or transmit site. The gain of this antenna is typically 5 dBi or higher. For significant higher gain values, horizontally-polarized log-periodic antennas can be designed to provide short range coverage with a fairly omnidirectional radiation pattern for low frequencies changing to more moderate- to long-range coverage and directional behaviour for higher frequencies.

FIGURE 3-5

Broadband horizontal dipole - short to moderate range



Spec-3-05

Horizontally-polarized rotatable log-periodic antenna

Using horizontally-polarized log-periodic dipoles mounted upon masts one can achieve even higher gain values (up to 12 dBi-depending on the height of the mast). These directional antennas have a half-power beamwidth of typically 60° to 70°. With the use of a rotator, the antenna can be turned to cover all azimuth angles (see Fig. 3-6).

FIGURE 3-6

Example of horizontally-polarized antenna with rotator for monitoring 2 to 30 MHz

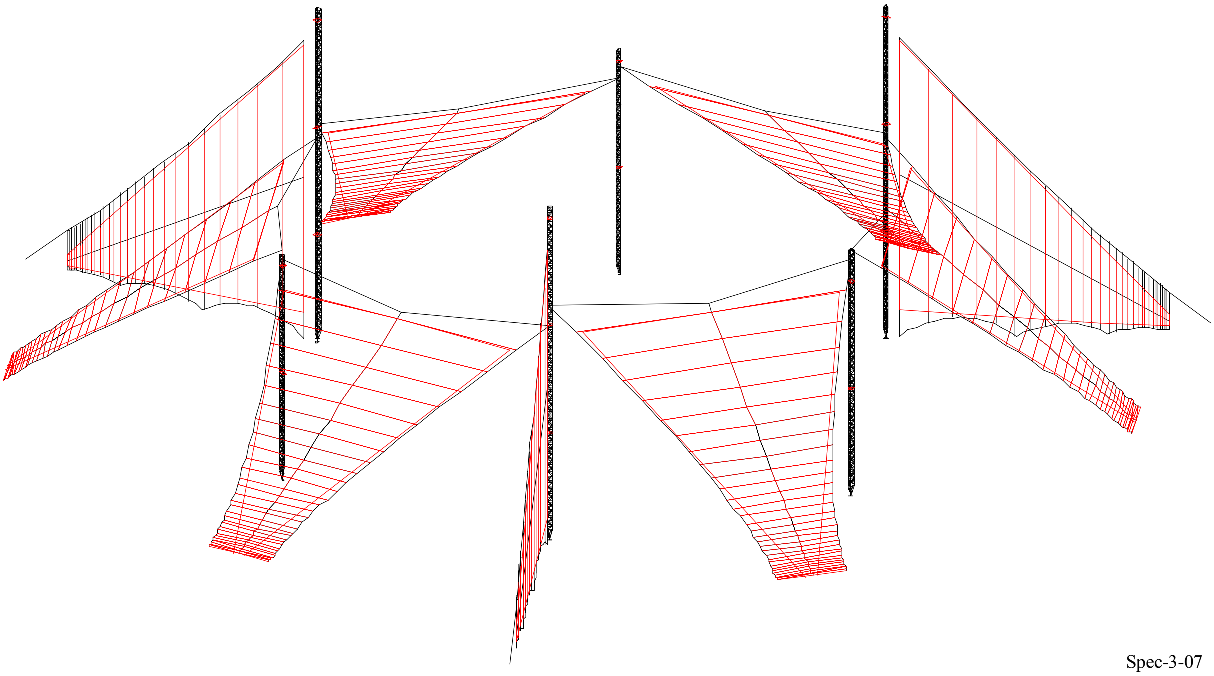
Spec-3-06

Log-periodic star-shaped curtain array

A log-periodic star-shaped curtain array can provide directive beams of either vertical polarization or horizontal polarization, or both polarizations. A vertically polarized array can have six curtains each with a half-power beamwidth of about 60° and each spaced at 60° intervals around a central support mast (up to 60 m high). A horizontally-polarized array can have six horizontal curtains that share six support masts, which would also provide 360° azimuth coverage on six 60° beams. An array that provides both polarizations is illustrated in Fig. 3-7; this particular example includes six horizontally polarized antennas and three vertically polarized antennas.

FIGURE 3-7

Example of log-periodic star-shaped curtain array



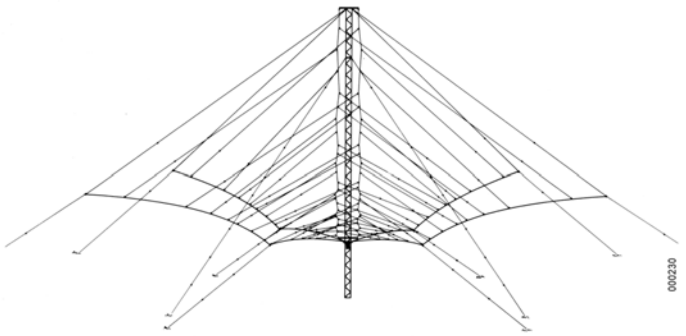
Spec-3-07

Omnidirectional circularly-polarized LPA (see Fig. 3-8)

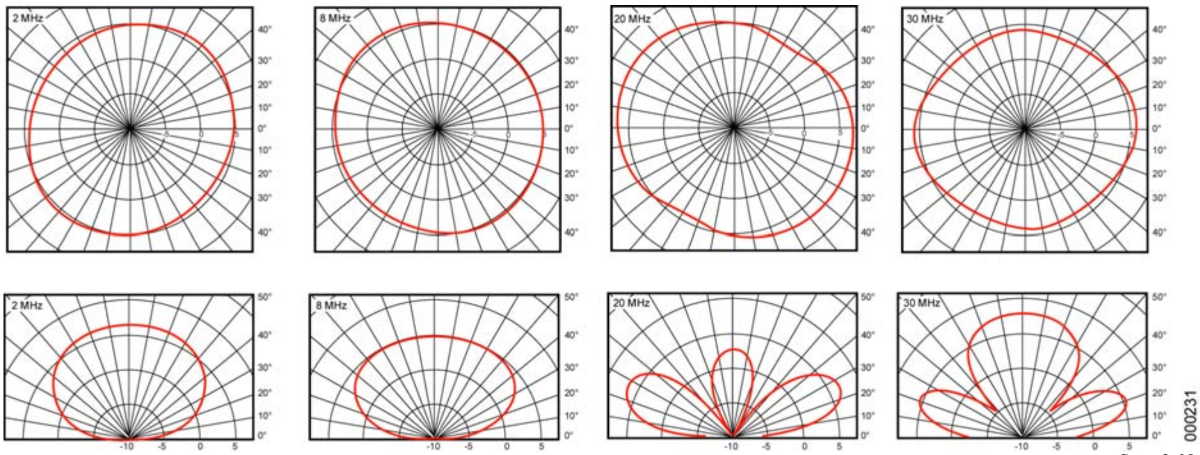
An antenna type that provides omnidirectional coverage over the entire HF band is a circularly-polarized log-periodic antenna (CPLPA). This antenna has the advantage of providing short- to moderate-range communications from one structure. At the lower frequencies the antenna radiates at the higher elevation angles for shorter-range coverage and at the higher HF frequencies the take-off angle is lower for reception from longer ranges. This antenna is supported by one tower and has two sets of orthogonal log-periodic dipole arrays, each dipole being a centre-fed inverted Vee connected to feedlines supported along the sides of the tower. Tower height is 28 m and requires an area of 94 m x 94 m. The gain of this antenna is 5 dBi.

FIGURE 3-8

Circularly-polarized log-periodic omnidirectional antenna (short to moderate range)



Azimuth patterns at elevation angle of beam maximum (gain (dBi))



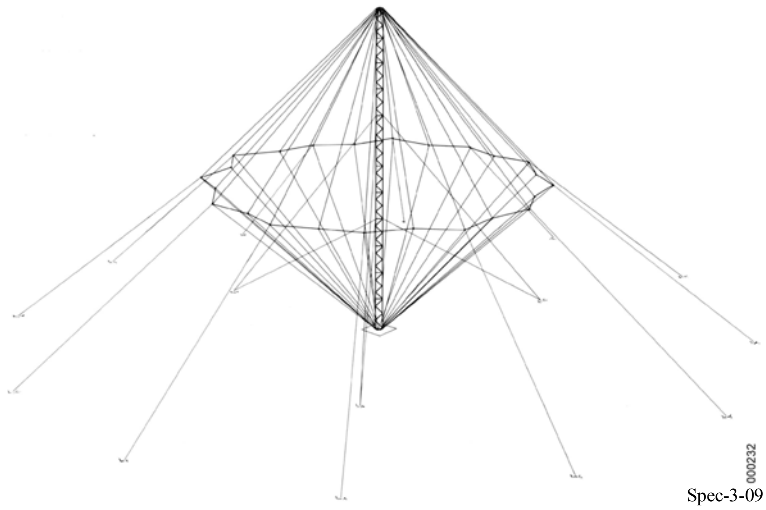
Spec-3-08

Vertically-polarized broadband monopole omnidirectional antenna

This antenna is a broadband omnidirectional antenna that can be used to receive short-range ground wave and moderate- to long-range skywave. A typical vertically-polarized broadband monopole is shown in Fig. 3-9. This antenna for the 3 to 30 MHz frequency range is 25 m high with a diameter of 52 m. The vertically-polarized broadband monopole and CPLPA have nearly equal gain at low frequencies at the lower take-off angles; however, the CPLPA is superior at the higher frequencies.

FIGURE 3-9

Broadband vertical omnidirectional antenna - moderate to long range



Loop arrays

Electrically small, inefficient antennas such as loop antennas can be used to advantage in a wide range of receiving applications in the HF frequency range. Noise caused by antenna inefficiency has the same effect as other sources of noise on the *S/N*. When external noise is greater than the noise from antenna inefficiency (and internal electronics, if present), an antenna is said to be "externally noise limited". The internal noise of an externally noise-limited antenna is relatively insignificant, since the greater external noise source determines the system's *S/N*. When external noise is relatively high, small receiving antennas work as well as the full-size fully, efficient antennas.

The basic loop is a large low-inductance aluminium tube. It is fed at the upper mid-point via a broadband, passive matching network. One advantage of loops over dipoles is their lower input impedance. The loop's performance is comparatively unaffected by nearby conducting bodies such as trees, buildings and snow. Moreover, since the radiation resistance of electrically small antennas is low, mutual effects are generally insignificant, enabling loops to be configured in various arrays that tailor their performance to particular receiving requirements.

The azimuthal pattern of a single loop is a figure eight at the horizon, increasingly omnidirectional at higher angles of arrival, and virtually independent of azimuth at angles of arrival above 50°. Signals from multiple loops can be combined in phase, or "beam formed". The resulting pattern is directional, with a bearing corresponding to one of the array directions. The directional pattern has its maximum gain at some angle below the zenith. Increasing the number of loop elements, increases gain and directivity. While this directional pattern is useful for monitoring, if an array of loop elements is used for DF, the elements should not be combined, so that the response of each element may be separately measured.

Beam forming is accomplished by bringing the feed cables from each element in an array to a delay/combiner unit, or beam-former, located at the array's physical centre. In unidirectional beam forming, signals from each element are delayed by means of appropriate lengths of coaxial cable, or delay lines, then summed in a combiner. In bidirectional beam forming, the signals are split and fed into two separate sets of delay lines, then summed in two separate combiners.

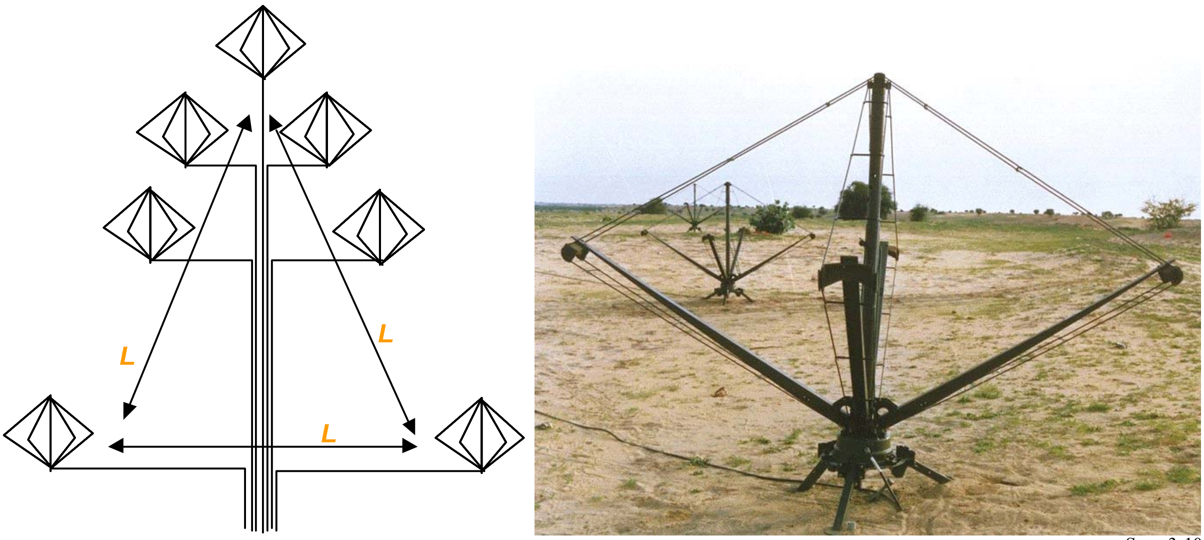
Multiple small arrays are often combined in rosette configurations. One common rosette consists of three bidirectional arms equally spaced in azimuth with a common centre. Each arm consists of eight loops. This three-arm, 24-element loop configuration can produce six beams, one for each 60° of azimuth.

Cross loop antenna

Another type of loop antenna consists of two perpendicular active frames, perhaps 2 m in height. This cross loop antenna may be used as a stand-alone or in an antenna array, with a switch commutation device and DF based on the interferometry principle. The array consists of seven or nine antenna elements, including a reference antenna, installed on the two sides of an equilateral triangle or in a circular configuration with approximately 200 m of aperture. Reducing the aperture reduces the DF accuracy. An antenna array is shown in Fig. 3-10.

FIGURE 3-10

1-30 MHz cross loop antenna array



Spec-3-10

Unlike a monopole antenna, this antenna is able to receive all polarizations. A switch inside the antenna allows the selection of one or the other of the two ports of the cross loop, depending on the chosen polarization. These antennas, along with the interferometry DF principle, can perform DF on sky waves and line-of-site propagation, and outperform U-Adcock type antennas that are limited to only vertical polarization and grazing incidence, a major disadvantage at HF because all polarizations are present in this frequency range. The interferometry DF principle allows single station location (SSL) measurements, whereas with the Watson Watt principle, the elevation angle cannot be measured and SSL is therefore not possible.

3.2.4 Antennas for VHF, UHF and SHF

The propagation conditions encountered in the VHF and UHF bands generally restrict reception to near LoS distances. In order to increase the reception area coverage, the VHF and UHF antennas are usually mounted at the top of a tower positioned near the monitoring building. In this manner, coaxial line losses, which can become high at these frequencies, are kept to a minimum.

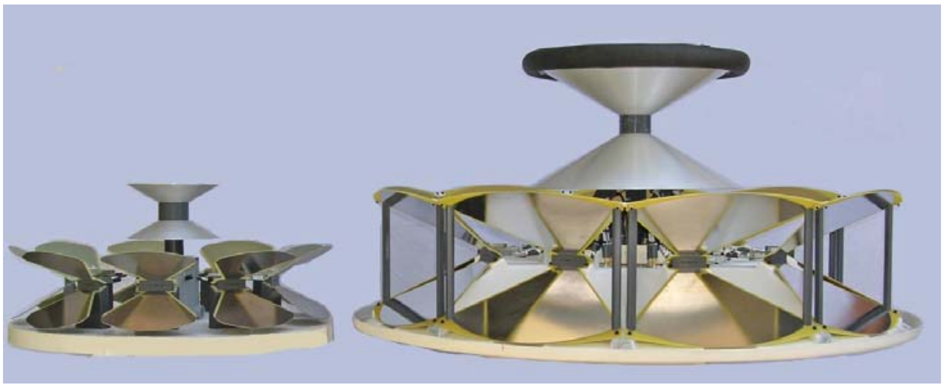
3.2.4.1 VHF and UHF omnidirection types

One example of an antenna used in the VHF/UHF range is the broadband omnidirectional biconical antenna illustrated in Fig. 3-11a). This antenna may be supplied along with a nine-element fan array, also illustrated in the figure, to provide DF coverage. Two size configurations of the antenna are illustrated. The smaller configuration on the left is compact and light weight enough to be used in a portable configuration, or it can be placed on the roof rack of a standard passenger automobile in what looks like a piece of luggage to provide an inconspicuous mobile monitoring station. The larger configuration on the right is available in either vertically-polarized or dual-polarized versions (vertically polarized is illustrated); the dual-polarized version has separate outputs for vertical and horizontal polarization. Both configurations provide very good coverage over a 150:1 frequency range of 20 to 3 000 MHz, the smaller one with somewhat reduced sensitivity at frequencies below 100 MHz.

The combination of the biconical antenna and the nine-element fan may be used for monitoring and DF over the entire VHF/UHF range in both fixed and mobile applications; however, for improved sensitivity and accuracy at fixed sites, the larger antenna in Fig. 3-11a) and an additional, physically larger array, consisting of a five-element VHF vertical dipole array illustrated in Fig. 3-12a) may be used.

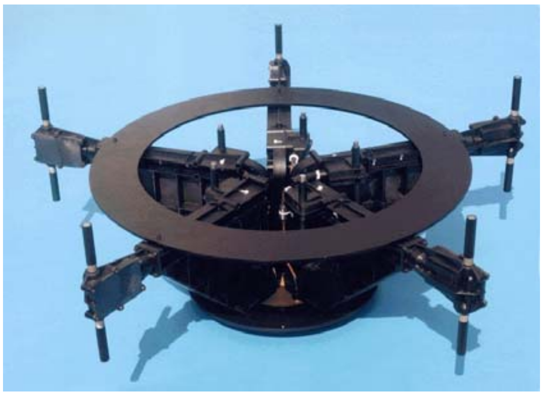
FIGURE 3-11

Examples of VHF/UHF antenna elements (enclosures removed)



(D = 0.8 m × 0.4 m) (D = 1.3 m × 0.7 m)

a)



(D = 1.1 m × 0.44 m)

b)

(Height: approximately 0.8 m)

c)

Spec-3-11

Figures 3-11b), 3-11c), 3-12b) and 3-12c) illustrate other antennas used for monitoring and DF in the VHF/UHF range. Figure 3-12c) includes a nine-element VHF vertical dipole array.

For optimum performance in applications requiring high dynamic range (good sensitivity and low distortion), the antenna should use passive antenna elements followed by active RF switching and preamplifiers. Use of passive antenna elements ensures that the antenna will be free of parasitic responses, has well behaved patterns and gain/phase response for DF accuracy, and does not produce distortion (IM or harmonic), a common problem in active element antennas. An example of such an antenna is given in Fig. 3-12b); three independent sets of dipoles are arranged in a pentagonal structure and allow coverage of the 20-3 000 MHz frequency range with vertical polarization.

This antenna type is designed to provide the best resistance against bad weather and lightning. Lightning protection is of utmost importance for a VHF/UHF DF antenna that, by its nature, should be installed at the highest possible location of the area to be monitored, thus directly exposing it to lighting. The antenna shown in Fig 3-12b) includes one resistant metal box containing the monitoring and DF equipment, thus protecting it from lightning. The structural tubing of this antenna provides grounding for the electrical charges picked up by the lightning arrester installed at the top of the antenna.

One should consider that active antennas might present parasitic responses, producing distortions such as IM and harmonics, lower MTBF and varying performance with aging, although they also present benefits such as broader range and larger antenna gain for a smaller size and lower weight. One should also consider the intended use and the local of installation such as the benefits and drawbacks of each technology is properly considered.

FIGURE 3-12

Examples of VHF/UHF (20-3 000 MHz) antenna arrays

a) b) c)

Spec-3-12

As an example, one could consider the installation of a monitoring station in urban areas with large spectrum use. Such installation might be desirable to monitor low-level transmissions that might not be detectable from even very sensitive stations and theoretically perfect sites located outside the urban centre. Due to high RF levels on urban centres, active antennas and broadband switching devices used in monitoring stations might have their performance and effectiveness strongly affected on this sites, pushing the demand for passive use of passive antennas and/or even filters and more band selective systems, such as to avoid interference.

However, passive element antennas suffer from poor sensitivity unless they are physically large and are built in multiple bands that are optimized for relatively narrow frequency ranges. This could result in a complex antenna structure that is difficult to install and maintain. Rather, if very high dynamic range RF preamplifiers and RF switching circuitry follow the passive elements, the antenna can both cover a wide frequency range and provide good sensitivity. This is possible if both the passive antenna elements and the active RF amplification operate at the same impedance, where it is possible to build the preamplifiers and switches with very high dynamic range and broadband response.

The high dynamic range RF switching and pre-amplification circuits should be physically mounted in the antenna, to eliminate the need for phase-matched RF cabling between the antenna and the rest of the system when used for DF, and to provide line amplification near the signal source to overcome cable losses that would otherwise increase the system noise figure and thereby degrade sensitivity. The RF preamplifier used in the antenna should have RF performance characteristics that substantially exceed that of the receiver to which it is connected, because the RF preamplifier must handle the entire VHF/UHF spectrum while the receiver typically has pre-selector filters that limit the amount of RF signal energy that the receiver RF front-end circuitry must handle.

Another useful antenna is illustrated in Fig. 3-13, which shows a VHF/UHF coaxial broadband dipole with optimum performance in the frequency range 80 to 2 000 MHz. In the lower frequency range the vertically-polarized antenna works in the coaxial mode, while in the upper range it works in the omnidirectional waveguide mode.

As noted above, active antenna systems can minimize the size of antennas for VHF/UHF. Figure 3-14 shows an active broadband antenna system using active dipoles as basic elements with wide dynamic range and high sensitivity. The vertical antenna is a centre-fed active dipole for the frequency range 20 to 1 300 MHz. The horizontal antenna covers the 20 to 500 MHz range and is built up as a turnstile type, consisting of two active broadband dipoles combined via a hybrid in order to provide a nearly omnidirectional radiation pattern. These small active antennas are highly suitable for broadband monitoring systems, including signal distribution to many receivers, because the distribution system will be more straightforward with only one antenna for the complete frequency range.

FIGURE 3-13

VHF/UHF broadband dipole

FIGURE 3-14

Active VHF/UHF antenna system

Spec-3-14

Another effective technical solution for improving characteristics of omnidirectional VHF/UHF monitoring antennas is mounting converters of radio signals on intermediate frequency in antennas (intermediate frequency (IF) converters) rather than amplifiers [Ashikhmin *et al.*, 2006], [Rembovsky *et al.*, 2006].

Improvement of antenna characteristics in this case is reached by high-frequency cable length reduction to a minimal value, considering that this cable is the main source of noise in transferring received signals from antenna elements to a radio receiver. The placement of IF converters in the immediate proximity of antenna elements allows for the elimination of the effect of a cable on the antenna (which, in this case, transfers IF signal) and also to transmit IF signal to distances up to several hundred meters. It results in increasing sensitivity and dynamic range of a system.

3.2.4.2 VHF and UHF directional types

In VHF and UHF bands, the need for antennas that have low-voltage standing wave ratio (VSWR) and uniform patterns has led to the development of arrays with a series of elements whose characteristics repeat according to the logarithm of frequency (log-periodic). These arrays can be made to achieve a moderate gain (10 dBi typical) with good directivity (a front-to-back ratio of 14 dB is typical), and a pattern that remains uniform over a frequency range of up to approximately 10:1. The radiation pattern is typically broad, approaching that of a dipole reflector-director antenna for most frequencies. The uniform gain, pattern and impedance characteristics of the antenna make it suitable for combining together to form a broadband array, for use where highly directional antennas are desired. In particular, the log-periodic antenna serves well as the illuminator for parabolic reflectors at UHF, where very narrow beamwidths are desired.

This antenna is generally constructed of a series of radiating elements, which are fed by, and positioned along, a central transmission line. The individual dipole pair elements are each designed to have the required antenna properties over a narrow part of the entire operating frequency band, and to maintain their characteristics as uniformly as possible over their active frequency range. The individual elements are repeated at intervals, which are constant with the logarithm of frequency. The number of intervals depends on the required gain and VSWR of the completed antenna design.

The overlapping of the characteristics of the individual elements of the array produces an active zone consisting of several adjacent elements, which progresses smoothly along the structure as the frequency is varied. The voltage standing wave ratio of the antenna is directly dependent upon the number of elements in the active zone of the antenna at a particular frequency and their efficiency in coupling energy between the electromagnetic wave and the transmission line.

Complete log-periodic antennas are available from a number of manufacturers for both wideband use and for narrow-band special services. Detailed design information is available in publications listed in the Bibliography and in other sources.

3.2.4.3 Antennas for frequencies above 3 000 MHz

To achieve the necessary high antenna gain for monitoring over long distances, primarily "dish and feed" antennas are used. The gain depends on the relation between dish diameter and wavelength, and on the aperture efficiency of the antenna.

For an optimized antenna system in the SHF range, several parameters have to be taken into consideration: narrow-band, broadband application and general monitoring or surveillance of signals.

For narrow-band applications, a horn or waveguide feeder, dipole or crossed dipole can be placed exactly in the focus of a parabolic reflector. The relation focus length/diameter can be optimized with respect to the high efficiency achieved by minimizing losses caused by either insufficient illumination or side radiation. The result will be an antenna gain as high as possible.

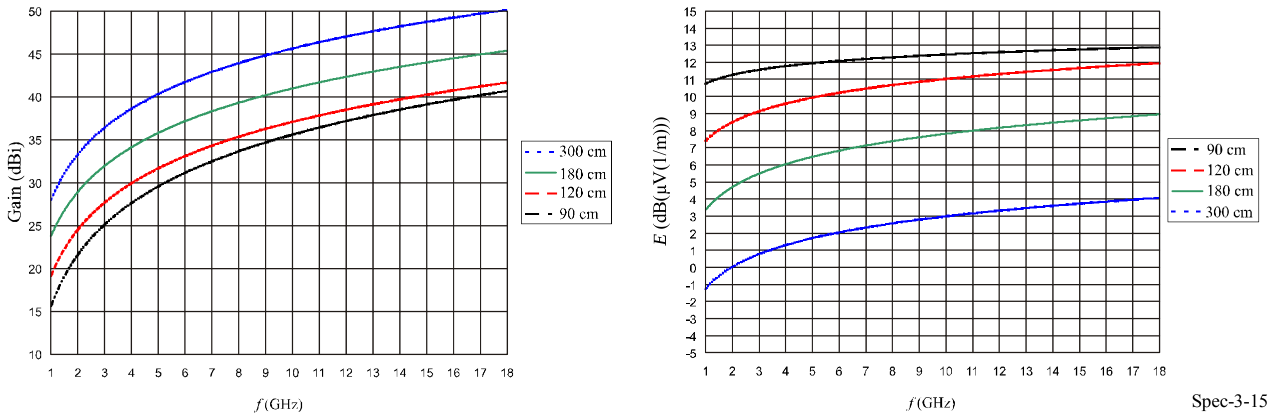
For monitoring and surveillance, high gain and a broad beamwidth for picking up the signal is required. In this case, a common method is focusing or defocusing the antenna feed by means of a motor-driven mechanical equipment. Variation of the beamwidth between 1:4 and 1:10 is possible.

For broadband applications, either linearly, dual linearly log-periodic antennas, conical spiral or cavity backed antennas may be used, the latter primarily for circular polarization. The broadband feeds, based on the log-periodic principle, do not have a constant phase centre. The phase centre moves from the shortest to the longest radiator of the structure, depending on the frequency. If the structure is positioned in the reflector for a certain frequency, defocusing will occur for the others. Optimization based on the calculation of additional parameters (e.g., length/diameter) allows to minimize losses caused by defocusing. To avoid these losses mechanical focusing, as described above, may be used.

Another solution is to use a special contour for the reflector, which is not perfectly parabolic. In this case, the antenna gain will increase and the beamwidth will decrease up to a certain frequency, then both will be nearly constant (see Fig. 3-15).

FIGURE 3-15

Gain and lowest measurable field strength for reflectors with different diameters and linear feed



Spec-3-15

Microwave antennas are mounted stationary on a tripod or tower for surveillance of signals coming from a certain direction. In this case manually, adjustable equipment is provided to adjust the antenna system exactly to the desired direction. Beamwidth of the antennas may vary between 20° and 0.05°, depending on diameter/wavelength.

For general monitoring, the antenna systems are installed on high-accuracy mono- or bi-axial positioners. Depending on the diameter of the antenna reflector, dimensions and costs may be highly different if operation and survival for high wind speeds is required. For terrestrial monitoring, mono-axial positioners with rotary joints or with cable twist equipment are used. The latter is limited by the azimuth rotating range (e.g., 360°). The elevation can be adjusted manually or remotely controlled within ±10°.

For satellite monitoring, bi-axial positioners allow additional movement between –10° and more than +90°.

The motor-driven positioners are remotely controlled via control units with different possible operation modes, e.g., variable speed, presetting of positions, scanning and antenna selection. Parallel and serial computer interfaces are provided for system integration. Figure 3-16 shows a typical block diagram. It is highly recommended to install low-noise amplifiers (LNAs) close to the feeder to avoid additional attenuation and noise caused by cables. These combinations are available as so-called “Active Feeds”, either with broadband preamplifiers (e.g., 1 to 18 GHz) or with amplifier units switchable in frequency ranges of 1 octave. An example of these feeds is shown in Fig. 3-17.

FIGURE 3-16

Block diagram of steerable microwave antenna 1-18 GHz

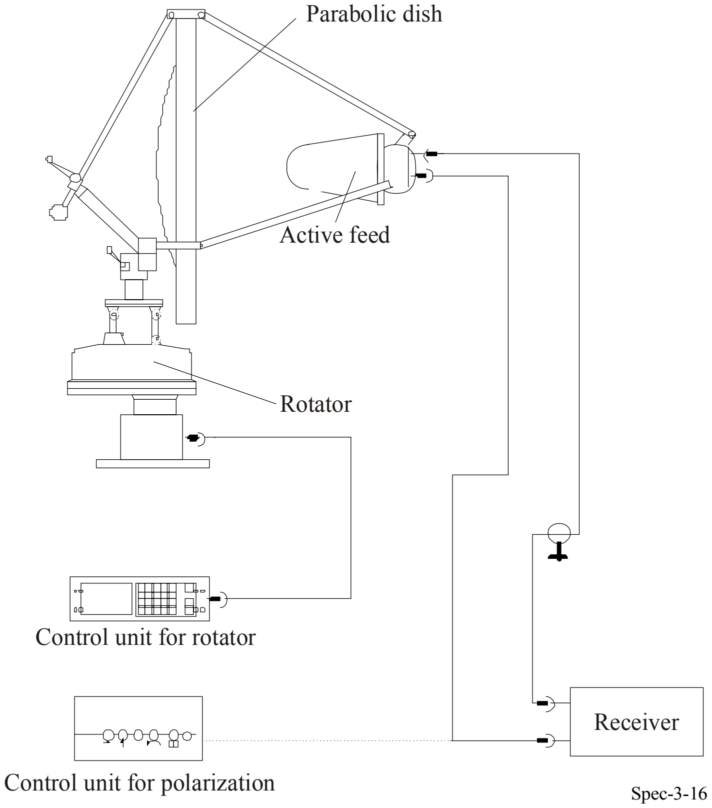


FIGURE 3-17

Example of a feed for a reflector antenna system 1-18 GHz (cross-section of the radome)

Therefore control units for remotely controllable polarization and frequency range are provided too. Additional features are switchable bypass, attenuators and built-in limiters. It is also recommended to install converters of the receiving system close to the antenna to achieve best system performance.

For large antenna reflectors, the feeder is not located at the focus of the dish but at its apex. An hyperbolic subreflector diverts the radiation. The reflector can also be fed in the "offset mode", where the antenna feeder is located in a tilt position out of the secondary radiation of the reflector.

For special applications, dual-shaped reflectors such as cylinder parabolic or cosecant may be used. In this case, the beamwidth in azimuth and elevation is different, depending on the application.

For mobile applications where roof space is limited, omnidirectional antennas can be used. Slant-linear-polarized omnidirectional antennas receive all polarizations including vertical polarization, horizontal polarization, right- and left-hand circular polarization-and cover many frequency bands. Typical ranges covered include: 1-4 GHz, 4-18 GHz, 1-18 GHz and 12-40 GHz.

Thus with three relatively small (300 mm maximum dimension) antennas, the entire band can be covered. It is very important that these antennas be mounted very close (within about 3 m) to the receiver in order to keep attenuation loss small in the connecting coaxial cables.

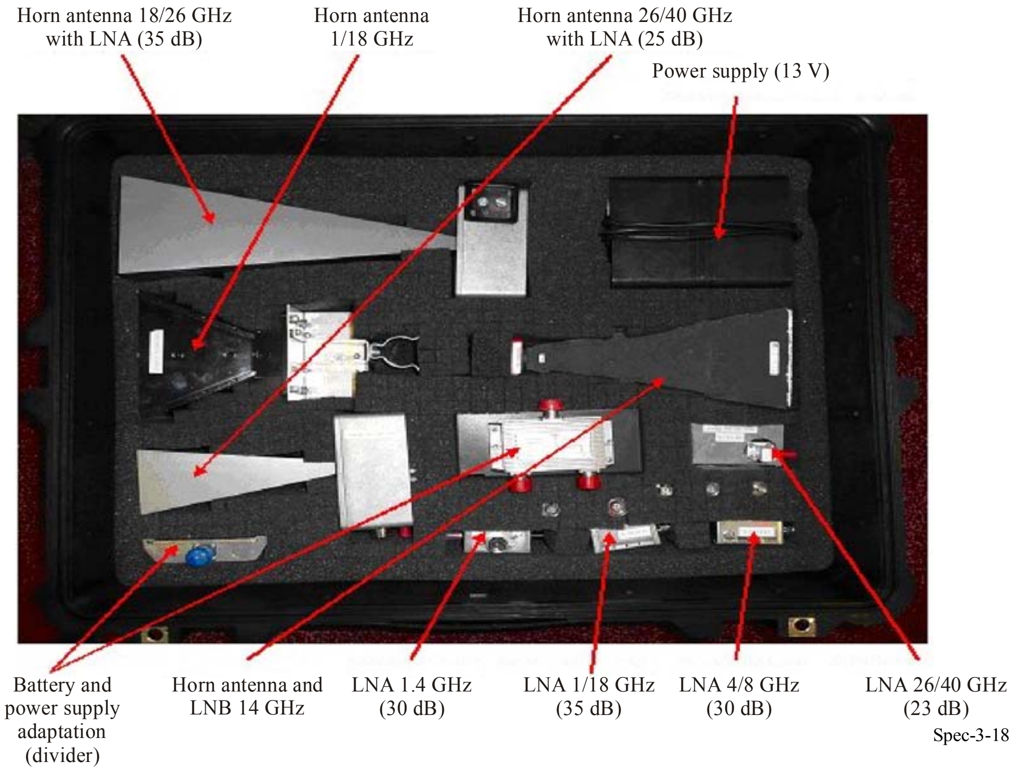
A compact solution to measure the SHF band from 1 to 40 GHz and above, consisting of several horns and a single tripod, could be envisaged.

In the 1 to 18 GHz band, to avoid a large contribution of noise, selective filters should be used and the LNA gain should be limited (less than 20 dB). In the band 18 to 40 GHz and above, measurements results could be improved by the use of waveguides. As waveguides are by definition band-pass filters, higher gain amplifiers could be used.

Taking into account these considerations, a typical example of a handheld system is illustrated in Fig. 3-18. It consists in a hand-held suitcase that contains a pack of horn antennas with amplifiers, filters, power supply, batteries and cables to carry out measurements from 1 to 40 GHz.

FIGURE 3-18

Typical compact solution to carry out SHF measurements



In addition, several cables and adapters could be added in the suitcase. The size of the suitcase is 600 x 500 x 230 mm, and its fully loaded weight is just 16 kg.

3.2.5 Siting of antennas

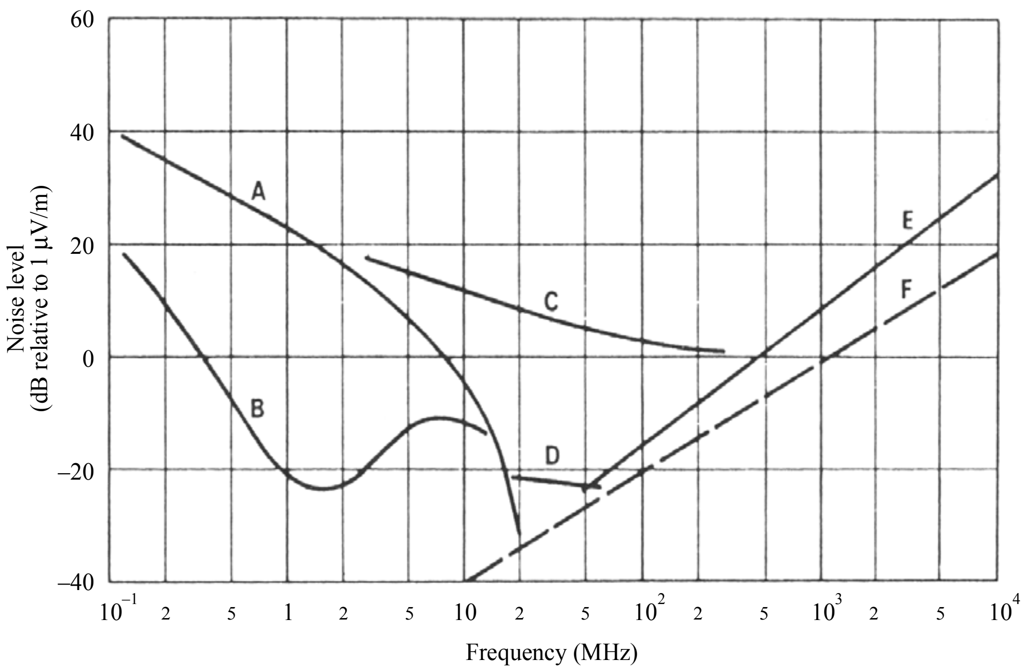
There are three primary considerations that must be examined when a site for monitoring station antennas is being chosen: the interfering noise level, the effects of terrain on the performance of the antennas, and the influence of other antennas and metallic structures or objects nearby. These factors must all be considered before a suitable antenna location and layout are established. Influence of nearby metallic structures such as antenna masts and mast guys should be considered during the design of the antenna structure. Other factors, such as economic and political considerations, will influence the location and layout of the monitoring station itself.

Noise that interferes with the reception of radio waves may be divided into two general categories: natural and man-made.

Natural noise is that produced by the various mechanisms of nature, both on the Earth itself and in neighbouring celestial systems. The major component of natural noise generated on the Earth is the static discharges resulting from the many storm centres, which are almost continuously active on the globe. Storms are most active in the equatorial regions and their noise is radiated toward the poles, resulting in atmospheric noise components that are largest at the equator and smallest at the poles. High-energy, galactic noise sources exist in the sky (in particular the constellations of Sagittarius and Cassiopeia) and may constitute a considerable portion of the noise picked up by antennas, which are located in an environment where the atmospheric noise levels are low, e.g., at higher latitudes. As shown in Fig. 3-19, cosmic noise is for most frequencies generally masked by other sources, but it can be significant in some cases, particularly if the receiving antenna happens to have a lobe oriented in the direction of a strong source.

FIGURE 3-19

Typical average noise level in a 6 kHz bandwidth (frequency range, 100 kHz to 10 GHz)



Curves A: atmospheric static noise, night
B: noon
C: large city ignition noise
D: cosmic noise
E: typical set noise
F: thermal noise

Spec-3-19

Interference to reception from man-made sources may take many forms (see also § 2.6 and 4.3). One of the most important sources to avoid when choosing an antenna site is a nearby broadcasting station. Even though the operating frequency of the station may be very different from the proposed monitoring frequencies, there can be significant interference caused by radiation of spurious emissions and harmonics of the principal frequency, and production of intermodulation or other responses caused by the overloading of the receiver's radio-frequency, intermediate-frequency and audio-frequency circuits. Receiver desensitization may also occur, even if spurious response is not noted.

Other man-made noise sources such as X-ray and diathermy machines, high-voltage power generation and distribution facilities, welding and heavy industrial fabrication processes, street lighting, heavy concentrations of vehicular traffic, and even large areas of residential buildings may create significant levels that may override wanted radio-frequency signals. In addition to direct radiation, noise from these sources may be conducted over power distribution lines to cause interference to areas at considerably greater distances than those affected by direct radiation.

Once a suitable location has been chosen from the standpoint of noise interference criteria, the influence of the terrain on reception must be examined. This is particularly important since the monitoring antennas are usually co-sited with a DF antenna. For the latter, it is important that the terrain be flat, free of discontinuities, and have an uninterrupted view in all directions in order to avoid errors in the azimuth of arrival of the radio waves. The siting of monitoring stations, and of DFs, is dealt with in § 2.6 and 4.7. However, it is true that except for limited, special, monitoring purposes, a good DF site is also a good location for monitoring antennas.

An effect which must be considered when choosing a site at which a number of different antennas are to be installed at the same location, is the interaction which will occur between them and with other nearby metallic structures such as antenna masts, mast guys, fences, metallic tubes, stairs and other metallic structures.

The interaction among multiple antennas at a site will be most significant for similar types of antennas either designed for the same frequency range or which attain near-resonance at the same frequency. For instance, it is recommended that two rhombic antennas should not be closer than about 10 wavelengths when one is in the lobe of the other at the receiving frequencies in use. For minimum interference between antennas of different types, it is recommended that maximum differences be provided in at least two of the general categories of space, frequency and polarization.

In addition to other antennas, surrounding metallic structures situated at distances less than several wavelengths from an antenna may unacceptably deform antenna characteristics such as elevation, azimuth antenna patterns and matching with feeders, relative to those in isolated conditions. Errors in the measurement of emission parameters, arising from such influence, can considerably exceed specified error tolerances indicated in Chapter 4.

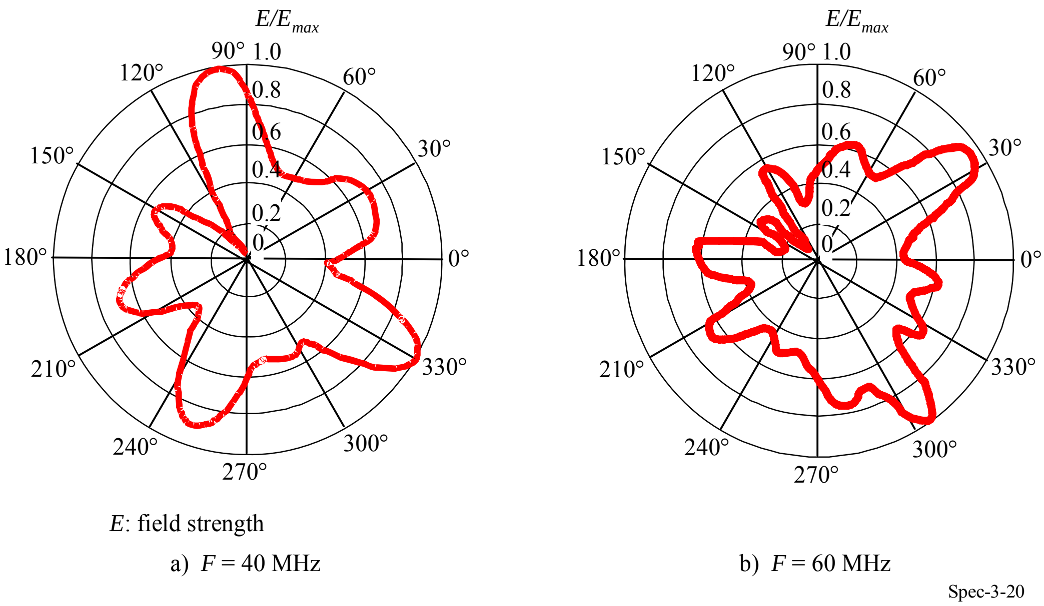
The quantitative determination of the influence of other antennas and metallic structures can be calculated with computer software [Kharchenko and Fomintsev, 2001], [Tanner and Andreasen, 1967], [Harrington, 1968], and [Thiele, 1973]. Metallic structures and other antennas within several wavelengths (usually from 4 to 8 wavelengths) from an antenna under consideration are modelled by wire structures, preserving the geometrical proportions of the structures. Then with the help of a method of moments computer program, the distribution of currents within all elements of wire structures are calculated; this electrodynamics model of the antenna and its surroundings allows the true characteristics of the antenna to be determined in the presence of scattering, reradiation and resonances produced by nearby metallic structures.

As an example [Kharchenko and Fomintsev, 2001] of the use of the given technique, Fig. 3-20 shows the calculated azimuth pattern of a 30-80 MHz omnidirectional disk-cone umbrella-type antenna in the presence of significant surrounding metallic structures. These structures include other similar antennas for the same frequency range and two disk-cone umbrella-type antennas for the range 80-100 MHz. There are also several rod communication antennas, a metal fence and some other metallic objects.

As is clearly seen from Fig. 3-20, surrounding antennas and other metallic structures convert an omnidirectional pattern such as illustrated in Fig. 3-8 to a directional one. Moreover, the variations in the patterns vary considerably with frequency, reaching differences of 20 dB due to non-linearity. This variation highly complicates the ability to obtain correct measurements from the antenna.

FIGURE 3-20

Actual azimuth pattern of omnidirectional 30-80 MHz antenna



Some specific recommendations on the placement of antennas relative to the monitoring buildings and to one another are for:

HF loop antenna arrays. These should be at least 100 m from the array-receiving building to prevent distortion of radiation patterns by the receiving building.

MF/HF wideband arrays. These should not be located too far from the building (≈ 100 to 200 m). Enough spacing should be obtained to prevent shadowing of the antenna by buildings, but not so great as to introduce significant losses in the feed line. Coaxial line is recommended, since these antennas are wideband units with closely controlled impedance characteristics and somewhat lower gain than resonant types.

Transmitting and receiving antennas. Maximum separation should be maintained between antennas that are used for transmission and antennas used for reception, so as to minimize the overloading of receivers by signals generated by local transmitters. Care should be taken to locate transmitting antennas so that their main lobe and side-lobes do not directly illuminate antennas used only for receiving purposes.

DF antennas. If DF equipment is to be installed at the monitoring station, the possible effect of reradiated components from the receiving antennas should be considered in regard to their effect in introducing errors in the DF equipment (see § 2.7 and 4.7).

Active antennas. Since mutual coupling between active antennas, as well as mutual coupling between them and other structures, is reduced to a minimum, active antennas may be installed closer together than passive antennas. Active antennas can be disturbed by high-power radio transmitters, and this needs to be taken into account when siting those antennas.

VHF/UHF antennas (above 30 MHz). These should be located high on towers near the receiving building to minimize losses in the coaxial cable, to maximize LoS coverage area. For a 20 km LoS radius, a 24 m tower is required. A 48 m tower would provide LoS coverage out to about 30 km.

Antennas for frequencies above 1 000 MHz. These should be located where a clear LoS is guaranteed (e.g., on a building, tower or mountain), especially for terrestrial monitoring. The receiving systems should be installed close to the antenna to avoid high losses in the coaxial cable.

3.2.6 Antennas for mobile monitoring stations

A mobile monitoring station offers the same functions as a fixed station in a mobile vehicle that can be driven from one location to another. This configuration provides measurement resources which can be easily moved to respond to a specific complaint or other monitoring need, and which can be located on the LoS propagation path of a signal of interest.

The chief limitation on antennas for mobile monitoring stations is their size. Owing to the inevitable lack of space, antennas must be small. Therefore, antenna size in the case of the lowest frequencies represents only a very small fraction of a wavelength. Loop antennas covering the frequency range 9 kHz to 30 MHz are available with or without ferrite material, and by reason of their clearly defined electrical characteristics, are particularly suitable for field-strength measurements and DF of ground wave signals. For frequencies between 30 MHz and 3 GHz, wideband omnidirectional antennas are available for receiving vertically or horizontally-polarized waves. Typical frequency ranges are 20 to 1 000 MHz, 200 to 3 000 MHz, or 30 MHz to 3 GHz.

A wide variety of directional and DF antennas are available for frequencies above 30 MHz, including wideband or narrow-band Yagi antennas, tunable dipoles, folded dipoles, biconical antennas and log periodic antennas. These antennas can cover fairly wide frequency bands and are capable of meeting all the requirements of a mobile monitoring station. A representative antenna is described at the beginning of § 3.2.4.1.

Most antennas for mobile stations are mounted on the vehicle. However, reflector antennas for frequencies above 1 000 MHz are usually not permanently installed on a vehicle, but carried along and erected when needed while the vehicle is stopped, as shown in Fig. 3-21. In all frequency ranges, active antennas may be used considering their technical data and their limitations, which are given in the discussion above dealing with omnidirectional antennas. Hand carried active antennas (see Fig. 3-22) may be used for the purpose of monitoring, field strength measurement, or even DF.

FIGURE 3-21

Transportable microwave antenna

Spec-3-21

FIGURE 3-22

Hand-held directional antenna

Spec-3-22

Typical mobile monitoring stations are shown in Fig. 3-23, each with a roof-top antenna mounted on a pneumatic mast.

FIGURE 3-23

Examples of mobile monitoring stations

Spec-3-23

Mobile stations are particularly important for monitoring at microwave frequencies. Microwave communication signals usually propagate in very narrow, well-defined beams designed for point-to-point, or point-to-multipoint communication. Therefore, it would be very unlikely for a fixed station to be located close enough to a microwave path, so as to be able to intercept a microwave communication signal. Because of its high cost and very limited benefit, it is not recommended to install microwave intercept at a fixed station; instead, this equipment should be in a mobile vehicle or portable configuration. For a dedicated vehicle, a complete system could be implemented to carry out measurements from 1 to 40 GHz and above.

In this case, illustrated in a typical block diagram (see Fig. 3-24), the antenna system consists of the following elements:

– Antenna system

– Automatic positioning system

– Antenna monitoring unit

– Output antenna table

– Azimuth and elevation control unit.

The antenna system could consist of several antennas to monitor the full band, as illustrated in Fig. 3-25. Moreover, to ensure flexibility in SHF measurements, taking into account different measurement situations and the low level of SHF signals, it is useful to include, close to the antenna system, some accessories like LNAs and YIG filters.

FIGURE 3-24

Example of a SHF monitoring system

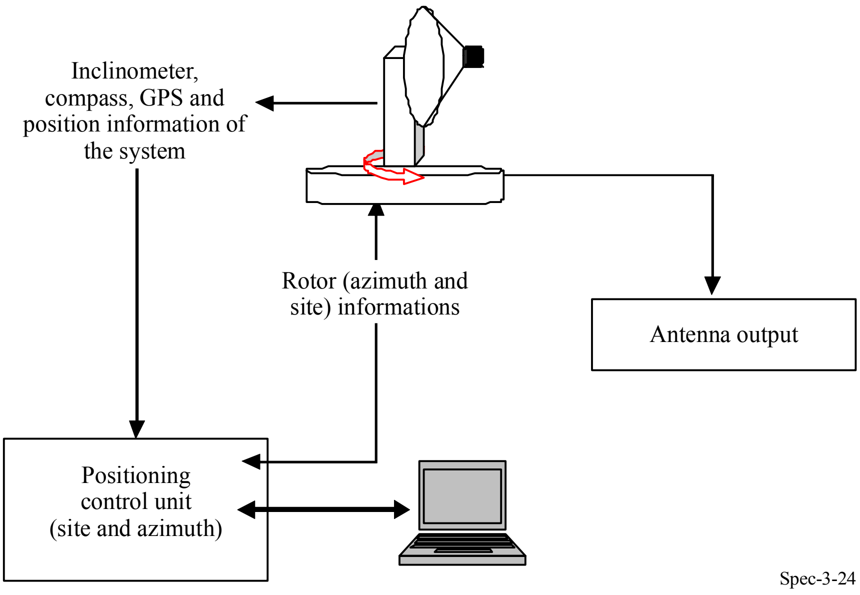
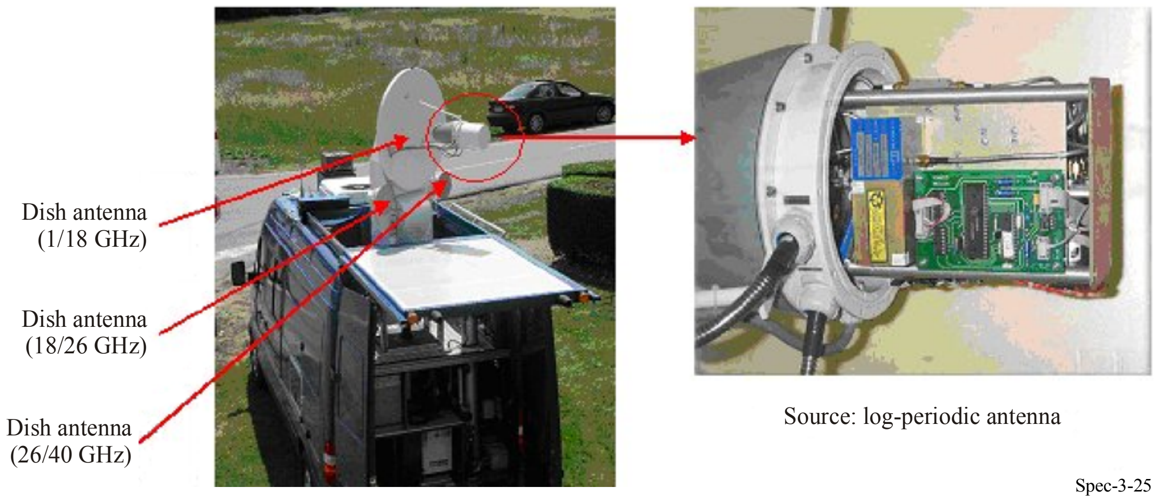


FIGURE 3-25

Overview of the antenna system



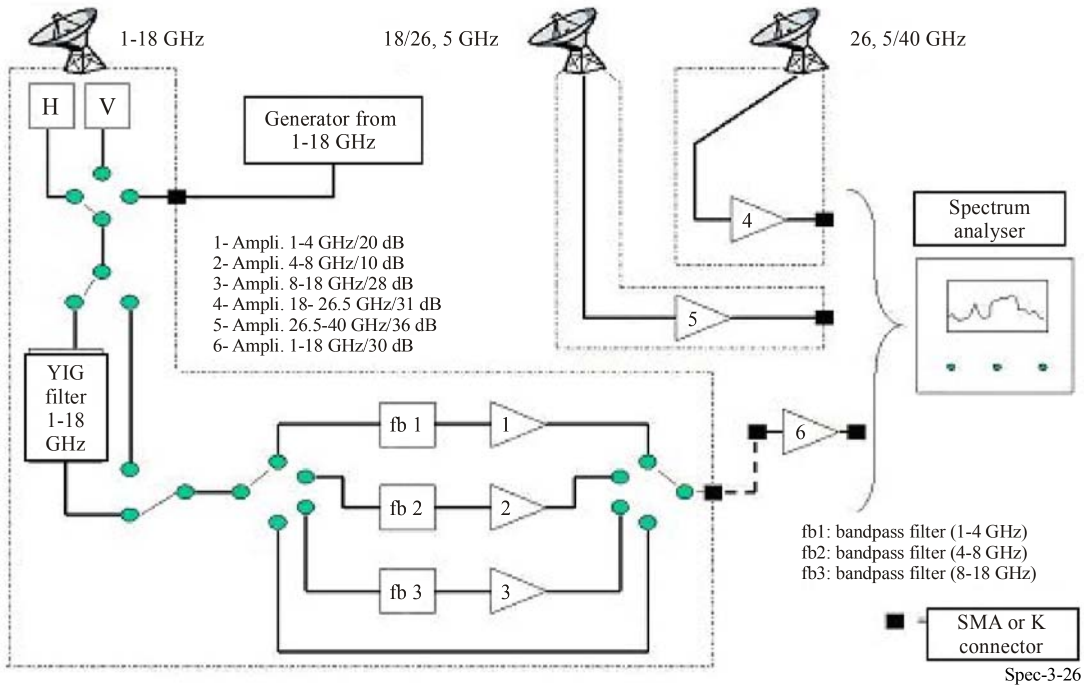
A PC provides the interface between the antenna system and the user.

The positioning control unit is the supervisor. It sends data to monitor the positioning system and receives information from different sensors to provide the status of the system and geographical referencing data.

An antenna output panel is available to the user to connect different measurement equipment with all available outputs (with or without LNA, filters and so on). Figure 3-26 gives a typical SHF measurement chain block diagram.

FIGURE 3-26

Block diagram of the receiving chain



3.2.7 Antennas for transportable and portable stations

Transportable and portable antennas are designed for minimum weight and size. The antenna shown in Fig. 3-11a) (left) is used for mobile or transportable uses. The antenna is easily transported in a packing case. The transportable antenna may be fixed at the top of a small telescopic mast, to minimize set up time. It can also be mounted on vehicles for semi-fixed stations.

Improvements in technology and integration allow transportable antennas to offer similar functionality and performance as antennas for fixed and mobile stations. These antennas associated with an integrated receiver allow a station to become transportable or portable, which is especially useful for in-town or difficult access areas for monitoring tasks. The spectrum is very dense in city areas, and monitoring measurements on the streets are not always relevant; only measurements from the top of dedicated sites, generally buildings in town, deliver reliable results. For this monitoring operation, compact and low-height/weight portable antennas and stations are needed. The transportable or portable configuration provides measurement resources that can be easily moved to locate on the LoS propagation path of the signal.

Three examples of portable antenna/stations are as follows:

Type 1: The first type of portable antenna/station requires deployment. The equipment is carried on a person's back to a dedicated measurement site. Figure 3-27 is an example of such a DF antenna, which enables fast deployment (a few minutes). The antenna and monitoring station is completely integrated, including receiver, cable switching unit and antenna, and carried on the back. The antenna structure is completely enclosed in a plastic box.

Type 2: The second type of portable antenna does not require deployment. The entire station (antenna and receiver) is integrated in a man-pack, which operates while the operator moves. The MMI is either integrated on a PDA allowing the operator freedom of movement, or on a laptop computer. A built-in DF antenna is integrated on the side of the receiver. The monitoring tasks are performed by a single person, with hands free for man-portable applications. A DF antenna for upper frequency bands could be provided.

FIGURE 3-27

Example of a portable VHF/UHF antenna

a) The antenna is enclosed in its box ready to be carried

b) A 20-3 000 MHz antenna in deployed configuration where a compact receiver and DF is installed

Spec-3-27

Type 3: A third type of portable antenna is a very compact solution. The hand-held directional antenna serves as monitoring and DF antenna and is connected to a hand-held receiver that allows for front panel operation without the need of an additional PC/PDA. The monitoring tasks are performed by a single person.

Another antenna type that may be required for specific use is shown in Fig. 3-28. This is a flexible monitoring antenna mounted on the envelope of a balloon which may be very useful for short-duration events, for example, to monitor special events such as state visits and sporting events.

An antenna altitude of up to 100 m allowed by such a balloon may detect and measure a maximum number of signals of interest. It is also better than terrestrial stations for intercepting a maximum number of signals without disturbance from buildings, forest and other high obstacles, and the presence of multipath.

The balloon is associated with a compact receiver (installed on the ground), is deployed quickly and easily, and can rapidly monitor the VHF/UHF frequency bands including unlicensed users and interference.

To avoid excessive cable loss due to the balloon height, two configurations are used:

– A monitoring receiver and processing unit may be located below the balloon. In this case, two cables (supply and data transmission) run to the ground station.

– A down-conversion unit may be used to convert the RF signal into an FI baseband. With analogue conversion, a RF cable may be used if the balloon is at a low height. For digital conversion, an optical or a data link may be used to transfer data to the ground station.

FIGURE 3-28

Example of a balloon support for a flexible VHF/UHF antenna

3.2.8 Transmission lines and distribution systems

3.2.8.1 Transmission lines

Transmission lines at monitoring stations conduct the received power from the antenna to the receiver.

Among the various types of transmission lines the preferred solution at monitoring stations is the coaxial transmission line. Its impedance is uniform provided the dimensions of the various parts including the connectors are adequately controlled. Signals on good coaxial cables are not severely affected by the presence of other objects. Coaxial cables are manufactured in a wide variety of sizes and materials. Properties of the available coaxial cables are many and varied, and cover a wide price range. There are a number of manuals available, particularly from cable manufacturers, which list individual coaxial cable properties. It is important to use double-shield braid or solid outer conductor type coaxial cable.

A 3 dB total attenuation may be quite acceptable for a receiving transmission line. The use of an integrated receiver at the antenna base avoids long cable runs, reduces insertion loss and eliminates any need for an LNA in a switching unit.

3.2.8.2 Distribution systems

Once the energy received by a particular antenna has been conducted to a point inside the monitoring building, there is usually a requirement to distribute this energy to a variety of receiving positions. The distribution system should take into account the final use that is to be made of each output so that the optimization of results can be obtained. In general, the level of the signal should be maintained as high as possible, so that undue sensitivity is not required of receiving equipment. Also, the quality of the signal (*S/N*) should be maintained, or the degradation kept as low as possible, so that the advantages of high gain antennas and low-loss distribution cables are not compromised.

Receivers which are simply connected in parallel across a transmission line will degrade the monitoring system performance because of e.g., standing waves, undefined power splitting and local oscillator reradiation. This method is not recommended. Instead, matching and signal splitting should be used.

As technology evolves, the number of antennas in a radio monitoring station is increasing; this results in complex receiving systems and distribution systems. It is sometimes necessary to receive signals from different frequency band antennas with different receivers. Distribution systems have benefited from computer and software technology and have evolved from mechanical to digital equipment modules.

3.2.8.2.1 Principle

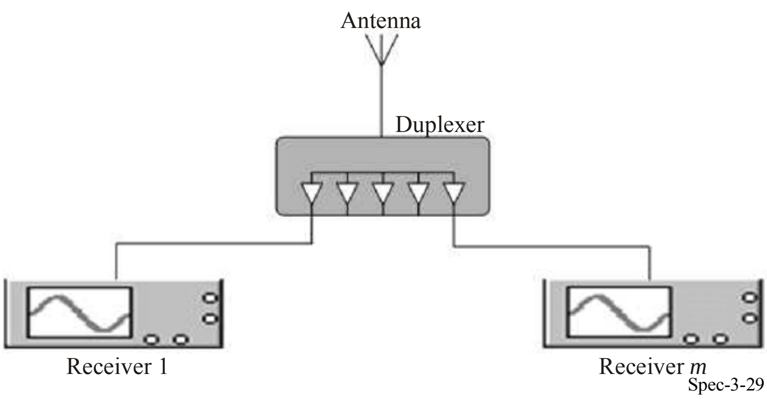
Distribution systems generally include an antenna switch and antenna duplexer. State-of-the-art technology is used to combine the two to achieve remote control via network.

3.2.8.2.1.1 Antenna duplexer

In a receiving system, the equipment which distributes a signal from one antenna to a multi-channel receiver or multiple receivers is known as a duplexer. A duplexer is the first component of the receiving system and it should have good linearity to minimize intermodulation. Figure 3-29 shows the connectivity of antenna, distribution system and analyzing equipment.

FIGURE 3-29

Example of distribution system

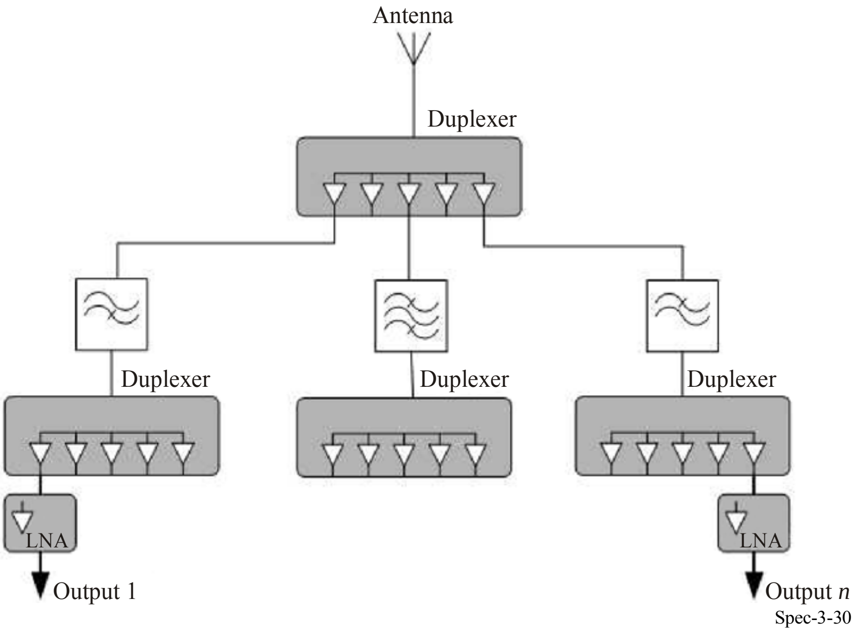


An antenna duplexer may be comprised of multiple duplexers and may include single filters that isolate different signal paths; an LNA is used to compensate for the attenuation and the controlling circuit. A block diagram of a multipath duplexer is shown in Fig. 3-30.

Because of the non-linearity of some of the components, the degradation of the noise figure is inevitable in the case of a multi-level duplexer for connection. Therefore, to maintain its performance, 2-level and 3-level duplexers are widely used. In general, noise figure and linearity degrade as the number of outputs increases.

FIGURE 3-30

Typical block diagram of a multipath duplexer

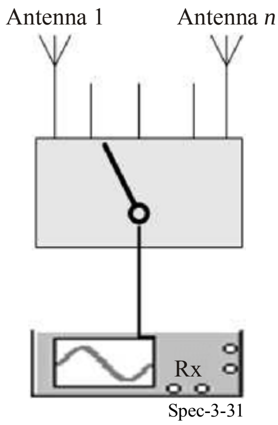


3.2.8.2.1.2 Antenna switch

An antenna switch selects from several antenna inputs a wanted input signal for one receiver. An RF antenna switch is shown in Fig. 3-31.

FIGURE 3-31

Typical antenna switch



Like antenna duplexers, an antenna switch consists of different components for different frequency bands because of the frequency limitation of individual components; insulation design is necessary between these components. LNA are sometimes used to compensate for the attenuation of components.

3.2.8.2.1.3 Distribution system

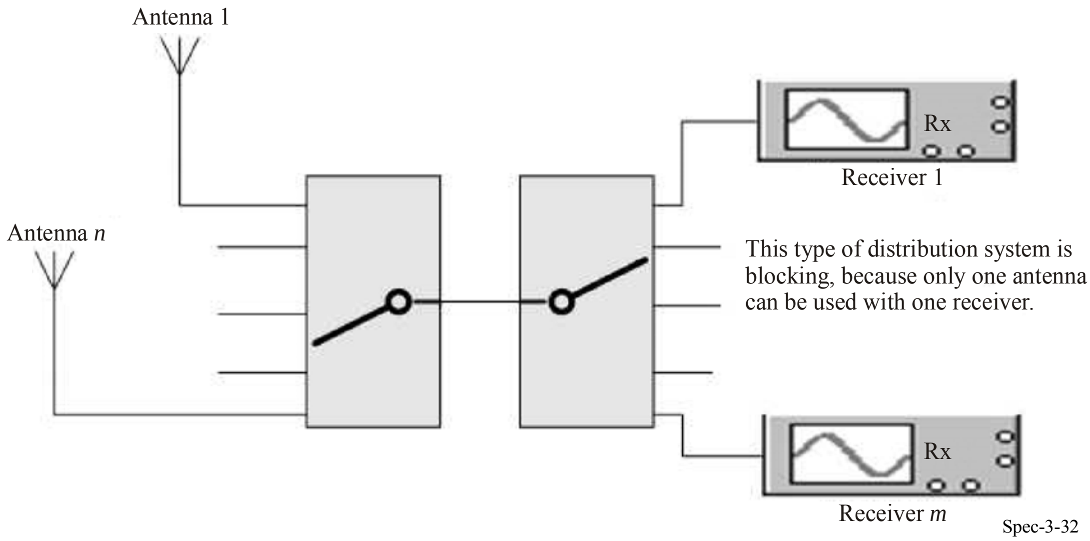
An RF signal distribution system is used to distribute signals from different antennas to different receivers. Signals from any antenna are available to any one of the receivers; any input signal can be delivered to any output of the distribution system.

There are two types of distribution systems. One is similar to what we see in a switching system, and is known as a blocking system. In such a system, only one antenna is connected to the receiver, and any new attempts to connect will be blocked. A typical blocking distribution system is shown in Fig. 3-32.

The other type, which utilizes newer technology, allows the connection to be established between multiple antennas and any of the antennas, or one antenna and multiple receivers.

FIGURE 3-32

Typical distribution blocking system



In fact, an ideal $M \times N$ matrix is composed of an M duplexer and an N antenna switch. Each antenna provides the n paths duplexer with its outputs, while the n paths outputs of the duplexer are connected to the inputs of the n antenna switch. Each antenna switch will provided the n receivers with its outputs. The principle of a non-blocking antenna matrix is shown in Fig. 3-33.

For example, if an x receiver has to be connected to a y antenna, the signal of this antenna will be split into m outputs by the y duplexer and switched to the x receiver by the x antenna switch.

where:

n: maximum number of antennas with duplexer

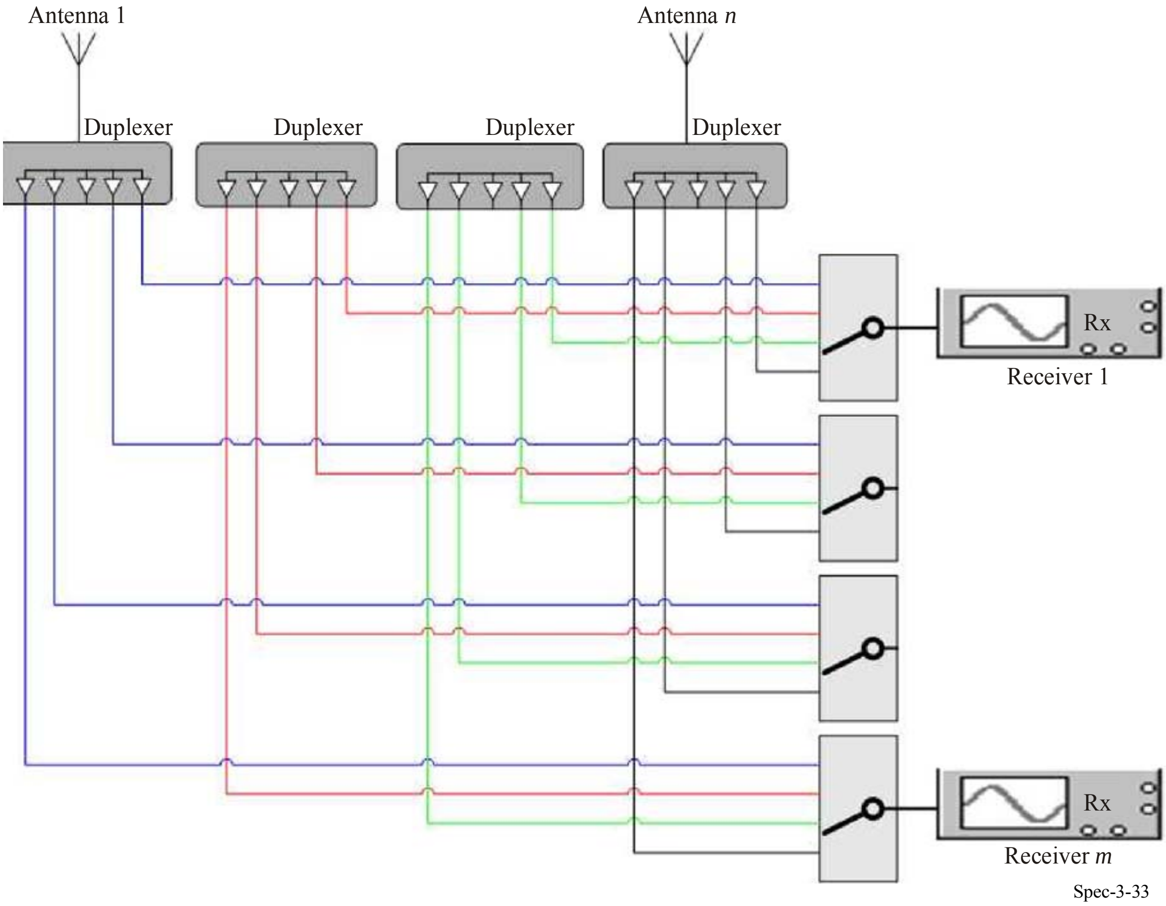
m: maximum number of receivers

x: selected receiver

y: selected antenna.

FIGURE 3-33

Typical non-blocking distribution system



3.2.8.2.2 Performance

Despite the burgeoning development of digital signal processing technology in signal detection, demodulation and DF, analogue technologies are still necessary in signal distribution. A good distribution system should be optimized for performance in such areas as sensitivity, dynamic range, switch of RF signal, capability of distribution, and isolation between channels. Specifications of a distribution system should include the following major parameters:

– Frequency range

– Insertion loss

– Isolation

– Dynamic range

– Third order intermodulation product (IP3)

– Noise figure.

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ITU-R Recommendations:

NOTE – In every case the latest edition of all the referred Recommendations is encouraged to be used.

Recommendation ITU-R F.162 – Use of directional transmitting antennas in the fixed service operating in bands below about 30 MHz.

Recommendation ITU-R BS.705 – HF transmitting and receiving antennas characteristics and diagrams.

3.3 Monitoring receivers

3.3.1 General considerations

The performance of a monitoring station is directly related to the quality of the station equipment, including the antennas, receivers, radio DF and processors. Antennas, DF and processing equipment are discussed in § 3.2, 3.4 and 3.6.2. An in-depth study of receivers would require a dedicated book, so only an overview of the composition of receivers, definition of the main features and operating precautions is provided here.

The function of a receiver is to select a radio signal from all the signals intercepted by the antenna to which it is connected, and to reproduce at the receiver output the information transmitted by the radio signal or its characteristics. In the past, most receivers have used entirely analogue circuitry, but most modern receivers are digital, using digital signal processing (DSP) techniques to implement many receiver functions, from simply digitizing the detector output to digitizing the full base band, including digital demodulation, such as performed by "software-defined radio" systems. Both types of receivers, analogue and digital, are discussed below.

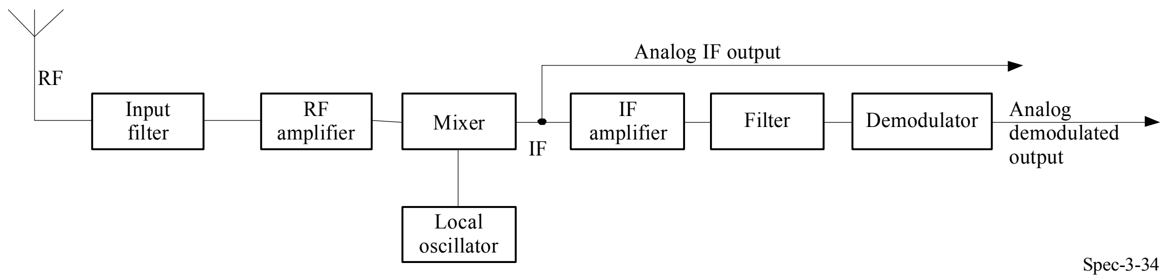
Due to technological improvements, modern receivers are becoming more and more compact. Miniaturization of high stability oscillators allows the analogue portion of a receiver to become smaller. For digital receivers, the digital part is becoming more powerful and compact, due to improvements in analogue to digital converters, memory and processors. Interfaces are now fully digital.

3.3.2 Analogue receivers

The block diagram in Fig. 3-34 shows the main stages of an analogue receiver. The input filter, which is typically a bank of suboctave preselector or tracking filters, allows for the reception of the desired signals and eliminates those which are out-of-band, in order to preclude intermodulations in the high-frequency amplifier. This filter should include the centre frequency of the transmission to be received, and have a passband wide enough to receive the entirety of the desired transmitted spectrum.

FIGURE 3-34

Typical block diagram of an analogue receiver



The designer of a monitoring station must then pay attention to the power of transmissions likely to be received within the passband of this input filter; signals other than the desired one are likely to generate spurious signals by intermodulation in the RF amplifier and/or to result in sensitivity degradation of the RF amplifier due to its blocking. To eliminate these effects, it is necessary to have sufficient RF amplifier linearity.

The purpose of the input filter is also to attenuate reception of the image frequency.

The RF amplifier, by its gain, partly determines the receiver sensitivity. But it also has another very important purpose: with the input filter, it prevents the local oscillator signal from being conducted to the antenna, which would radiate it, thus generating a spurious radio signal.

The intermodulation between two signals occurs when such signals go through a non-linear circuit as described in § 6.5. Intermodulation signals can be superimposed on usable signals, and interfere with them. The quality of a receiver, from the intermodulation point of view, is characterized by the value of its third-order intercept point, which should be as high as possible.

Receiver sensitivity is limited by the noise generated by its input circuits, in particular by the RF amplifier and the mixer. The sensitivity is also expressed by the noise figure in Table 3-2, which should be as low as possible. The relationship between sensitivity and noise factor, for the same receiver, involves the receiver passband.

When a receiver is connected to an antenna, in addition to its own internally generated noise, natural noises of external origin are added, such as atmospheric, galactic and solar noise, as well as artificial noises such as industrial interference, radiation from electronic equipment and radiation by transmitters generally. The designer of a monitoring station has, therefore, to select the receiver from the standpoint of its sensitivity, according to the noise levels measured.

It should be noted that a receiver with very high sensitivity would have poor performance as regards linearity, i.e. intermodulation and blocking. Blocking characterizes degradation of receiver sensitivity and can be caused by only one unwanted signal situated in the vicinity of the wanted carrier and outside the receiver IF passband.

Due to this fact, monitoring receivers usually contain switchable or programmable-gain preamplifiers. This allows the receiver to operate either in high sensitivity mode (with the preamplifier in the “on” mode) or high linearity/low distortion mode (with the preamplifier in the “off” mode).

Other characteristics should also be specified or investigated, such as:

– bandwidths of intermediate frequency filters;

– types of demodulation needed;

– effectiveness of the automatic gain control;

– effectiveness of the automatic tuning system;

– frequency response of the circuits processing the demodulated signals;

– precision and legibility of displays; and

– variations in characteristics depending on the temperature.

Normally two types of receivers are used to cover the frequency range from 9 kHz to 3 000 MHz, one for frequencies up to 30 MHz and the other for 20-3 000 MHz. If an extended frequency range (e.g. up to 40 GHz) is to be covered, additional equipment may be required. In selecting the receivers, the various types of modulation to be monitored e.g., AM, CW, SSB, ISB, FSK and FM, should be taken into account and provision made for the reception of these emissions.

All the qualities expected of receivers for use at a main receiving station are required of monitoring receivers, with the addition of good frequency setting accuracy (better than or equal to 1 Hz), rapid tuning and a minimum of waveband switching.

Provision should also be made for the connection of additional units, i.e., radio teleprinter keying units, oscilloscopes, panoramic adapters, etc. The intermediate frequency output of the receivers should be provided at low impedance via buffer stages. To obtain long-term high-frequency stability, it is useful to have an input for an external frequency standard (see § 3.3.4). It is also necessary to provide for the insertion of an attenuator at the receiver input to eliminate spurious frequencies caused by high-level signals overloading the receiver input stages. Interfaces for remote control and data output should also be provided.

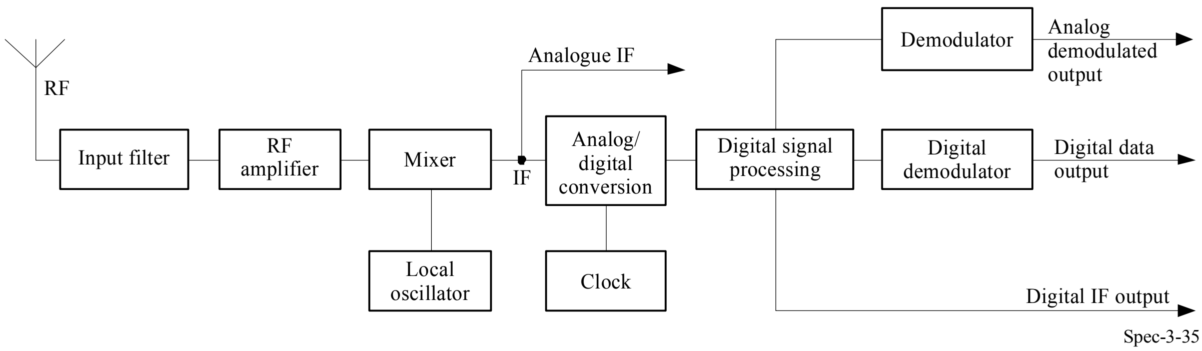
3.3.3 Digital receivers

The advent of high-speed, low-cost digital signal processing (DSP) chips and high dynamic range analogue to digital (A/D) converters has made possible the design of high performance receivers that use digital circuitry to replace analogue circuitry. These “digital receivers” provide improved performance in frequency conversion; filtering and demodulation, which leads to increased selectivity, stability and automatic, gain control. Additionally, functions such as adaptive interference cancellation, and speech enhancement and recognition not found in analogue receivers may be available in digital receivers. These functions are very important when attempting to sort and identify specific signals in a congested signal environment. The performance of these receivers, because of the use of digital circuitry and associated software algorithms, does not vary with regard to time and temperature. One of the most significant features of digital receivers is improved flexibility, an example of which is the ability of the digital receiver to accommodate complex modulation formats commonly used in cellular and high performance control links. Additional IF bandwidth, demodulation modes, or other functions can be made in a DSP-based circuit by software change versus costly equipment replacement of analogue receivers. Filters can be synthesized by digital processing to provide extremely sharp filter shape factors, while maintaining very flat amplitude and linear phase response over the desired pass band. This process minimizes signal distortion usually introduced by analogue filters. It is also possible to generate very narrow (less than 50 Hz) filters allowing direct measurement of transmitter carrier spurious components such as power line related hum.

The basic elements of a digital receiver: the RF tuner, IF digitizer, signal processor, and analogue signal reconstruction modules, are shown in Fig. 3-35.

FIGURE 3-35

Typical block diagram of a digital receiver



The first major processing step in a digital receiver is the conversion of the desired RF signal to digital form. This process is performed by the combination of the RF tuner and the IF digitizer. The RF tuner, including analogue preselection, translates the desired portion of the RF spectrum to a wideband, or pre-IF, for processing by the IF digitizer. The IF digitizer utilizes an A/D converter and other circuitry to digitize the IF from the RF tuner. The resulting digitized signal is used by the signal processor to perform such functions as filtering, fine tuning and demodulation. Digital output from the module is then made available for further processing and/or recording. The analogue signal reconstruction module converts the digital outputs to analogue for operator monitoring or further processing.

The receiver characteristics listed in § 3.3.2 apply also to digital receivers. Receivers for the execution of spectrum monitoring tasks according to ITU-R Recommendations should provide the following functions:

– scan of predefined frequency ranges;

– memory scan of several hundred channels;

– audio monitoring of FM, AM, CW, SSB, ISB, ASK, FSK, PSK, IQ and pulse transmissions;

– identification;

– storage of measured values for a later use or download.

Processing these different functions for the various signals available, with optimum *S/N*, requires a large number of IF bandwidths.

Modern digital monitoring receivers include a display and control unit, either a separate PC with computer software that provides a "Virtual Control Panel" or a built-in control unit. The receiver has a remote interface, including LAN (Ethernet) that provides for both local and remote control operation. Also, the operational concept of a monitoring receiver should meet all the demands made on a receiver for measurement of frequency and frequency offset, field strength, modulation, bandwidth and spectrum occupancy. For the spectrum occupancy the receiver has to scan the frequency range of interest with digital control and has to display the associated spectrum.

Digital receivers may be packaged separately, but are often integrated into the measurement and processing system as described in § 3.6.2. The receivers include a number of interfaces, such as: Digital IF output, I/Q-based output for DF, wideband IF output for external panoramic display, output for external loudspeaker, and headphone socket.

With the help of a digital down converter (DDC) a selected signal is mixed down to baseband for further processing (demodulation, decoding, identification, measurement of modulation- parameters). By using a bank of DDCs in parallel (implemented e.g. in FPGA, DSP or ASIC technology) many signals can be mixed down and processed in parallel. Every DDC can be tuned in the frequency range covered by the wideband IF and works as a virtual receiver. This technology is especially useful for processing signals that were recorded within a digital wideband IF by replaying the digital IF back to the wideband receiver and using the DDCs to select the signals of interest for processing.

This processing technique makes it possible to detect and analyze short-duration transmissions such as frequency hopping signals. The bursts of hopper transmitters are received with the wideband receiver (live or replayed) and detected with an automatic burst detection algorithm. By using DDCs the hops are mixed down to baseband and analyzed (exact length, bandwidth, modulation-parameters). An evaluation process investigating the measured information of all detected bursts determines the different types of bursts, the different hop rates und hop-sets (frequency-sets) of the received transmitters. This statistical analysis provides information about hopper scenarios like the number of active hopper transmitters and the types of communication methods used.

3.3.4 Frequency synthesizers for receivers

One of the most essential components of the receiver is the frequency synthesizer. The main purpose of the frequency synthesizer is to provide a standard source of RF energy of which the frequency, power level and modulation characteristics are known exactly. The accuracy required for a frequency used for controlling and checking modern receiving systems is becoming more and more stringent and is the reason why the synthesizer must have the highest possible precision and stability. Consequently most monitoring stations have a frequency synthesizer which covers a wide frequency range with very high precision.

3.3.5 Typical specifications for monitoring receivers

A monitoring receiver should generally meet the specifications for VLF/LF/HF and VHF/UHF receivers that are given in Table 3-2. This table applies to both analogue and digital receivers. One should also consider these specifications as a general guideline to select equipment that is able to provide a good performance and reliability for the tasks required by a monitoring system. For certain applications it is possible to find on the market simpler equipment that might be sufficiently suitable when considering the desired application.

Certain receiver parameters given in Table 3-2, such as third order intercept, noise figure, and filter parameters, are so important and have such a direct influence on the suitability of a receiver for certain monitoring tasks, that their specification and measurement procedures are defined by ITU-R Recommendations. Measurement results strongly depend on the test procedures used, and standardized test procedures allow easier and more objective comparison of products from manufacturers. Scanning speed, discussed in Recommendation ITU-R SM.1839, required for different measurements is very dependent on the intent and application of the measurement; for example, the required receiver scanning speed to detect the presence of a single-event signal burst is much faster than receiver scanning to measure some parameter or characteristic of the signal.

TABLE 3-2

Typical specifications for general purpose monitoring receivers

Function	VLF/LF/HF	VHF/UHF
Frequency range	9 kHz to 30 MHz	20 MHz to 3 000 MHz
Tuning resolution	≤ 1 Hz	≤ 10 Hz
Tuning error	≤ 1 ppm, or ≤ 0.01 ppm using global positioning by satellite[1] for external reference	≤ 0.1 ppm, or ≤ 0.001 ppm using global positioning by satellite(1) for external reference
Synthesizer settling time	≤ 10 ms	≤ 5 ms
Input (antenna input) VSWR	50 Ω, nominal ≤ 3	50 Ω, nominal ≤ 2.5
Preselection (highly linear receivers may meet intermodulation specifications without preselection)	Set of suboctave band filters or tracking filter	Set of suboctave band filters or tracking filter
3rd order intercept	≥ 20 dBm (> 3 MHz)(1)	≥ 10 dBm(1)
2nd order intercept	≥ 60 dBm (> 3 MHz)	≥ 40 dBm
Noise figure	≤ 15 dB (> 2 MHz)(2)	≤ 12 dB(2)
LO-phase noise	See below	See below
IF rejection	≥ 80 dB	≥ 80 dB
Image rejection	≥ 80 dB	≥ 80 dB
IF bandwidths (–6 dB)	Internal or external filters, preferably digital, from 0.1 to at least 10 kHz(3)	Internal or external filters, preferably digital, from 1 kHz to at least 300 kHz(3)
Selectivity 60 to 6 dB (shape factor)	2:1(3)	2:1(3)
Detection modes (in digital receivers, demodulation may be done in internal or external DSP)	AM, FM, CW, LSB, USB	AM, FM, CW, LSB, USB
AGC range (for digital receivers, may be partly implemented in internal or external DSP)	≥ 120 dB	≥ 120 dB
Outputs –IF	Digital IF output	Digital IF output
Audio	0 dBm, 600 Ω, or digital streaming audio and ear-phone jack	0 dBm, 600 Ω, or digital streaming audio and ear-phone jack
IF monitor	For external IF monitor, or digital data stream	For external IF monitor, or digital data stream
Remote control	Ethernet LAN, or GPIB, or RS-232	Ethernet LAN, or GPIB, or RS-232
IF spectrum (may be done in DSP)	Built-in or external, FFT processing; refresh ≥ 10/s	Built-in or external, FFT processing; refresh ≥ 10/s
RF spectrum (may be done in DSP)	Built-in or external; refresh ≥ 10/s	Built-in or external; refresh ≥ 10/s
RF and IF spectrum display	Via local or remote control	Via local or remote control
Electromagnetic compatibility	IEC 61000-4-2, -3, -4 CISPR 11, group 1, class B	IEC 61000-4-2, -3, -4 CISPR 11, group 1, class B
Operating temperature range	0° to 45° C	0° to 45° C
Relative humidity	95% non-condensing	95% non-condensing
Vibration	IEC 68-2-6	IEC 68-2-6

(1) Measurement procedures according to Recommendation ITU-R SM.1837.

(2) Measurement procedures according to Recommendation ITU-R SM.1838.

(3) Measurement procedures according to Recommendation ITU-R SM.1836.

Phase noise

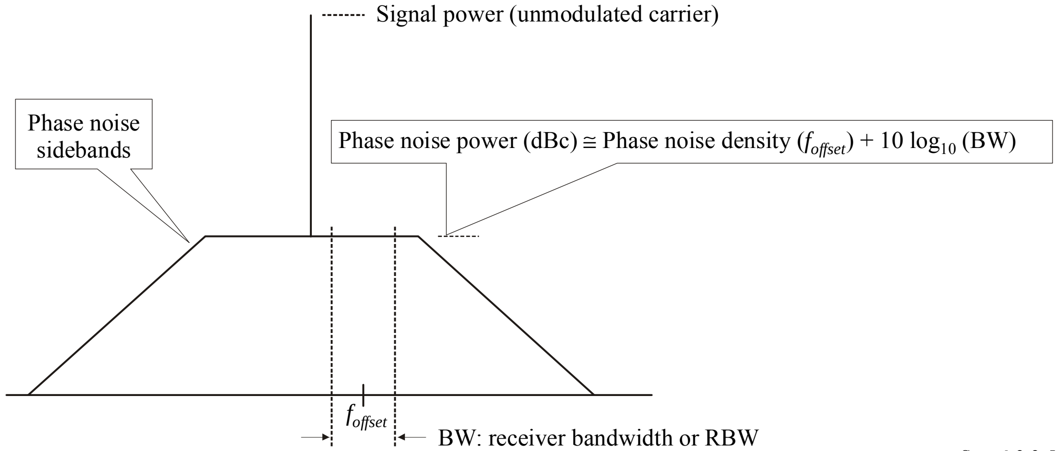
The phase noise performance of a receiver directly impacts the ability to resolve closely spaced signals of different amplitudes. It can also prevent accurate demodulation. Phase noise in a receiver phase modulates received signals increasing their bandwidth. Two adjacent signals that may not have overlapping spectrums at the input to the receiver may interfere with each other in the receiver once modulated by receiver phase noise.

Phase noise is multiplicative and therefore is specified as a noise density relative to a carrier (dBc/Hz), the larger the signal, the greater the phase noise power. The greatest impact of phase noise is on closely spaced signals of unequal power.

The larger signal will have greater power in the phase noise sidebands and therefore have greater impact on the detection or demodulation of the weaker adjacent signal than the other way around. For large signals, phase noise limits the receiver's dynamic range.

Phase noise density is usually specified at fixed frequency offsets such as 10 kHz or 100 kHz. The phase noise density is generally greatest at small frequency offsets. For this reason the phase noise requirement is largely determined by the types of signals that are to be monitored. Phase noise requirements will be much greater with narrowband signals than with wideband signals, so receiver specifications will be driven primarily by the narrowest carrier (or subcarrier) to be monitored.

With the assumption that the phase noise spectrum is relatively flat across the bandwidth (BW), the dynamic range near a large signal can be estimated as follows:



Spec § 3-3-5

Example of application of the above equation:

Bandwidth or RBW	Phase noise	f_{offset}	Phase noise power
25 kHz	–100 dBc/Hz	10 kHz	–56 dBc

The frequency offset and required bandwidths affect the phase noise power. HF applications may have narrower bandwidth requirements whereas UHF applications may have wider bandwidth requirements.

References

ITU-R texts:

NOTE – In every case the latest edition of all the referred Recommendations is encouraged to be used.

Recommendation ITU-R SM.331 – Noise and sensitivity of receivers.

Recommendation ITU-R SM.332 – Selectivity of receivers.

Recommendation ITU-R SM.1836 – Test procedure for measuring the properties of the IF filter of radio monitoring receivers.

Recommendation ITU-R SM.1837 – Test procedure for measuring the 3rd order intercept point (IP3) level of radio monitoring receivers.

Recommendation ITU-R SM.1838 – Test procedure for measuring the noise figure of radio monitoring receivers.

Recommendation ITU-R SM.1839 – Test procedure for measuring the scanning speed of radio monitoring receivers.

Recommendation ITU-R SM.1840 – Test procedure for measuring the sensitivity of radio monitoring receivers using analogue-modulated signals.

Report ITU-R SM.2125 – Parameters of and measurement procedure on HF/VHF/UHV monitoring receivers and stations.

3.4 Direction-finding (DF)

3.4.1 General considerations

Identification of an unknown transmitting station can be facilitated if the location of the transmitter can be determined by triangulation or SSL using DF equipment. A more accurate determination of the transmitter location requires bearings to be taken by several DF stations established at suitable geographical locations. Ideally, a "cross bearing" or a "fix" (i.e., the point where the bearing lines intersect) can be obtained when a minimum of two DF stations, which need not necessarily be in the same country, work in unison. A monitoring station that has the possibility of taking bearings can provide an experienced operator with information, which will enable him to identify transmissions with a higher degree of confidence.

The complexity of the DF equipment depends upon the required accuracy and the local conditions and is discussed in more detail in § 4.7. Since the DF antenna must be set up at a place clear of any buildings, antennas, power and telephone lines and other prominences, it should generally be installed at some distance from the rest of the monitoring station, or perhaps at a separate location, where it is operated under remote control.

The accuracy of the bearings depends upon the following factors (not in order of importance):

- antenna aperture, as described in § 3.4.2;
- antenna configuration, including number of antenna elements, their organization into frequency bands, element directivity and other factors;
- type of DF equipment;
- number of receiver channels;
- nature of site;
- signal strength and *S/N*;
- integration time;
- propagation conditions;
- amount of interference.

In the frequency range where skywave propagation is present, typically 1-30 MHz, an SSL system allows determining the geographical position of a transmitter with a single radio DF that measures elevation as well as azimuth angle of arrival. Processing data supplied by the radio DF (azimuth, elevation, position), associated with ionospheric predictions or preferably real-time ionospheric measurements from a sounder, allows estimating the transmitter distance. The SSL concept thus allows performing the location mission when, for geographical, timing, availability reasons, a complete triangulation radio DF location system could not be installed, or the signal of interest could not be received at multiple stations.

For further information see Recommendations ITU-R SM.854 – Direction finding and location determination at monitoring stations, and § 4.7.

3.4.2 Antennas

The DF antenna is one of the most important components of DF equipment because it largely defines the DF accuracy. The aperture of the antenna array (D/λ; D: diameter of the antenna array, λ: wavelength of the received signal) plays a most important role in determining the bearing accuracy. DF antennas with $D/\lambda > 1$, so-called wide-aperture antennas, overcome multi-path problems and other propagation effects, noise, interference, site irregularities and other sources of error, providing higher *S/N*, smaller DF errors, higher immunity to reflections, higher sensitivity, and shorter integration times for a given level of accuracy than narrow-aperture antennas ($D/\lambda < 0.5$). Not all DF methods allow the use of wide-aperture antennas, but where they may be used, they provide the most accurate DF results.

Each DF antenna consists of a number of antenna elements (minimum three). Depending on the DF method various configurations of the DF antenna array are possible. Wider aperture DF antennas tend to have more antenna elements to fill the aperture and avoid ambiguities; the probability error introduced by random noise tends to reduce by the reciprocal of the square root of the number of elements. In the HF range circular and "L"- or "X"-shaped linear arrays are common, in the VHF/UHF range mainly circular arrays are in use. The DF method has also an influence on whether a wide frequency range can be covered by only one antenna array or whether the range has to be divided into a number of arrays for different sub-ranges.

Generally one has to discriminate between DF antennas for fixed and mobile application. The type of antenna elements depends on the frequency range and application: in the HF range, arrays of monopoles or crossed-loop elements are used for fixed systems, whereas mobile systems use antenna arrays consisting of either loops or ferrite elements (see § 3.2.3.1). For the VHF/UHF range, mostly arrays of dipoles or fans are in use (see § 3.2.4.1).

3.4.3 Equipment

DF equipment may be integrated in with the measurement equipment at a monitoring station as described in § 3.6.2, or may consist of separate units. For portable units, see § 3.2.7. The frequency range of DF equipment is not only determined by the DF antenna but also by the receivers, which form part of the equipment. In practice, there is MF/HF DF equipment (e.g., 0.3-30 MHz) and VHF/UHF DF equipment (e.g., 20-3 000 MHz).

The number of receivers may vary from 1 to n, where n is the number of elements that form a DF antenna array and it depends also on the DF method. Multiple receiver systems require less integration time and/or less S/N for a given accuracy and therefore provide faster response time than single channel systems. If more than one receiver is used, all receivers have to be tuned by one common oscillator. In modern receivers, the IF is processed in digital form. A very important feature for DF receivers is the selectivity of the receiver to avoid a mutual interaction of two adjacent signals. At least one of the DF receivers should offer the possibility to demodulate the modulation of the received signal.

Some DF methods require a calibration of the receivers, RF distribution and antennas at certain time intervals. For this purpose, a defined signal will be injected in parallel into the receiving paths, and after measuring amplitude and phase for each path, corrective steps are taken to restore identical characteristics for each channel, if necessary. A very important feature is the possibility to remote control the equipment over any distance. Interfaces for RS-232, ISDN, LAN WAN and cellular telephone links are common.

3.4.4 Number of receivers

This section compares DF systems with varying numbers of receiver channels, considering the advantages and disadvantages of each. A DF system may have a single-channel receiver, dual-channel receiver, triple-channel receiver, or a receiver with up to as many channels as there are antenna elements. Systems with at least two receiver channels, but less channels than the number of antennas, are termed multi-channel systems. Systems with the number of receiver channels equal to the number of antennas are termed N-channel systems, where N is the number of receiver channels and antennas.

3.4.4.1 Single-channel systems

Advantages	Disadvantages
– Only one receiver channel required – Less cabling from DF antenna to equipment – No phase matching/calibration required – For *interferometer* single-channel DF using multiplexing circuits, accurate phase measurement is possible	– Amount of switching and associated sampling time require substantially more measurement time than DF systems with more than one channel – Sensitive to rapid signal phase variations, which can result in bad data and/or long integration times – If multiplexing circuits are used, antenna switch is complex

Single-channel DF systems can be divided into two groups:

– Simple single-channel DF systems, where each antenna element is sampled sequentially with one receiver channel, and

– Interferometer or multiplexed single-channel systems, where the reference antenna element is sampled together with each other antenna element and both signals are combined and routed to one receiver channel.

In either case, after each switch, the IF filter in the receiver must be allowed to settle before the voltage can be sampled. The total sampling time depends on the settling time of the filter, which is tied to its bandwidth, and the number of antenna elements. This sampling time is substantially longer in single channel systems than in systems with more than one receiver channel.

During the sampling period in a single-channel system, the wave state of the signal could change due to changes in the internal modulation of the signal or effects of the propagation medium such as fading, multi-path and reflections that arise during the sequential sampling of the elements of the array. These wave-state changes during the sequential switching process can introduce errors in single-channel systems, because they may be indistinguishable from changes in the signal that arise from sequentially sampling antennas with different patterns or orientations of their main beam. The single-channel system can only deal with errors introduced by this mechanism through measurement of the signal over periods of time long enough to average out such effects. In cases where sufficient averaging time can not be applied, such as in the case of short duration signals, single-channel systems can be confused. However, single-channel DF systems can be built that fulfil the requirement of 10 ms. Response time as described in § 4.7.1.1.16.

3.4.4.1.1 Simple single-channel DF systems

Simple single-channel DF systems sequentially sample each antenna element. In contrast to interferometer single-channel DF systems using multiplexing circuits, only amplitude is measured and processed. Phase is not measured. Systems that do not make use of phase information in the arriving wave are inherently less accurate than systems that use all of the available information in the arriving wave.

3.4.4.1.2 Interferometer or multiplexed single-channel DF systems

Interferometer single-channel DF systems use a quadrature-multiplexing technique. This allows the measurement of amplitude and phase, since the phase-reference element is always measured together with all other antenna elements.

During the measurement process, in which all antenna elements are sampled one after the other, the amplitude of the signal could change due to changes in the internal modulation of the signal or effects of the propagation medium such as fading, multi-path and reflections. To avoid a decrease in accuracy, additional averaging is required. Furthermore, the amplitude difference between two antenna elements cannot be simultaneously measured and can only be obtained by averaging over time, losing information that would be useful in systems where directional antenna elements are employed.

After each switch between antenna elements and in the quadrature-multiplexer, the IF filter in the receiver must be allowed to settle before the voltage can be sampled. The total sampling time depends on the settling time of the filter, which is tied to its bandwidth, and the number of antenna elements. This sampling time is substantially longer in interferometer single-channel systems than in simple single-channel systems.

3.4.4.2 Multi-channel systems (one reference channel and one or more switched sampling channels)

Advantages	Disadvantages
– Requires less time to obtain a result than a one-channel DF, i.e. shorter response time – Accurately handles changes in wave state due to propagation or modulation conditions – Phase and/or amplitude matching are easily accomplished by calibration or double averaging method – Simultaneously measures amplitude difference between channels	– Two or more receiver channels needed; cabling is more complex – Amount of switching and associated sampling time require more measurement time than DF systems with as many receiver channels as antennas – Regular calibration needed to match both receiver channels or, for dual-channel systems, double averaging method may be used

Multi-channel systems have more than one receiver channel, but less receiver channels than the number of antennas; they have one reference channel and one or more switched sampling channels. They have only one local oscillator, since all channels are driven from the same oscillator source. The channels do not have to be identically matched with filters which have exactly the same filter shape; rather, un-matched receivers may be used which are driven from the same oscillator. These receivers provide coherent detection of the signals in the two channels, and are calibrated over the entire RF path from antennas to A/D converters as to any phase delays, differences in the filter shape, etc., taking into account feed line differences between DF elements and the sampling circuits. This calibration is also the backbone of built-in test and diagnostics for such a system.

To avoid matching elements and/or calibration source and to simplify the measurement, but without the end-to-end calibration and built-in test, a double averaging method may be used in the case of two receiver channels, where a measurement of amplitude and phase difference between the two channels is made, and then the switching reverses the antenna connections and another amplitude and phase measurement is made, and the results are averaged, canceling out any amplitude and phase mismatch without separate calibration. A disadvantage of this double averaging method is increased measurement time.

Since systems discussed here have a reference antenna and receiver channel that can serve as a reference for phase, the difference in phase between the sampled and reference channels can be precisely measured to an accuracy of one-tenth of a degree or better. The difference in amplitude between the sampled and reference channels can also be precisely and simultaneously measured, allowing the system to distinguish amplitude changes arising from any differences in directivity of the antennas, which single-channel systems cannot do without averaging over long periods to average out effects of modulation and propagation.

The measurement of voltage on each sampled antenna is compared with the voltage on the reference antenna measured at precisely the same time. Measurements on the sampled channel are normalized by the reference channel; the voltage on the sampled channel is divided by the voltage on the reference channel.

This normalization divides out the effects of propagation and modulation changes that introduce error as discussed above in connection with single-channel systems, since modulation and propagation factors affect each antenna equally, under plane wave reception conditions (usually assumed case). This normalization eliminates all external factors that may affect phase and amplitude measurement accuracy.

3.4.4.3 *N*-channel systems (*N* = number receiver channels = number antennas)

Advantages	Disadvantages
– Faster DF measurements than other methods – No antenna switching is needed	– Multiple receiver channels needed; cabling is more complex – Need for phase and amplitude calibration increases complexity of the system

N-channel systems with one receiver channel for each antenna are the fastest and highest performance systems, because the arriving wave can be sampled simultaneously on all antenna elements, rather than sampling the antennas sequentially as is done in systems with less receiver channels. All receiver channels are driven from one common local oscillator.

These systems are more costly than systems with less receiver channels, as a function of the number of receiver channels and the need to either phase match the channels, or to provide real-time calibration among them. The channels do not need to be precisely matched, but rather may be simply calibrated in real time.

N-channel systems measure voltages and phases on each element relative to one of the elements which is chosen as a reference, so they have all the advantages of systems discussed in the previous subsection in terms of being able to measure both phase and amplitude information relative to the reference element.

3.4.5 Signal processing

Bearing processing can be based on different DF methods. Each principle has its advantages and disadvantages, depending on the application. The methods mainly used are the following:

– Rotating antenna characteristic;

– Wullenweber;

– Adcock/Watson-Watt;

– Doppler/pseudo-Doppler;

– Phase interferometer;

– Correlation/super-resolution.

DF equipment produces a bearing with more or less accuracy and will also indicate the receiving level of the signal to which the system is tuned. Some DF equipment produces for each bearing a quality value that can be used to suppress “wild” bearings. Phase-sensitive DF equipment for the HF range indicates also the elevation angle of the received signal if it arrives as a sky wave.

One very important feature of modern DF equipment is the ability to operate in a “DF scan” mode. With this feature, it is possible to scan through defined frequency ranges performing spectrum occupancy and simultaneously calculating the associated bearings of any signals above a threshold. This DF scan function is performed with DSP where Fast Fourier Transform (FFT) techniques are applied to subdivide the receiver bandwidth into many individual channels or FFT bins. Occupancy information and voltage information for a DF processing technique are computed by the FFT for each individual channel.

DF scan is discussed and illustrated near the end of § 3.6.2. This processing technique makes it possible to intercept short-duration transmissions such as frequency hopping and burst emissions.

3.5 Additional and separate equipment

Most spectrum monitoring stations use automated, integrated systems described in § 3.6. These systems make the ITU-recommended measurements of frequency, field strength, bandwidth, and modulation, as well as spectrum occupancy and DF measurements, with integrated measurement equipment. However, instead of or complementary to these automated, integrated systems, additional and separate equipment is also available to perform these measurements and to assist in identification. Some of this equipment is discussed below.

3.5.1 Frequency measuring equipment

Most frequency measuring equipment is designed to compare the frequency to be measured with a standard frequency, the precision of which directly determines the accuracy of measurement. Hence, the basic equipment for frequency measurement is a frequency standard from which reference frequencies or reference time intervals can be generated. It is recommended that this standard be provided by a global positioning system. A conventional oscillator with a frequency divider serving as a multiplier, a frequency synthesizer or a harmonic generator for specific frequencies can also be used for this purpose.

Frequency measurement accuracies available from frequency measuring devices are given in § 4.2.4.2.4.

The frequencies of distant transmitters should always be measured with a receiver according to the comparison method against a standard frequency. For additional details on frequency measurements, see § 4.2 and Recommendation ITU-R SM.377.

3.5.2 Field-strength measuring equipment

Measurement of field intensity or field strength is mainly based on the determination of the response of a receiving antenna to the electric or magnetic fields that impinge upon it. A receiver connected to the antenna detects this antenna response. The response to the electromagnetic field must be analyzed with regard to the behaviour of both the antenna and the field. A field-strength measuring set generally consists of several units that are normally assembled to form a single set. These units are:

– an antenna, the characteristics of which are known;

– a receiver which includes a step attenuator, allowing the sensitivity to be adjusted;

– a generator to calibrate the receiver sensitivity;

– a measuring device, calibrated either linearly or logarithmically, according to whether the receiver input voltage or the field strength is to be measured.

Field-strength measuring sets should have the following properties:

– high stability; it should be possible to measure over a fairly long period without the necessity of frequent recalibration;

– good relative precision; in practice, measurements of a constant field, carried out separately by two operators, should yield the same results;

– a wide range of measurement (ranging from several microvolts (mV) to several volts per metre (V/m));

– the indication of the measuring instrument should be proportional to the r.m.s., peak or average value of the field strength, depending on the type of measurement.

Field-strength measuring sets, as in the case of the monitoring receivers, should have a special output for connection of a DC recorder to allow records to be made over longer periods of time.

For further details of field-strength measurement techniques, see § 4.3 and Recommendation ITU-R SM.378.

3.5.3 Spectrum analysing and bandwidth measuring equipment

Although the equipment described above will perform many of the monitoring functions, certain additional instruments will permit more effective operation of a monitoring station and will expand its capabilities.

Recent technological advances in the capabilities of spectrum analyzers and vector signal analyzers, having large dynamic ranges of displayed signal amplitude, have resulted in an increased importance for visual monitoring operations. Spectrum analysis provides a means for rapidly recognizing and classifying various types of complex emissions. Visual monitoring can increase efficiency of monitoring operations by defining areas of current activity worthy of further examination. Service to users of the radio spectrum is speeded by the use of visual display techniques to synchronize the occurrence of interference with the activity of the emissions causing the interference.

Nowadays, computers and process controllers are used more and more in monitoring stations to generate reports and/or to control the monitoring equipment.

Three broad classes of equipment provide analysis of the radio spectrum in the frequency domain:

– wideband analyzers are available which can display selected portions of the spectrum with a definition of between 10 Hz/div. and more than 100 MHz/div.;

– panoramic display modules, connected to receiver intermediate frequency outputs, are available which show a limited portion of spectrum surrounding the tuned receiver frequency. This usually does not exceed about 40% of the IF frequency for common receiver types.

Panoramic receivers are also available which can display the entire range of the selected tuning module or smaller portions of it (sometimes simultaneously), using both FFT and IFM methods.

Apparatus is available for automatic comparison and control of a frequency source relative to a standard frequency transmission.

See § 4.5 for further information on bandwidth measurements.

A spectrum analyzer can be used for the following purposes:

– complete signal analysis (amplitude-modulation, frequency-modulation or pulse) as a function of time and frequency;

– waveform monitoring;

– detection and identification of spurious amplitude-modulation and frequency-modulation signals;

– measurement of pulse rise time, pulse width and pulse repetition rates;

– measurement of spectral characteristics of pulse modulation signals;

– application as a sensitive pulse and CW receiver in propagation studies, plotting of antenna patterns, etc.

The quality of the bandwidth measurements depends upon the following technical characteristics of the bandwidth measuring set or the spectrum analyzer:

– detector and averaging;

– sweep width;

– filter bandwidth;

– relative amplitude accuracy;

– amplitude dynamic range.

The performance of all types of instrument used for bandwidth measurements is limited by fading and interference, especially for observations on long-distance transmissions. With a spectrum analyzer it is possible, by superimposing the results of several successive sweeps, to obtain very useful information on the spectrum occupancy of the frequency bands received at the monitoring station.

For further information on bandwidth measurements, see § 4.5 and Recommendations ITU-R SM.328 and ITU-R SM.443.

3.5.4 Equipment for automatic monitoring of spectrum occupancy

Spectrum occupancy is one of the most important measurements required for spectrum monitoring. The goal of occupancy measurements is to determine how bands may be allocated and how the spectrum may be shared.

The equipment needed for such measurement may be as follow:

Antennas: For general occupancy rate measurement, omnidirectional antennas are required. The goal of the measurement is to measure the whole spectrum in one region.

For a particular measurement, and for example to determine the time occupancy for a dedicated transmitter, a directive antenna may also be used.

Receivers: For the occupancy rate, the wider the analogue bandwidth, the more information will be simultaneously available. With a narrowband receiver, the analogue bandwidth must switch frequency by frequency.

For occupancy rate and automatic monitoring, high accuracy measurements – including precise frequency and level – are not required. The main parameter is the overall scanning speed and the maximum instantaneous bandwidth:

– The shorter the synthesizer settling time, the quicker the occupancy is measured. A settling time shorter than 5ms in the VHF/UHF and 10ms in the HF band is preferred;

– a wideband instantaneous bandwidth makes possible a wide FFT, allowing less synthesizer switching. An instantaneous bandwidth on the order of 20 MHz in the VHF/UHF band and 2 MHz in the HF band may be used.

Digital treatment: FFT techniques are well suited to performing occupancy measurements, and have many advantages:

− FFT methods allow the instantaneous analysis of the whole IF bandwidth. Associated with a wideband receiver, FFT methods allow the computation of all signals falling in the bandwidth.

− New frequency modulations may be taken into account with high speed scanning receivers associated to FFT method. Modulations such as TDMA may not be seen with a swept spectrum analyzer because the band of interest may need more time to be scanned. Moreover, FFT techniques are better able to measure time-varying (gated, pulsed or transient) signals and complex modulated dynamic signals by processing all frequencies of the measured spectrum simultaneously.

− FFT methods allow other measurements to be made in parallel. While an occupancy measurement is applied to the whole bandwidth, a digital down-converter may select a specific signal in the bandwidth and then determine frequency or bandwidth.

− Occupancy measurement is supported by statistical computation. It implies that a large number of samples are required, depending on the occupancy rate and independent and dependent samples. FFT method, thanks to its rapid revisit time, allows a high confidence level to be reached in a short time.

− Occupancy measurements using FFT techniques offer advantages over conventional methods in terms of frequency accuracy, speed, digital storage of spectrum data, reproducibility of results, discrimination of closely spaced carriers and noisy environments.

Examples of occupancy data are shown in Figs. 3-36 and 3-37. Whereas the FFT is a modern and effective method of performing occupancy measurements, other methods are still possible.

3.5.5 Recording equipment

It is useful to record spectrum monitoring system data that contains radio spectrum and audio information. The recorded data can be reproduced and verified later and can be used for evidence against an illegal radio station. Cost-effective, unattended spectrum monitoring system operation, can also be realized by recording data results.

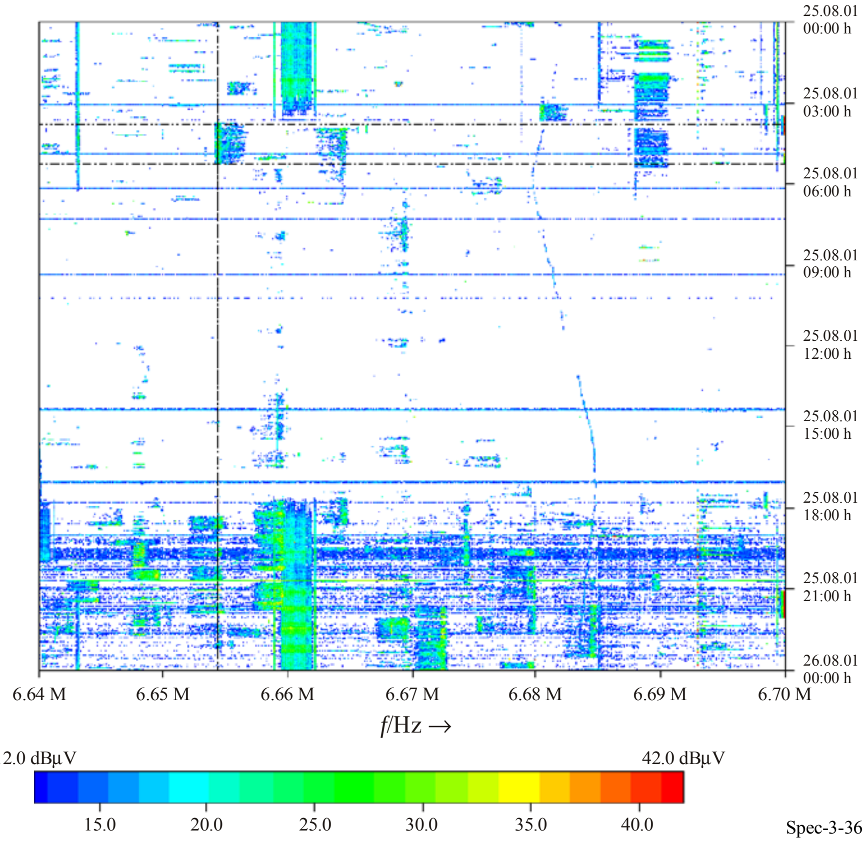
In addition to recording audio that is received at the spectrum monitoring station, information on time of detection, frequency, modulation, bandwidth, direction, field strength and ID should be recorded or logged.

3.5.5.1 Recording media

Solid state and disk-based data recorders are a preferred alternative to conventional tape recorders. Recording media should provide a significant continuous recording capacity and should be capable of random access to allow rapid replay of data. It is desirable for the equipment to provide for data recording, reproduction and editing.

FIGURE 3-36

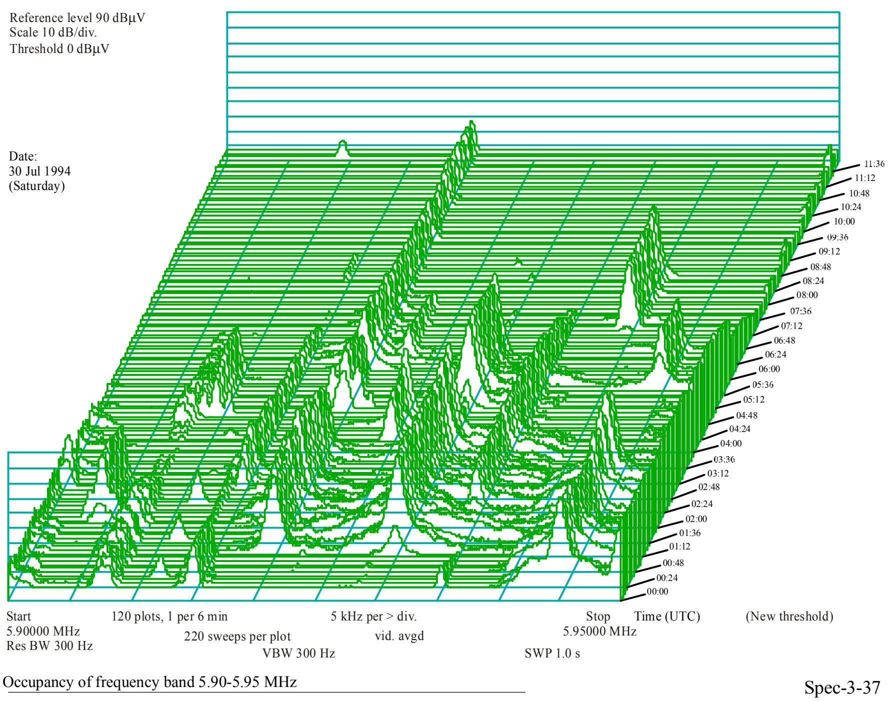
Example of a spectrogram representation



Spec-3-36

FIGURE 3-37

Example of a waterfall representation



Spec-3-37

Data recording for a period of at least 72 h of continuous recording time is preferred. Such long recording time allows long periods of unattended operation. The recording function should start when monitored data is received, to provide prompt capture of unexpected signals, and should stop when monitored data is not received. Formatting of recording media shall be carefully considered for easy reproduction of specific data. The operator should be able to insert a "mark" in a stream of monitored data, and the "mark" should be easily located, when desired, during replay.

Data reproduction functions should reproduce exactly the same monitored data based on the recorded data. The Radio spectrum information and sound information should be synchronized during reproduction. Data reproduction functions should also have a "mark" seeking function, fast forward, fast rewind, and header seeking function.

The data editing function should be capable of extracting and copying designated data from the recorded data. An operator should be able to easily designate a desired data selection for extraction and copying.

3.5.5.2 Wideband recording equipment

This section deals with the needs of digital data storage capacities in monitoring stations. This section gives no technical specifications but outlines how to determine the needed storage capacities. Indeed, technical evolution is so fast that today, specifications will be obsolete in a few years.

3.5.5.2.1 Recording data and format

With modern stations, there are five types of recording data and their associated files:

Type 1: Digital data, representing the in-phase and quadrature (I/Q) components of a continuous stream or block mode samples of the baseband or IF output is a common format. This raw data may be subsequently fed into a receiver to analyze the recorded signals. This is especially useful for mobile signal recording where the analysis equipment of the fixed monitoring station is not always available. Application examples include the analysis of short duration signals and signals captured during unattended recording.

Type 2: Spectrum data resulting from the FFT of time domain measurements. Modern monitoring stations may output several hundred FFT per second associated with wider bandwidth measurements. Text file is the standard file format.

Type 3: Demodulated and decoded data where the output format is text files.

Type 4: Audio digital data in wav, mp3 or other audio format files.

Type 5: Raw measurement data in text files.

The digital data storage in I/Q format typically requires high capacity storage and high recording bandwidth because of associated high data rates. Other types of recordings have lower requirements.

3.5.5.2.2 Digital data recording

Since the interfaces are either A/D converters or digital down converters, an important consideration is the length of recording, data type (bytes per sample) and signal bandwidth. Large storage capacities are available today and technology research will continue to develop larger capacity systems. Digital receivers can directly interface to the recorder, given that a suitable digital input/output is available on the receiver and recorder.

3.5.5.2.3 Recording equipment bandwidth

The bandwidth of the signal to be recorded impacts requirements for not only recording capacity, but also the recording bandwidth of the system. The recording receiver may be local to the storage equipment or may use wide area network interconnects. Wider bandwidth signals (for example, > 5 MHz) require very fast storage system access due to high data rates. Care should be taken when selecting network interconnects and recording equipment that have a high sustained data rate throughput greater than that required for the maximum signal bandwidth to be recorded, without placing high (> 30% in a packet-switched environment) loading on the interconnect capacity.

3.5.5.2.4 Recording equipment performance requirements

Storage capacity and data rate requirements may be computed as follows:

$$C\text{ (Mbytes)} = F_s \times N_b\text{\_Bytes\_Per\_Samples} \times \text{Rec\_time}$$

where:

F_s:	sampling frequency of the ADC or DDC (MHz)
N_b _Bytes_Per_Samples:	generally 4 bytes for I/Q samples of 16 bits
Rec_time:	recording time (s).

For example, a signal bandwidth of 10 MHz requires a sampling rate of F_s = 25 MHz baseband or 12.5 MHz I/Q. A baseband signal with 16 bits per sample and recording time of 1 min leads to:

Data rate: 25 (MHz) × 2 (bytes/sample) => 50 Mbyte/s

Storage capacity/recording: 50 (Mbyte/s) × 60 (s) => Storage capacities = 3 Gbytes

3.5.6 Modulation measuring equipment

Standard ITU-recommended modulation measurements are described in § 4.6. Wideband receivers and processing capabilities of modern stations allow modulation measurement, including digital modulation measurements. When using narrowband receivers with intermediate frequency outputs, specialized measurement equipment may be desirable. A vector signal analyzer (VSA), an external spectrum analyzer with vector analysis capability, or the monitoring station itself with appropriate software is useful for measuring digital modulation.

The necessary receivers for demodulation and measurement of *n*-PSK, QAM and other vector-type schemes described in § 4.6 are characterized by high performance down-converters whose IF amplitude and group delay response will not degrade the measured signal. The down-converter or receiver is followed by a VSA for digital modulation analysis [Blue *et al.*, 1993]. A VSA implements the final IF bandwidths using DSP in order to achieve IF passband responses that are stable and high performance. Additionally, by changing the DSP coefficients, a range of receiver filters can be synthesized for versatile coverage of a variety of modulation types.

If the optional RF down-converter of the VSA is used and it does not contain an RF preselector, an external preselector or banded filter must be used in dense signal conditions. The corrections for the preselector's passband response may have to be included in the correction procedure for the IF filter's passband response for the highest performance.

After setting the desired carrier frequency, modulation type and symbol rate, the DSP in the VSA or spectrum analyzer accomplishes the demodulation. In addition to displaying the modulated signal, the analyzer also provides digital modulation error measurements. This is accomplished by demodulating the signal and generating an ideal reference. The two are compared to generate the error measurement results.

For over-the-air monitoring of modulation quality, the transmission path may be the dominant factor when measuring the modulation quality factors. Multipath or other co-channel interference may render the modulation quality measurements highly questionable or useless. Therefore, detailed modulation measurements are only appropriate at the transmitter site, preferably with a direct connection to the transmitter. Such measurements include: error vector magnitude, phase and amplitude errors, carrier feed through, I/Q gain imbalance, amplitude droop and carrier frequency error.

General measurements that provide an indication of overall modulation quality and can be made at the transmitter site, or off-the-air some distance away, include: error vector spectrum (to highlight interference), adjacent channel power ratio, occupied bandwidth, spectrum emission mask, complementary cumulative distribution function, carrier frequency and code domain measurements (power, timing and phase).

The channel impulse response (CIR) measurement [Riedel; 1991; Bues and Riedel, 1993] is not a modulation measurement, but is a measurement of the propagation channel multipath. This multipath greatly affects the modulation quality at the receiving site. Another indirect measure of the modulation quality at the receiving site is measurement of the BER. These quality measurements are described in more detail in § 5.3.5.4.

3.5.7 Identification equipment

Identification of radio signals is one of the most difficult monitoring tasks. This difficulty is partly due to the infrequent emission of call signs, partly to the use of abbreviated or unregistered call signs and to a considerable extent to the difficulty in decoding signals due to the growing use of complex transmission systems, i.e., frequency shift, frequency division and/or time division multiplex. In addition, there are machine telegraph systems using a variety of codes other than Morse, facsimile systems, single and independent sideband systems and privacy devices.

Digital processing techniques and microcomputers have now made it possible to design multipurpose identification equipment, able to demodulate and decode most signals and to be programmed to respond to new transmission schemes. This subject is discussed in Recommendation ITU-R SM.1600 – Technical identification of digital signals.

A monitoring station must, in consequence, have equipment for the reception and/or identification of several types of analogue and digital modulations.

See § 4.8 for further information on signal identification.

References

BLUE, K. *et al.* [December 1993] Vector Signal Analyzers for Difficult Measurements on Time-Varying and Complex Modulated Signals. *Hewlett-Packard J.*, Vol. 44, p. 6-47.

BUES, D. and RIEDEL, P. [1993] Planning digital radio networks using Impulse Response Analyzer PCS and test transmitter system. *News from Rohde & Schwarz*, **141**, p. 26-27.

RIEDEL, P. [1991] TS 9955 measures channel impulse response in GSM radio networks. *News from Rohde & Schwarz*, **137**, p. 12-14.

ITU-R Recommendations:

NOTE – In every case, the latest edition of all the referred Recommendations is encouraged to be used.

Recommendation ITU-R SM.182 – Automatic monitoring of occupancy of the radio-frequency spectrum.

Recommendation ITU-R SM.328 – Spectra and bandwidth of emissions.

Recommendation ITU-R SM.377 – Accuracy of frequency measurements at stations for international monitoring.

Recommendation ITU-R SM.378 – Field-strength measurements at monitoring stations.

Recommendation ITU-R SM.443 – Bandwidth measurement at monitoring stations.

Recommendation ITU-R SM.854 – Direction finding and location determination at monitoring stations.

Recommendation ITU-R SM.1600 – Technical identification of digital signals.

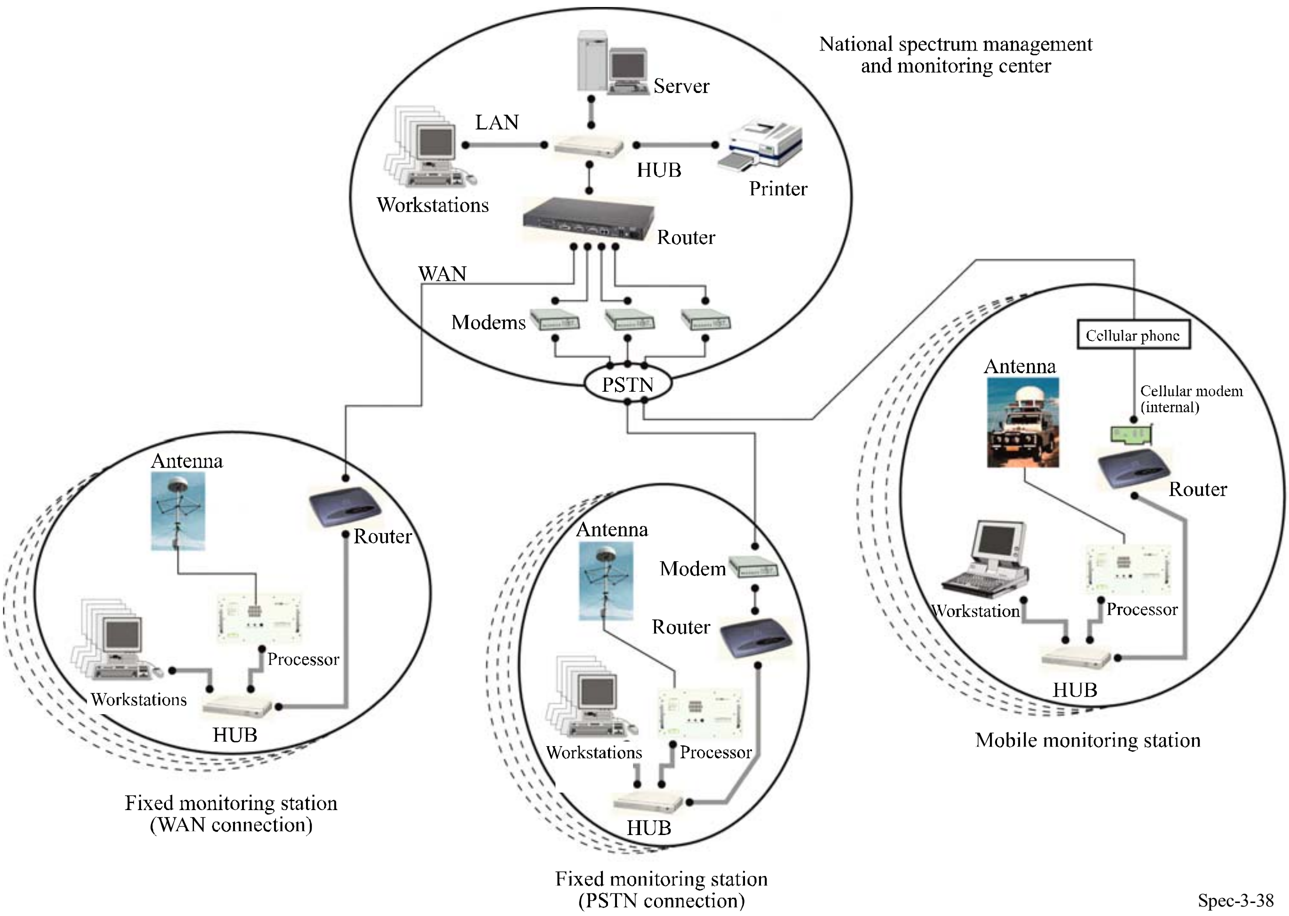
3.6 Automation of monitoring

3.6.1 Introduction

Automation, through the use of computers, modern client/server architectures and remote communications, simplifies many of the duties and responsibilities of the monitoring service. Computerized equipment provides a means to perform mundane repetitive measurement tasks rapidly and accurately, freeing service personnel for more demanding tasks. The use of databases and computer modeling streamlines spectrum management functions and can help prevent interference. Coupling of spectrum management and spectrum monitoring makes possible an integrated system, which can automatically use measured data from the monitoring system and license information from the management database to detect unlicensed transmissions and other licensing violations. The integrated monitoring and management system may have a central management facility, in which overall management of radio monitoring system is performed and statistical analysis of stored measurement data in the monitoring system database are available. These analyzed results are utilized for spectrum management planning (for example, frequency withdrawal and reassignment). A typical integrated system diagram is presented in Fig. 3-38 and described further in Recommendation ITU-R SM.1537. The configuration (number of workstations at each station, number of stations, etc.), methods of communication (TCP or other protocol; use of PSTN, radio or satellite) and other details will vary according to the application. An alternate system configuration includes the addition of a monitoring centre, which is connected directly to the monitoring stations and in turn to the management centre. A large monitoring service may have regional monitoring centers in addition to a main or national monitoring center to distribute control of monitoring operations.

FIGURE 3-38

Example of a monitoring system integrated with a management system



3.6.2 Automation of monitoring operations

Automated stations generally perform the functions of a fixed monitoring station, as described in § 2.4. All routine monitoring measurements are repetitive tasks that lend themselves easily to automation:

– *Occupancy measurements*: Fine-resolution scanning of the frequency bands with computer-generated displays and storage capacity of channel occupancy over several days is well suited to automation.

– *Frequency measurements*: These can be made automatically when the *S/N* is sufficient and for transmissions with carrier frequency. At HF, channels are usually very closely spaced; thus sharp frequency selectivity must be provided in the case where several frequencies are present in the same channel.

– Level and, if applicable, field strength measurements.

– Bandwidth measurements.

– Modulation parameter measurements. Advancements in DSP hardware and algorithms have led to the development of modulation recognition systems which identify modulation types in real-time. These systems may be implemented in stand-alone instruments, computer add-in cards and associated software, or may be integrated into other instruments (such as receivers or analyzers). These systems can be used to recognize various modulation formats (both digital and analogue), measure common technical parameters, and demodulate or decode the signals.

– *Signal analysis*: however, not all aspects of signal analysis can be done automatically.

– *DF*.

– *Station identification*: through location, message content information, or automatic signal analysis (code recognition, number of elements, transmission rate).

All of these measurements can generally be made automatically, but some measurements, such as bandwidth and modulation, require signals with good *S/N* to achieve sufficient accuracies. These measurement tasks yield technical measurement data that can be compared to the technical parameters recorded in spectrum management databases or to data desired therefrom. The technical parameters recorded for a transmitter in such a database include:

− Assigned frequency

− Calculated field-strength

− Emission class

− Assigned bandwidth

− Emission bandwidth

− Call-sign.

Each monitoring station usually has a list of transmitters and the operators match the listed transmitter parameters against the observations recorded by the automated equipment. Integrated automated systems may automate this comparison task in addition to collection of the data, which is an example of automatic violation detection discussed below. Either way, the comparison must be made using tolerances in measured parameters that are consistent with ITU-recommended measurement accuracies, to minimize false alarm rate. The goal is to confirm the compliance with established procedures and with the technical data listed in their database file. When discrepancies or anomalies are detected, they typically include:

– Illegal or unlicensed transmitters or frequencies

– Unauthorized operating periods or locations

– Illegal emission classes or poor modulation quality

– Excessive frequency offset

– No call-sign or incomplete call-sign

– Excessive bandwidth

– Excessive power (excessive field-strength).

3.6.2.1 Levels of automation

Automation can occur at many levels within monitoring operations. A single workstation may conduct an automated occupancy survey using pre-programmed parameters. Several workstations at a site may be tied to a single set of measurement equipment to share those measurement resources. An entire station, or network of stations, may be automated, possibly because of their remote location, and the results of their monitoring may be retransmitted to a more centralized station. Individual positions at several sites may be linked together in such a manner that one position automatically tunes positions at other sites to obtain multiple simultaneous measurements on signals of interest. Computer-controlled equipment may be programmed to identify frequencies on which there are transmitters which are not included among a database of licensed transmitters and to identify transmitters which are not operating within their licensed parameters.

Automation can help reduce the time to locate and identify a signal, reduce the personnel needed to operate stations and make these personnel available for higher priority functions such as assisting a mobile station in DF operations or performing data analysis, and increase the portion of the radio-frequency spectrum that a service can effectively monitor. On the other hand, the absence of an operator or technician at a remote site may result in long equipment down times-should there be an equipment failure. Also, automated equipment may not give the sensitivity for tuning difficult to receive signals that an operator can achieve through manual tuning, which may often be the case in the HF environment. In any case, when automating a position or station, a service should incorporate the option to revert the position or station to manual operation, either locally or remotely. Automation of older equipment usually requires a separate computer, and often the older equipment needs to be replaced.

3.6.2.2 Station automation

Modern DSP techniques allow economical automation of entire stations. An automated station consists of:

– a small group of sophisticated measurement equipment modules, including digital receivers operated by a computer, which is often referred to as a measurement server, and

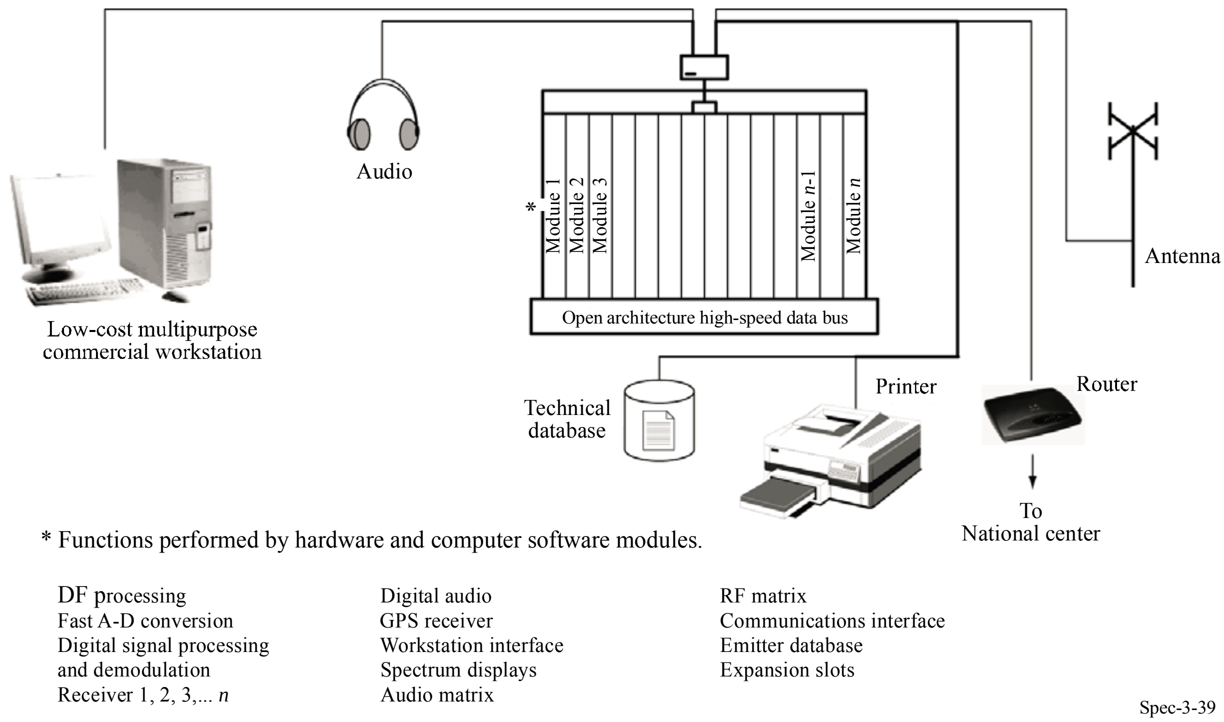
– operator workstations, often referred to as clients, which are used for operator interface and which contain computer software that make the system easy to use and easy to maintain.

The station can be operated either locally or be remotely controlled from a more convenient location. The links between the measurement stations and control stations can be radio or terrestrial. Essentially, the station becomes a node on a wide area network administered at the control station.

A fully automated station typically has the architecture illustrated in Fig. 3-39. This station consists of antennas, a compact measurement server which is a modular, high-speed bus unit including processors, receivers and other electronics, one or more low-cost commercial workstation clients, and various peripheral equipment including printers, phones, and modems. An alternate but related station architecture includes separate but highly integrated units including digital receivers, direction-finders and processors; in this case, the portion of Fig. 3-39 containing the open architecture high-speed bus with various modules is replaced by separate units, including a digital receiver, a digital direction-finder and a processor. An automatic built in test equipment (BITE) can provide the current status of all devices and can give alarm in case a device shows a fault.

FIGURE 3-39

Typical modern integrated radio spectrum monitoring station



The functions of an automated monitoring station include:

- Monitoring, demodulation and decoding
- Audio recording
- Technical measurement and analysis including frequency and frequency offset, level/field strength, modulation parameters including AM modulation depth and FM frequency deviation, bandwidth, and spectrum analysis
- Spectrum occupancy
- DF
- Automatic real time comparison with licence parameters
- Automatic alert generation on abnormal or unknown transmissions.

3.6.2.2.1 Typical automated station modes of operation

Automated monitoring stations typically have three modes of operation which are used to perform these tasks:

Mode 1: Interactive or real time operational.

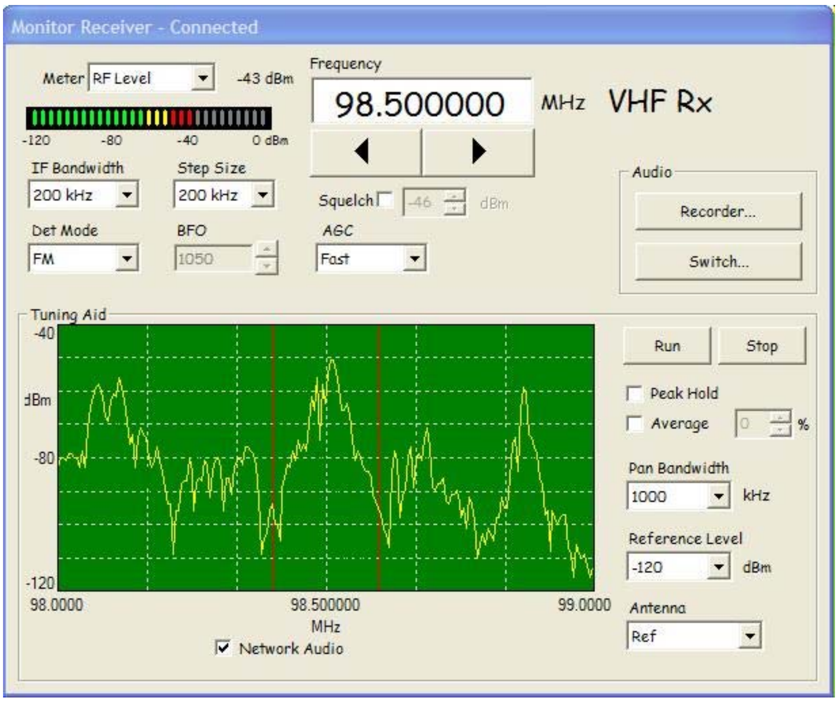
Mode 2: Automatic or scheduled.

Mode 3: Background.

Interactive mode allows direct interaction with various functions that provide instantaneous feedback such as monitoring receiver tuning, demodulation selection, and pan-display selection. An interactive mode is necessary even in an automated system to allow operator intervention when necessary, so that equipment can be remotely controlled by operators as well as by the automated system software. Interactive functions are controlled from “virtual control panels” on the client workstation, using screens such as is illustrated in Fig. 3-40. Synthetic panoramic and spectrum displays are created on the operator workstation, and include waterfall displays (three dimensional displays of signal amplitude, versus frequency, versus time) and spectrogram displays (two dimensional displays of signal frequency versus time, with signal amplitude indicated by colour).

FIGURE 3-40

Example of a virtual control panel for monitoring receivers



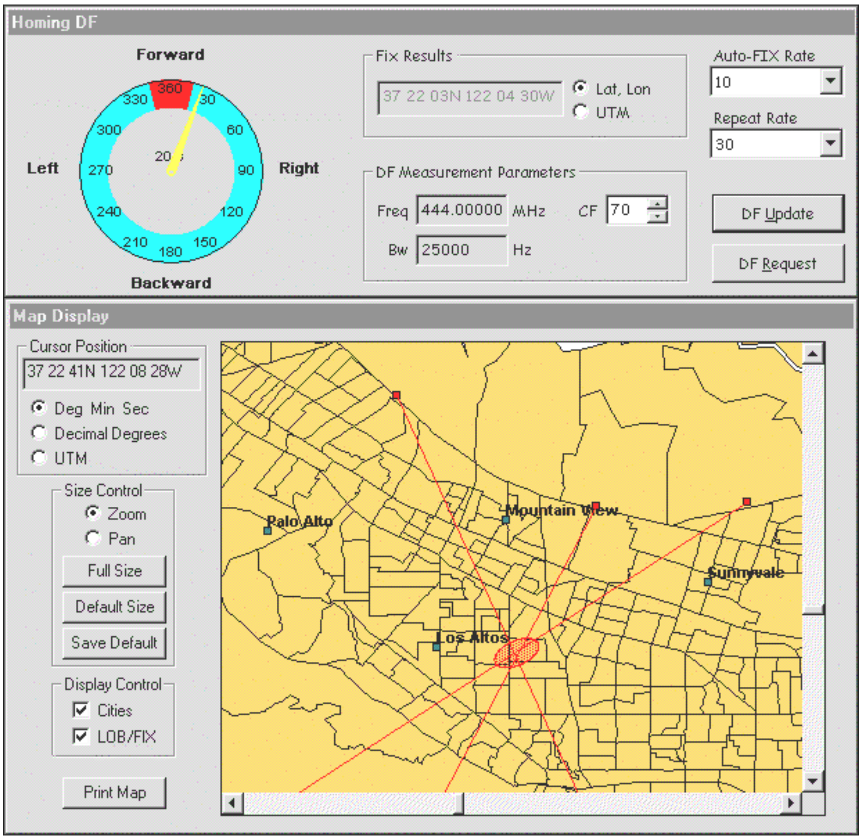
Spec-3-40

DF homing is an important example of interactive operation. DF may be commanded in a mobile unit as the unit is in motion. DF results are presented with respect to the front of the vehicle, as illustrated in Fig. 3-41, and allow the driver to decide which direction to drive to approach the desired signal transmitter. DF results from different locations are also displayed on a geographic map, allowing triangulation by the system to locate the signal transmitter. A high precision GPS receiver continuously updates the exact location of the mobile unit, and an electronic compass measures the orientation of the vehicle with respect to North.

Automatic or scheduled mode may schedule tasks to be executed immediately or to be executed at specified times in the future. Functions that are performed under the scheduled mode include technical measurement and analysis, and DF. Measurement parameters, such as measurement and averaging methods, and measurement time (or times, in the case of measurements which are to be repeated) may be specified, or default values provided by the system may be used. The operator may use a screen containing a calendar with days of the week and multiple intervals within each hour of the day to schedule these functions. The client requests time slots for the desired measurements from the measurement server. The time slot assignment approach allows multiple clients to connect to a single server. In order to handle scheduling attempts of multiple measurements in the same time slot, the server should support a “convenient” mode of scheduling. When the requested time slot is already reserved, the client’s request for a server time slot is moved to the first available time slot. The server can look for the available time slot within a specified time window that is typically a few minutes. The measurement server performs the requested measurements, using appropriate scheduling and priority algorithms to resolve any scheduling conflicts, and retains the measured results until the client requests them. For some measurement types, the server may have the capacity to record signal audio along with those requested measurements.

FIGURE 3-41

Example of DF homing display and geographic map



Spec-3-41

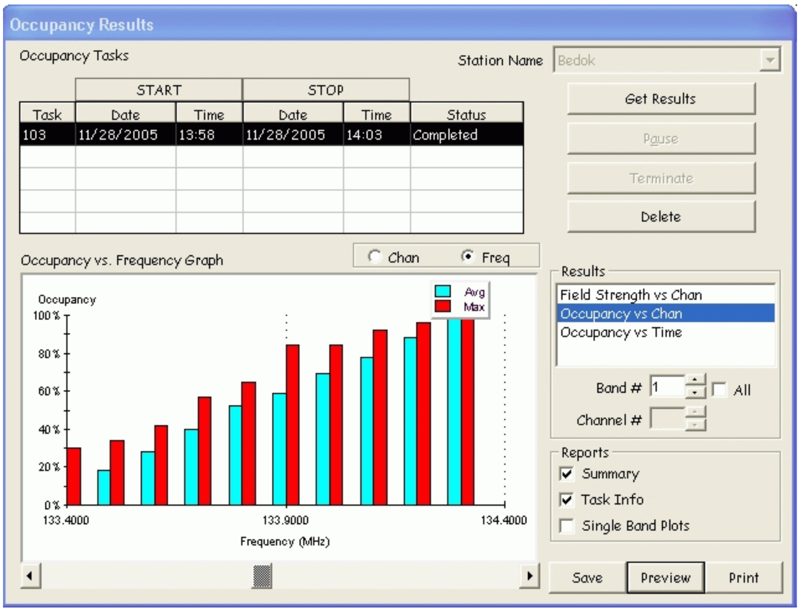
Background mode is used for performing tasks such as spectrum occupancy and automatic violation detection – tasks where it is desirable to collect data over long periods of time. Wideband scanning for occupancy, or DF combined with occupancy (termed “DF scan”), may be specified, and the system may be scheduled to perform an automatic scan over particular frequencies or ranges of frequencies, and upon detecting a signal, initiate operator specified activity, such as DF or technical measurement.

Background mode operates on a lower priority than scheduled mode, so specific scheduled measurements will interrupt the background mode to use the measurement server. After the scheduled measurements are completed, control returns to any background mode measurements that were in process.

When the client requests the results of measurements, the client may see them displayed in convenient formats. Much of the information is displayed graphically, in the form of occupancy histograms (see Fig. 3-42), field strength versus frequency plots, geographic map displays showing location results (see Fig. 3-41), and other graphical displays.

FIGURE 3-42

Example of occupancy histogram

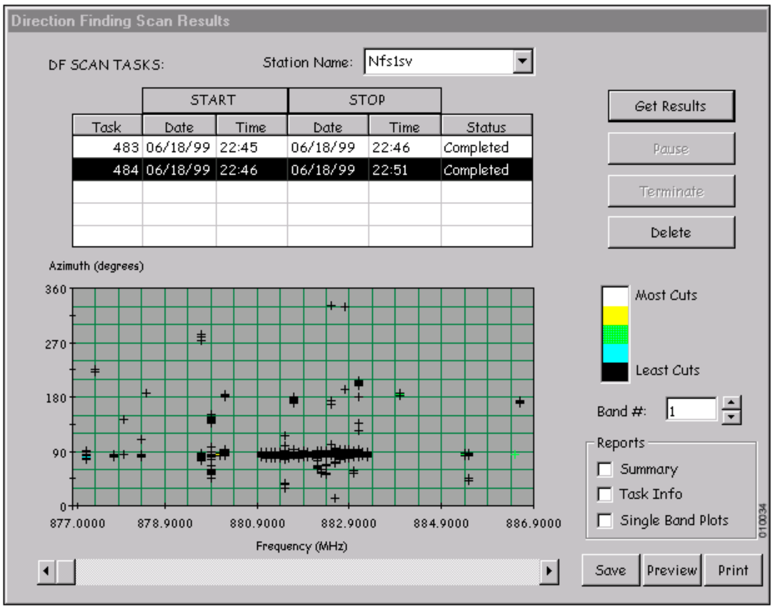


Spec-3-42

These systems can perform DF on many frequencies simultaneously and provide azimuth versus frequency plots (see Fig. 3-43) which are useful for intercepting and processing modern digital modulations; DF results on such a display at the same azimuth from many different frequencies are a clear sign of the presence of a frequency hopping signal.

FIGURE 3-43

Example of DF scan display results



Spec-3-43

Sophisticated client/server systems can be designed to be easier to use than systems with separate or stand-alone units of equipment such as receivers and spectrum analyzers. With task icons and toolbars on the computer screen, which the operator can access via pointing, and clicking on a computer mouse, these systems can be very intuitive and easy to learn. For administrations with difficulty in obtaining qualified operators, simplicity of operation of a monitoring system is a very important consideration.

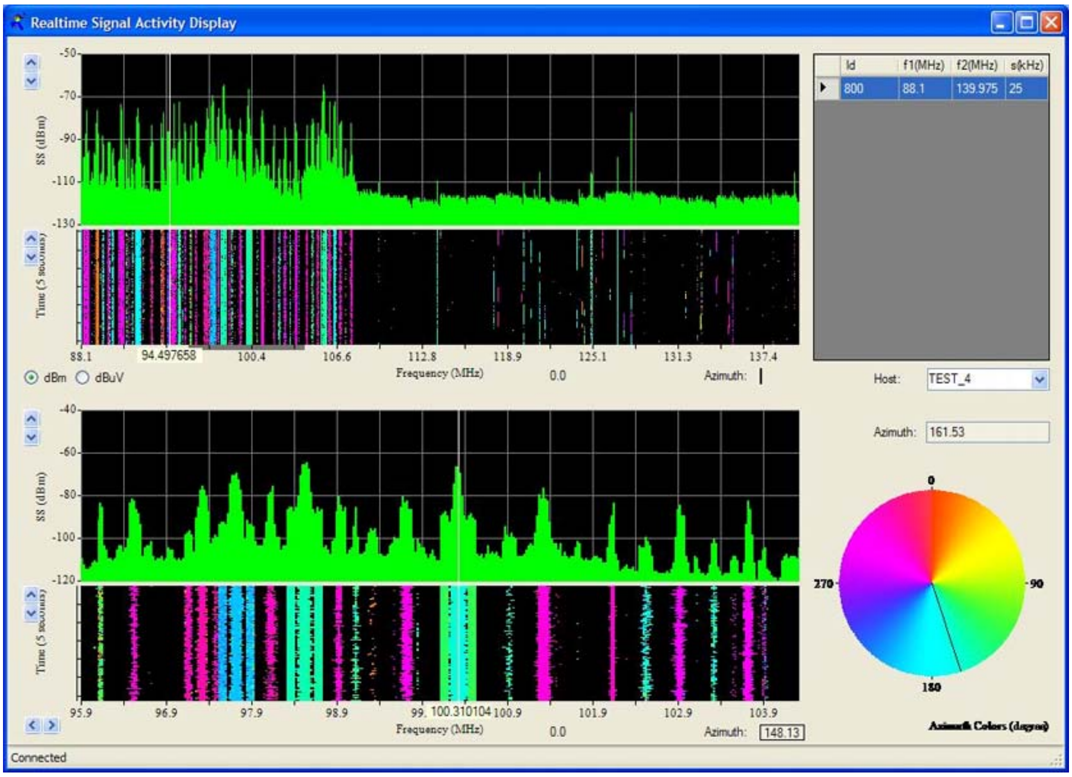
3.6.2.2.2 Examples of automated broad bandwidth displays

Modern DSP-based measurement servers are able to provide very broad instantaneous bandwidths, up to 20 MHz per Recommendation ITU-R SM.1794, along with a high dynamic range so that strong signals within this bandwidth do not prevent weak signals in the bandwidth from being received and processed. Automated systems with very broad instantaneous bandwidths are able to scan the spectrum at very fast rates, automatically tuning the receiver and gathering occupancy data, allowing very frequent revisits and refresh of data displays to give the operator a better understanding of the radio spectrum. They are able to effectively acquire and measure intermittent, broadband and frequency agile signals that may appear to be noise when monitored with a narrow bandwidth system. To provide the highest performance when narrower measurement bandwidths are desired, a smaller instantaneous bandwidth, which reduces noise and improves *S/N*, can be selected automatically instead of the broader bandwidth.

Operators can view a very broad bandwidth panoramic display, improving their ability to locate interferers and identify the kinds of signals and interference being monitored. A typical display is illustrated in Fig. 3-44. This particular display covers over 50 MHz of the spectrum, with a panoramic display across the top of the screen, below which is a spectrogram display showing signal activity over the past 5 s, with signals colour-coded as to their direction of arrival. The colour-coded direction of arrival display can be changed to a colour-coded display of signal strength upon operator command. The bottom portion of the display provides a magnified panoramic display and spectrogram display where the operator can simply click on the upper display to indicate the frequency region to be magnified, and the system automatically produces a magnified display; in the illustration, an 8.5 MHz portion of the upper displays has been magnified to fill the horizontal region available for display. The display is continuously updated in real time, with the spectrogram display continually advancing in time to show current signal activity with directions of arrival.

FIGURE 3-44

Typical display of very broad bandwidth measurements

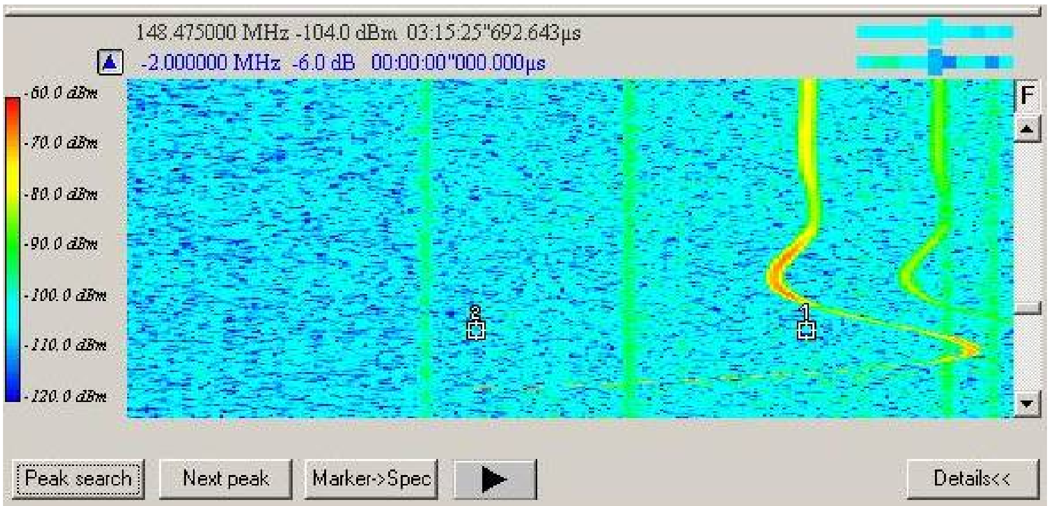


Spec-3-44

The display in Fig. 3-45 shows a transmitter signal without stabilization. Only a wideband receiver can detect such signals that disturb adjacent channel signals. A narrowband receiver is either too slow to detect these signals or too narrow to see the fluctuation of the signals.

FIGURE 3-45

Typical display of a very fast fluctuation wideband signal detected by a wideband receiver

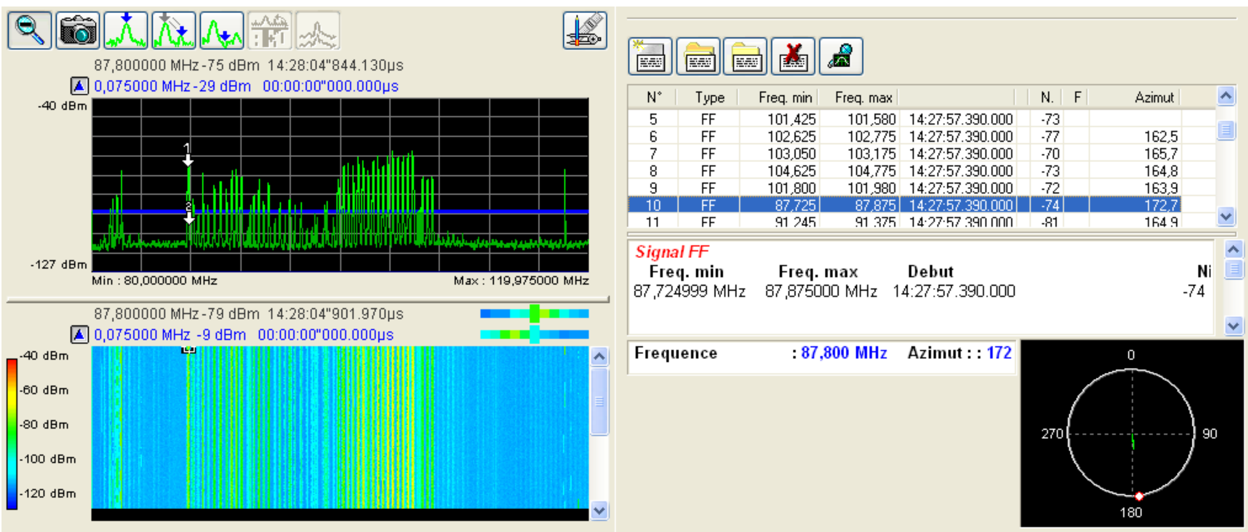


Spec-3-45

Operators can view a very broad bandwidth panoramic display, improving their ability to locate interferers and identify the kinds of signals and interference being monitored. Such a display is illustrated in Fig. 3.46, showing a real-time instantaneous 40 MHz bandwidth without any scanning. The wide instantaneous bandwidth allows the detection of very short duration signals in several microseconds.

FIGURE 3-46

Typical display of very broad bandwidth measurements



Spec-3-46

DSP allows great flexibility in adding capability to a monitoring system in the future. Should new signal types appear that require special processing, or new bandwidths be desired, they can be added to a DSP-based system simply by changing the monitoring system computer software.

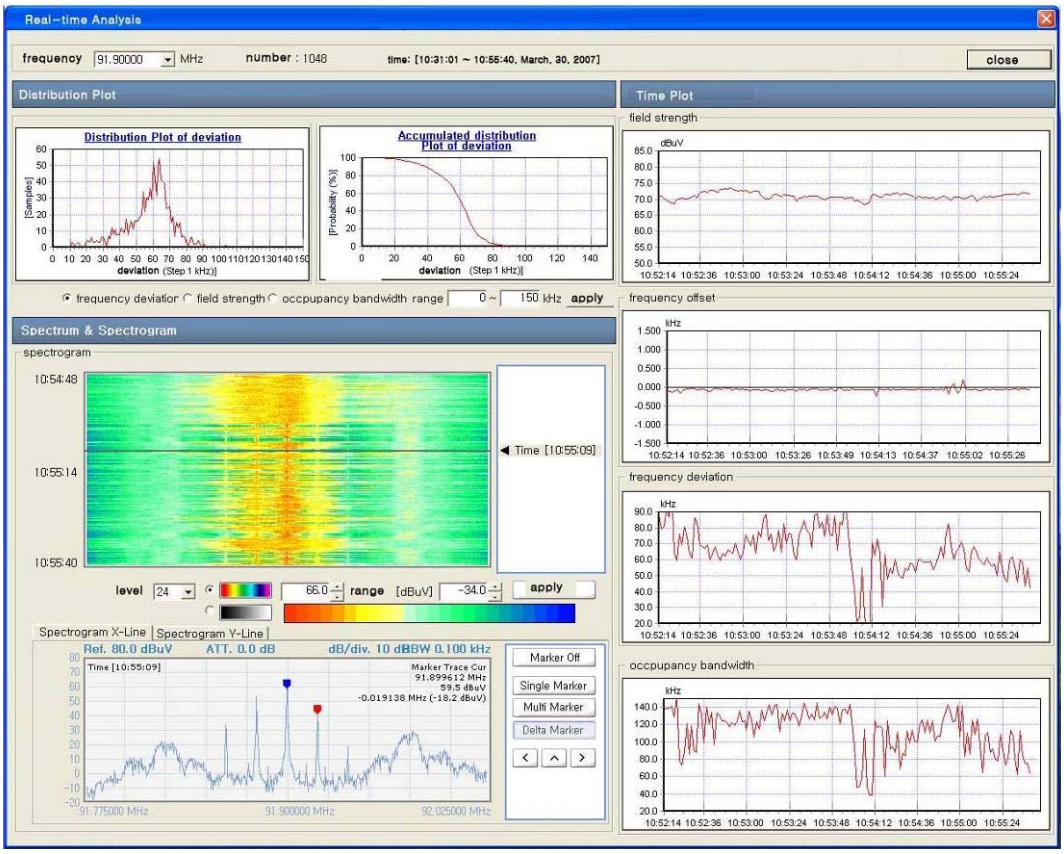
3.6.2.2.3 Examples of measured results analysis

Automated monitoring stations could have a measured results analysis mode of operation. This mode is used for analyzing the measured results from the measurement equipments under various conditions. The analysis can be performed in a spectrum management centre.

The radio quality measurement results are displayed graphically, in the form of graphs of measured values (field strength, frequency offset, frequency deviation, occupancy bandwidth) versus time, distribution plots of deviation, or accumulated distribution plots of deviation and spectrogram. A typical spectrogram display is illustrated in Fig. 3-47. While graphs of measured value versus time are most useful for an analysis over short periods of time, distribution plots of deviation or accumulated distribution plots of deviation are useful in analysis over longer periods.

FIGURE 3-47

Typical graph for real-time analysis of measured results



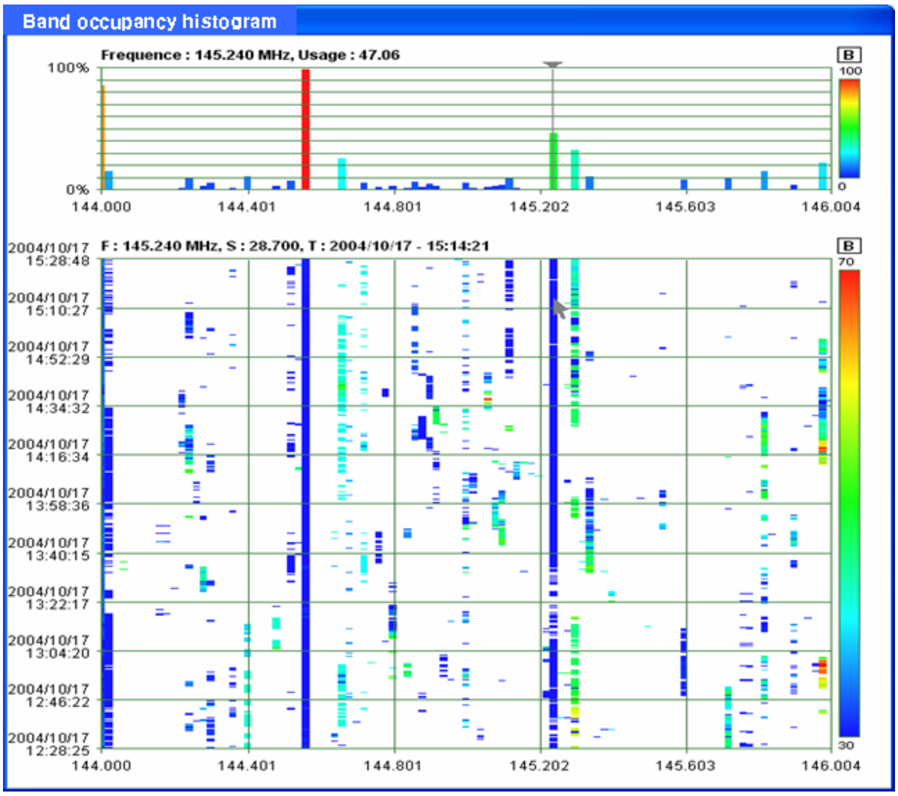
Spec-3-47

Band occupancy measured results may be displayed in a time versus frequency plot; field strength is displayed graphically with color. A typical display is illustrated in Fig. 3-48. The band occupancy histogram with signal spectrogram shows signal appearance rate, spectrum occupancy rate and field strength.

Spectrum analysis can be performed through various functions using rapidly-produced spectrum measurement results. The spectrum band is compared with a frequency distribution chart and signal frequency is displayed according to marker indication. A typical display is illustrated in Fig. 3-49. Measured and analyzed results are used for predicting the possibility of interference and detecting the arriving radio wave.

FIGURE 3-48

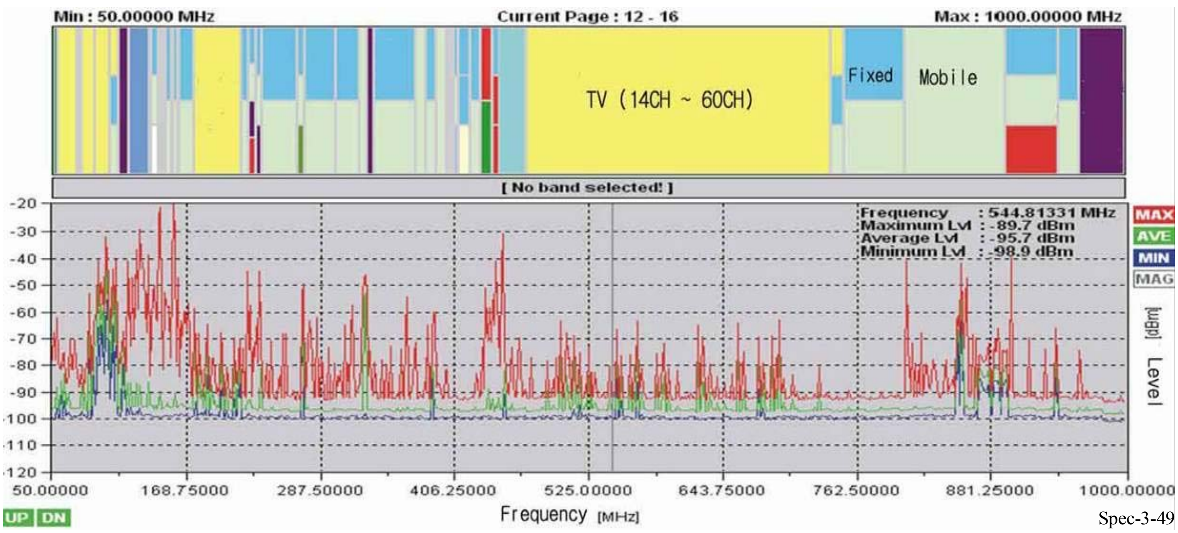
Band occupancy histogram with signal spectrogram



Spec-3-48

FIGURE 3-49

Spectrum band compared with frequency distribution chart



Spec-3-49

3.6.2.2.4 Real-time operation with fast spectrum scanning, instantaneous DF and operator alerts

There are certain frequency bands in which maintaining real-time control of radio transmission activity at all times is an essential requirement. This includes rapid identification and location of legal transmitters and rapid identification, location and elimination of interferers. Examples of frequency bands that require such protection are the aeronautical band, the maritime band, and various emergency channels that are essential for search and rescue operations. This type of spectrum protection requires a radio monitoring system capable of operation in real-time, with fast scanning of the spectrum and instantaneous DF measurements on all active signals. When detecting signal activity on any of the emergency channels, the system needs to be able to issue real-time alerts to local or remote operators.

Integrated signal search, DF and monitoring functions into one single processor allows fast scanning of the spectrum with simultaneous DF measurements on all detected signals. Typical systems can revisit up to several dozen maritime mobile and emergency channels at least ten times each second, and can detect and measure signals as short as 10 ms.

DF results are measured simultaneously for up to several dozen channels, and presented on the operator display in real-time. Lines of bearings (LoB) for selected channels are displayed on a large digital map and on a polar histogram. If two or more monitoring stations operate in a netted configuration (as discussed in § 3.6.3), then the system would display on the operator's workstation not only the LoB but also the resulting triangulation fix of the corresponding transmitter. This operation would be performed automatically by the system with no operator intervention, and the location estimate would be displayed on the operator screen within a fraction of a second after the start of transmission.

All DF measurements may be automatically stored in a local database on the operator workstation, and retained there for a reasonable period of time such as 48 h. The operator may perform a variety of functions from his workstation computer, including:

– Monitor continuously signal activity, LoB and fixes in all his assigned channels.

– Freeze the DF results and create a transmitter location report that is automatically stored in his local database.

– Review and play back DF results and fixes stored on his computer.

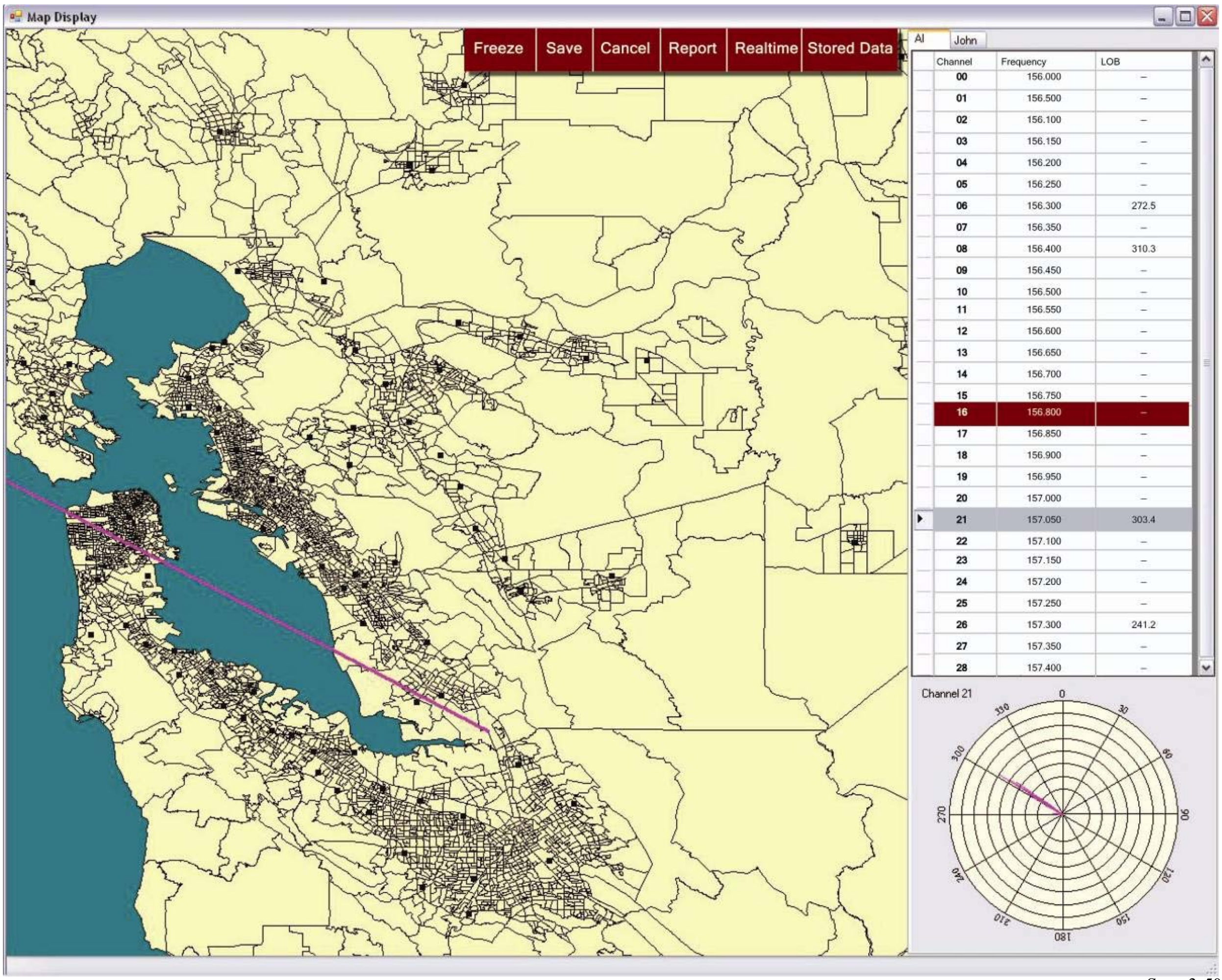
– Review DF results stored on his computer and create signals activity lists.

An example of real-time operation in the maritime band with fast spectrum scanning and instantaneous DF is illustrated in Fig. 3-50. LoB are measured simultaneously for up to 29 channels in real-time and are displayed in numerical form on the screen (upper right). LoB for selected channels are displayed on the map (left) and on polar histogram (lower right). In this example, the operator has selected Channel 21 for monitoring, so this is the LoB shown on the map and on the polar plot. The special function keys available to the operator are shown at the top of the screen.

Figure 3-51 illustrates the case when a signal is measured by more than one radio station. In this example, there are two radio stations. The system automatically calculates the fix and displays the results on the map in real-time.

FIGURE 3-50

DF results measured simultaneously for many channels refreshed in real time (upper right); LoBs for selected channels display on map (left) and polar histogram (lower right)



Spec-3-50

FIGURE 3-51

Automatic calculation and display of a fix in real time, for a signal measured by more than one station

Spec-3-51

The software may allow the operator to define several "high priority" channels. If any signal activity is detected on any of the high-priority channels, the software automatically alerts the operator on the screen, it issues an audible alarm at the workstation, and it can be scheduled to send a message to an external e-mail address or cell phone number.

3.6.2.2.5 Example of DF homing automation

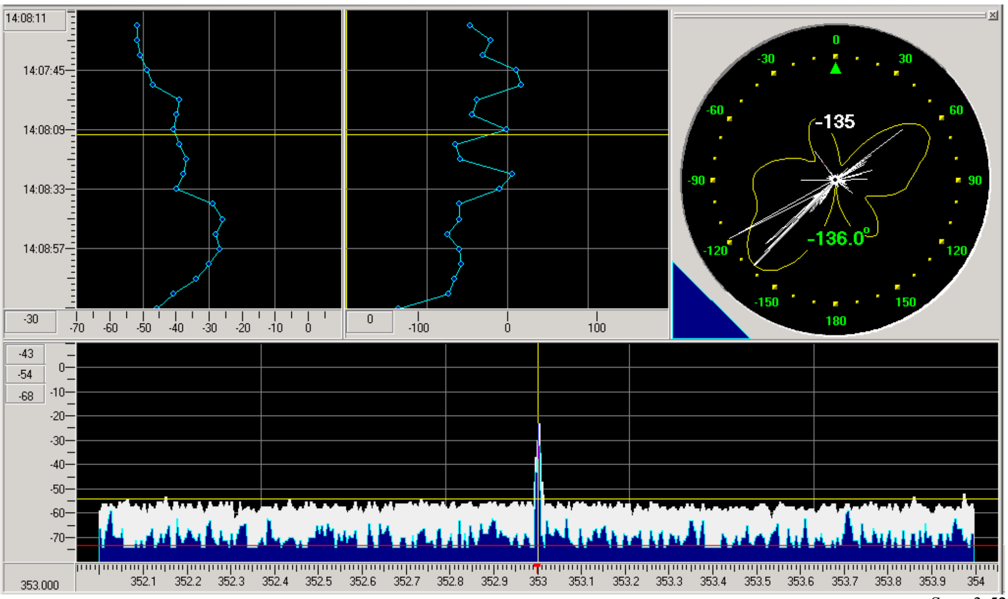
Advanced monitoring automation software [Rembovsky *et al*., 2006] also provides statistical processing with continuously obtained bearings at mobile monitoring stations to simplify operators' activities related to searching for signal transmitters.

A typical display window of the equipment control software working on one signal of interest is shown in Fig. 3-52. It contains the graph of the amplitude history (located at the left top corner of Fig. 3-52) and the graph of the bearing history (located in the middle). Both graphs have the common time ordinate. Abscissa of the amplitude history is the level of the bearing signal (dB), and abscissa of bearing history is the angle of bearings (degrees).

The history graphs allow tracking in time the change of signal amplitude and bearing. In addition, the circular limb at the right top of the window simultaneously indicates instantaneous bearing values and the curve of the bearing direction distribution density (the bearing histogram) whose maximum corresponds to the most probable bearing direction of arrival. Change of direction of the bearing distribution curve maximum is reflected on the bearing history graph. In conditions of strong interference, the angular value of a maximum shows a preferred direction of the direction finder movement.

FIGURE 3-52

A window of the programme in the homing mode



Spec-3-52

The history graphs of amplitudes and bearings in Fig. 3-52 provide very useful information for real time homing. In this example, gradual increase of the signal amplitude from −50 dBmV up to −30 dBmV and bearing values at the beginning of the graphs confirm that, during this period (from 14.07.45 to about 14.08.45 in Fig. 3-52), the mobile monitoring station moved closer to the signal transmitter. Then (from about 14.08.45 in Fig. 3-52), the signal transmitter is situated left of the vehicle because bearings have systematically shifted to the left and signal amplitudes start to systematically decrease. For locating the signal transmitter, the mobile monitoring station should turn 180º, return back and search for the transmitter at the right side of the station.

Advantages of homing with amplitude and bearing history graphs include increased reliability, shorter search time, and reduction of the effect of errors caused by surrounding objects because the mobile monitoring station is in continuous movement, and the most probable direction to the signal transmitter is determined by a statistical processing of continuously obtained bearing data.

3.6.2.2.6 Automated site search for sources of electromagnetic emissions

Mobile station fitted out with a high-speed correlation/interferometry DF system capable of providing DF information (azimuth and elevation) can be used for locating a transmitting set, HF consumer or medical equipment, and other sources of radio interference [Ashikhmin *et al*., 2003], [Rembovsky *et al.*, 2006]. The mobile station should also be fitted with a video camera and customized software.

An investigation session for a particular frequency range consists of three steps:

Step 1: Compilation of frames of raw data.

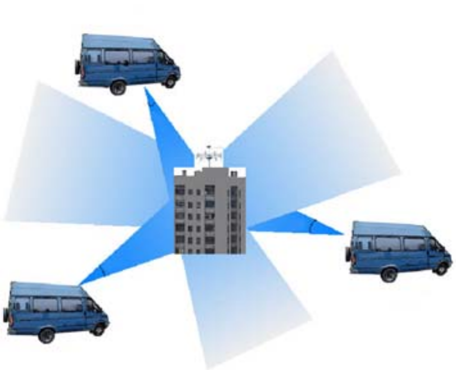
Step 2: Analysis of frames and determination of frequencies to be studied more closely.

Step 3: Analysis of the frequencies in the list and precise determination of source locations.

The mobile station is positioned at several points in the near vicinity of the site under investigation, and others that are at a relatively great distance (Fig. 3-53). For each position, one 'frame' of raw data is collected. The data are as follows: spectra and bearing panorama (frequency, level, azimuth, and elevation), digital camera imagery of the site that describes angular boundaries of the site, as seen from the station's position. Under urban conditions, bearing analysis relies on probabilistic methods, due to the effects of multipath propagation and other local effects. Ideally, the position should be chosen so that the site being surveyed is within LoS, and there are no high buildings or large metallic structures near the mobile station. The more the frames obtained from different positions are used, the greater will be the positioning accuracy.

FIGURE 3-53

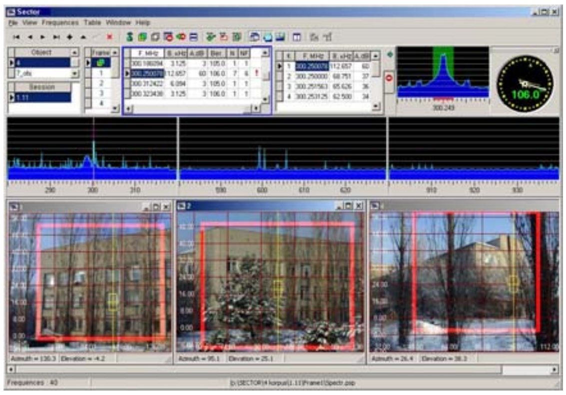
One operational session of the mobile station corresponds to several "frames"



Spec-3-53

FIGURE 3-54

View of the analysis module screen after the second step



Spec-3-54

During the Step 2, collected raw data are used to obtain a list of frequencies that shall be studied based on the following criteria: azimuth and elevation measured on a frequency shall be within the site angular boundaries for two or more frames; signal level measured from a distant position is much weaker that from a near position. Figure 3-54 shows software screens in cases when the frequency list is obtained based on three frames for distant and three frames for near positions. The programme shows the digital images of the site obtained in the immediate proximity of the site. Analysis led to the identification of a signal transmitted at 300.25 MHz, present in all six frames, with an angle of arrival from inside the site's angular boundaries. The most probable transmitter location is the premise on the first flour (fourth or fifth window of the building from the left).

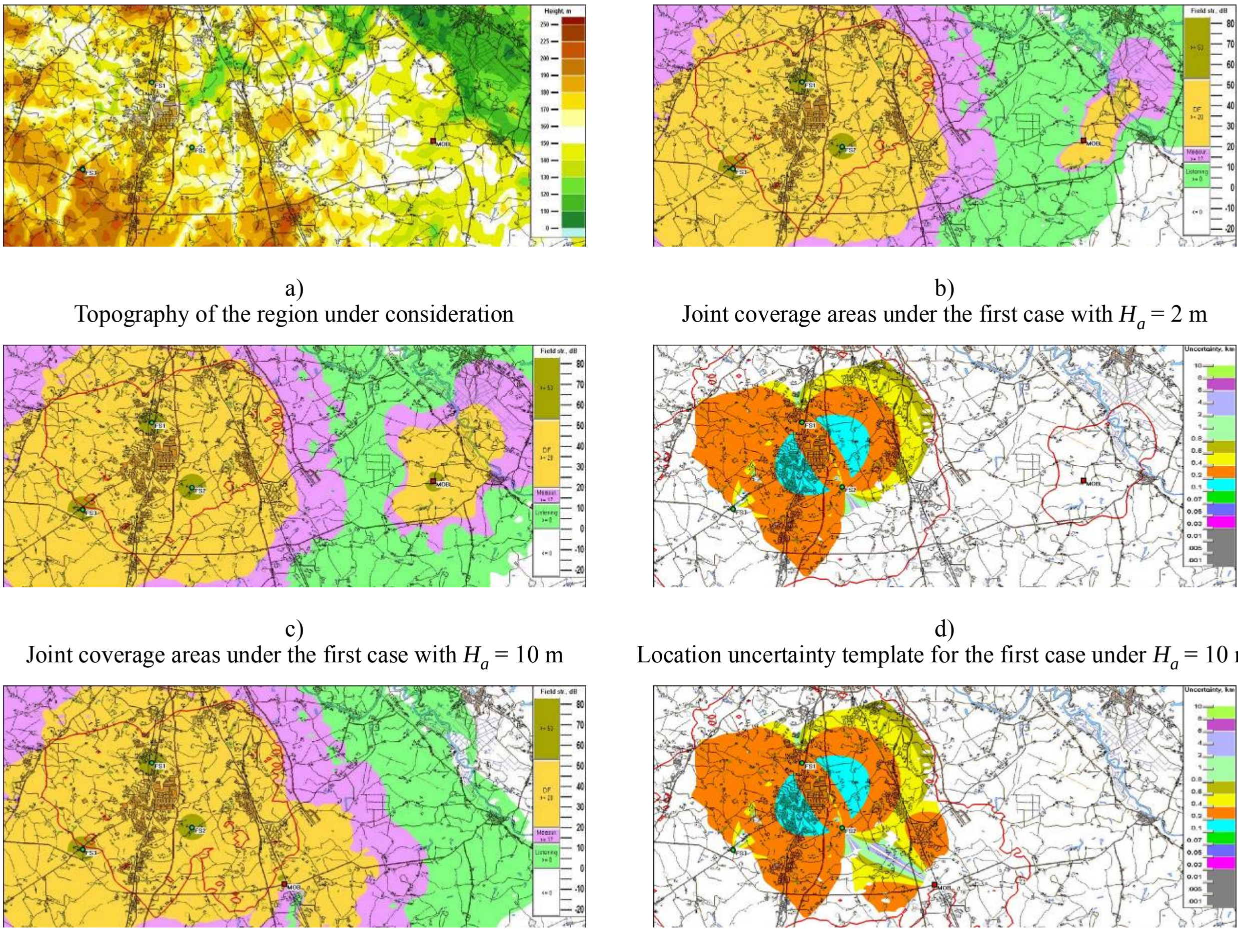
During Step 3, the frequency list is analyzed based on DF from near positions. DF data are superimposed on the video image of the site in real time, the signal is listened to by the operator. In order to increase reliability, the station can be positioned at several locations.

3.6.2.2.7 Visualization of coverage areas of VHF/UHF spectrum monitoring stations

Practice shows [Bondarenko *et al*., 2008] that the methodology [Kogan and Pavlyuk, 2004] and relevant software (see "Case study 9" in Chapter 5 of the Handbook on Computer-aided techniques for spectrum management, Edition of 2005) for planning and design of spectrum monitoring networks can be successfully used for automation of visualization of VHF/UHF fixed and especially mobile monitoring station coverage areas in the course of their operations. This tool also allows determining interaction conditions of fixed and mobile monitoring stations in performing various monitoring functions that increase the operational efficiency of the stations.

An example presented in Fig. 3-55 illustrates these functions. Calculations were made using a set of incoming parameters presented in [Kogan and Pavlyuk, 2004].

FIGURE 3-55



a)
Topography of the region under consideration

b)
Joint coverage areas under the first case with H_a = 2 m

c)
Joint coverage areas under the first case with H_a = 10 m

d)
Location uncertainty template for the first case under H_a = 10 m

e)
Joint coverage areas under the second case with H_a = 2 m

f)
Location uncertainty template for the second case under H_a = 2 m

Spec-3-55

Figure 3-55a) shows the topography of the region under consideration. It contains some hills with height differences of up to 120 m. Let us suppose that there are three fixed monitoring/DF stations around a city (FS1, FS2 and FS3) with DF uncertainties of 1^{o} r.m.s., and one mobile station (MOB) with a DF uncertainty 2^{o} r.m.s. that is, in the first case, initially situated rather far from the group of fixed stations.

Figures 3-55b) and 3-55c) present coverage areas of all stations when the mobile station one stays rather far away from the group of fixed stations. Figure 3-55b) corresponds to the mobile station antenna height, H_a = 2 m (installed on the roof of the car) and Fig. 3-55c) with H_a = 10 m (erected antenna mast). A red line within the DF coverage area shows the borders of an area where location by triangulation is provided.

Figures 3-55b) and 3-55c) also show that the mobile station in this position, being connected to a joint local monitoring network with the fixed stations, can interact with them only when performing the listening function within the territory where relevant coverage areas intersect. Elevating the antenna mast up to 10 m demonstrates a significant increase in coverage of all monitoring functions with the exception of location.

Figure 3-55d) presents location coverage template whose outer borders correspond to the red line within DF coverage areas of Figs. 3-55b) and 3-55c). Different colour zones within the template show gradations of the location uncertainty (km) as is given by the colour index at the right of the figure. The mobile station does not influence the template at all. The outer red line here corresponds to the borders of joint DF coverage areas given in Figs. 3-55b) and 3-55c).

Figure 3-55e), which deals with the second case, presents coverage of all stations when the mobile station with an antenna height of 2 m stays at the top of a hill very close to the group of fixed stations. Calculations show that, in this situation, erecting the antenna mast to a height of 10 m does not improve significantly the situation.

In the second case, DF coverage areas of the fixed and mobile stations intersect, which means that the fixed and mobile stations can interact using the location triangulation function. This is demonstrated in Fig. 3-55f) that shows the extension of the template in the South-East direction. More details and explanations can be found in [Bondarenko *et al*., 2005].

The short description above demonstrates the high potential of the monitoring coverage area visualization tool for supporting routine operations of the fixed and, especially, mobile monitoring stations. With such tools, operators of monitoring stations have "eyes" to see the actual coverage areas of individual stations or groups of stations combined in a joint local network, through different monitoring functions, as well as by the interaction of mobile stations with the nearest fixed stations during the course of their mission. Today, it is possible to determine quickly the gain that a mobile station can achieve by the deployment of a high semi-stationary antenna and, through this, determine not to spend time on such an action if the gain at a particular site is negligible. Thus, the operators for the first time are able to be fully informed of the situation they are dealing with. This technique also provides the capacity to survey a future route of a mobile monitoring station before an actual mission is undertaken and to choose the best observation sites along the route to optimize the mission and to shorten its duration.

3.6.3 Computerized monitoring networks

3.6.3.1 Introduction

Spectrum monitoring stations should be linked together through a computerized network, and should be networked to the administration's spectrum management system as recommended in Recommendation ITU-R SM.1537 and as described in § 3.6.3.3. Spectrum management and monitoring includes a set of administrative and technical activities, which can be conveniently performed within the framework of a networked, integrated system.

Spectrum management activities ultimately result in the issuing of licences or authorizations. To perform these management tasks, a computer database is essential. This database, which incorporates administrative and technical data such as assigned frequencies, licence holders, equipment characteristics, etc., forms the core of the computerized automated spectrum management system.

Spectrum monitoring allows checking that these frequencies are used in accordance with the provisions of the authorization or licence, and measures the spectrum occupancy by means of monitoring stations.

An important and indissoluble relationship exists between spectrum management and spectrum monitoring; close cooperation should be maintained between both, so that the spectrum monitoring tasks are useful for spectrum management.

The main domains of interaction between spectrum management and spectrum monitoring are as follows:

– spectrum management establishes the official list of assigned frequencies for emission monitoring;

– spectrum management provides general instructions concerning bands to be scanned and specific tasks for monitoring;

– spectrum monitoring receives requests for specific tasks from the spectrum management: e.g., complaints of interference to be monitored to solve the problem and measurement of occupancy on frequencies to be assigned;

– spectrum monitoring allows the measurement of technical parameters and checking for technical compliance of transmitters, identification of unlicensed or non-compliant transmitters and detection of specific problems.

Interaction between spectrum management and computerized spectrum monitoring systems allows operation to be optimized both for the efficiency of operation and cost of the system. The system is organized around a computerized database associated with the use of personal computers. The database is the core for all functions and associated applications: data updating, invoicing, frequency assignment, etc., as well as updating of technical parameters concerning frequencies and transmitters.

3.6.3.2 Integrated computerized national systems

A complete integrated computerized national spectrum management and monitoring system relies on one or more data servers with a network so that workstations or clients throughout the system can access the database. Management system servers include a main server and occasionally one or more servers for a database extracted from the main database and/or a database dedicated to an application or at a local command centre. Each monitoring station, whether fixed or mobile, has a measurement server and one or more workstation(s), as illustrated in Fig. 3-39. Each station uses a modular architecture based on server and workstation computers interconnected via Ethernet LAN.

All stations are linked over a wide area network. This fully integrated system should provide rapid access by any operator position to any of the server functions available in the system. The block diagram shown in Fig. 3-38 illustrates this system configuration.

The main server contains a relational database that is loaded with administrative and technical data of the region or national network, with data content as recommended by the ITU Handbook on Computer-aided techniques for spectrum management and Recommendation ITU-R SM.1370. This server generally is a Structured Query Language (SQL)-based system, allowing the user, with appropriate access, to easily query the database. Modern databases provide redundant systems and data in conjunction with periodic backups. The database with a distributed computerized network allows for the implementation of a client/server architecture and a distributed computerized system:

– the database server centralizes data management, thus facilitating security and preserving a high integrity level; it contains data on applications, licenses, sites, equipment, invoicing, frequency assignment, etc.; portions of this database may optionally be copied to local or mobile servers for specific applications;

– the management, supervisor and data entry workstations are personal computers which allow the database to be loaded with administrative and technical parameters and which are used by management and monitoring personnel for frequency management, technical monitoring, etc.

The database software should provide for electronic data input from an existing database, should one exist, either directly or through a specially-prepared data conversion program.

3.6.3.2.1 Operation of the network of automated stations

In an integrated system, the management system should be interfaced to the monitoring stations through a wide area network (WAN) to allow remote as well as local tasking of, and reporting from, the monitoring stations. Tasking for the monitoring stations includes systematic measurements in conformity with ITU-R Recommendations such as spectrum occupancy, signal parameter, and DF measurements on a specific frequency that may follow a complaint. Measurement servers (described under § 3.6.2.2) at the stations receiving the tasking automatically execute the requested measurements. This information is made available to supervisory personnel in alphanumeric or graphical reports.

The monitoring reports may include results of measurements and geographical displays of a coverage area or region, including:

– locations of the monitoring stations

– locations of known transmitters

– results of the stations' DF bearings for transmitter location.

Monitoring stations may be fixed or mobile and it is useful in a computerized national system to have both types. Fixed stations are appropriate for monitoring signals over long time periods, or for HF, where requirements for antenna space is important and propagation is typically long range via skywave. Fixed stations near urban areas are also useful for monitoring VHF/UHF in urban areas. Mobile and transportable stations are appropriate for monitoring VHF/UHF/SHF (and HF groundwave) since, with shorter-range propagation in these cases, the measurement system must generally be moved to the area of interest. They are also needed in many cases where illicit stations or the source of interference has to be located precisely.

3.6.3.2.2 Remote access to system resources

Integrated, networked, multitasking systems, with the client/server architecture described above in § 3.6.2.2, typically allow a client at any station to access the resources of any or all of the measurement servers, both those co-located with the client and those at other stations. Thus, all of the resources of a multistation network are available to any given operator, provided that the operator has the proper authorization to access all of those resources.

The monitoring stations may be controlled remotely from a workstation at a spectrum monitoring centre, the spectrum management centre, a local command centre, or locally at the station itself, and monitoring results may be reported back to that workstation. This remote control accommodates spectrum monitoring operators who may need to work from a central location rather than traveling to distant monitoring sites, provided that the situation does not require an experienced monitoring operator at the site. It is important to note that operators still need to analyse measured data and validate any data before entry into a central database.

Communication links only need to be available between stations when a client is issuing tasking to remote servers, and later when the client is requesting results of his tasking; as long as communication links are available when the tasking is issued, if they then become unavailable, measurement results are not lost, but are retained on the measurement server until requested.

3.6.3.2.3 Automatic violation detection

An integrated spectrum management and monitoring system may compare measurements from the monitoring system with licence information from the management system to perform automatic violation detection – to identify frequencies on which there are transmitters that are not included in the licence database and to identify transmitters that are not operating within their licensed parameters. Automatic violation detection allows the operator to define a monitored range by specifying the start and stop frequencies of the band(s) to be searched, and to specify search parameters, including the time period over which the search may be done.

The system should be able to perform a scan over the specified frequency range and for the specified time period. The system uses the measurements obtained from the scan and then uses information in the license database to determine which signals in the measured spectrum are not in the licence database, thus automatically providing a list of frequencies being used that are not in the database. The system should also check other signal parameters, such as bandwidth, over modulation deviation from licensed centre frequency, and issue alarms or reports where violations are found. Reports therefore alert the operator to unexpected or noncompliant signals based on either default criteria or on criteria that the operator has specified, and provides the basis for closer examination by the operator. Automatic violation detection results, including information on unlicensed or noncompliant transmitters by frequency or by channel, are displayed on a results screen. A geographic map display similar to Fig. 3-41 may display locations of licensed stations and indicate the locations of unlicensed or noncompliant transmitters.

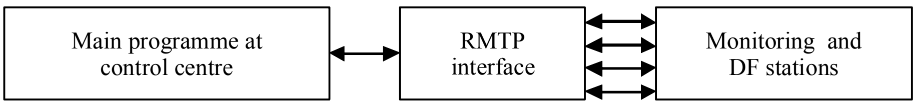
In order to facilitate the automatic violation detection process and assure it is operational even in the event of unavailability of communications among stations, each client, whether at a fixed or mobile station, should maintain its own database of licensed stations in its area of operation. This database should be obtained from the management system database. With the availability of this local database, each client can continue to operate and perform automatic violation detection, even if communications are unavailable.

3.6.3.2.4 Example of radio monitoring transfer protocol to operate many monitoring stations from a control station

A radio monitoring transfer protocol (RMTP) has been developed to allow a single control station, with local or remote users, to operate separate remote fixed and mobile monitoring stations provided by different equipment suppliers. Since manufacturers generally consider their communication and control protocol to be proprietary, a standard message protocol used by the control centre was established, and manufacturers were encouraged to provide an interface to this standard control centre protocol. Figure 3-56 shows the software structure.

FIGURE 3-56

Monitoring network software structure



Spec-3-56

The control centre can obtain status of the various remote stations which are on line, open windows to control their receivers and set other tasking parameters for the remote stations, request technical measurements and DF measurements, perform scan over specified frequency bands using specified bandwidths, and perform other typical monitoring system functions.

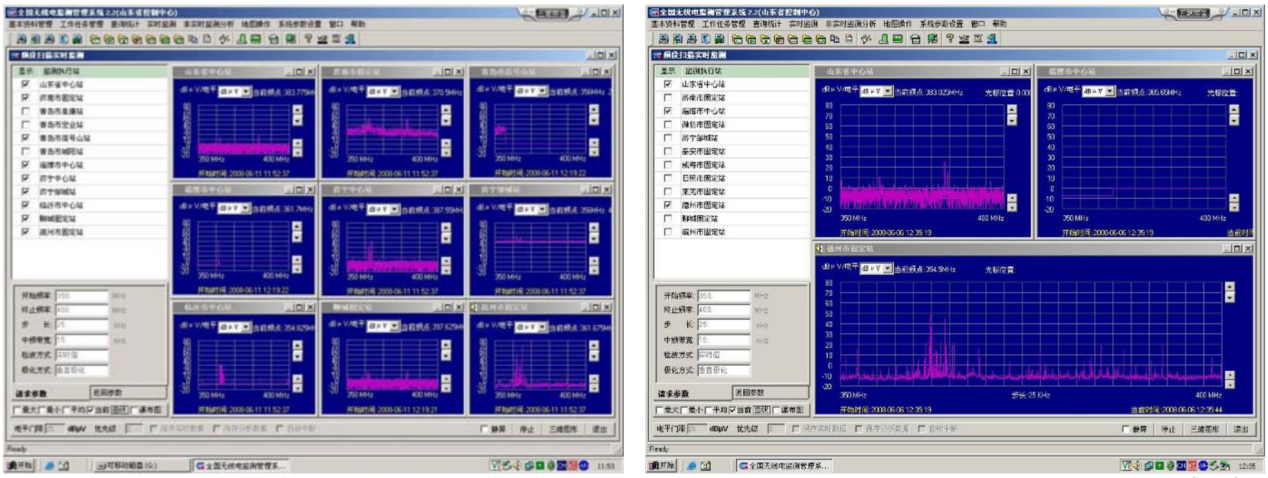
The control centre can obtain measurement results, display measured DF and location information on geographic maps, view panoramic displays (provided the communication channels have sufficient bandwidth to refresh pan displays in real time), view spectrum displays, waterfall displays and other spectrum monitoring data. The control centre can compare measurements with the licence database to determine frequencies where there are likely to be unlicensed stations and to find licensed frequencies that are not being used.

Although the monitoring data may be measured on equipment provided by different manufacturers, the data are all obtained from the remote monitoring stations using RMTP and displayed on screens at the control centre. Figure 3-57 provides two examples of a control centre screen; on the left are nine spectrum displays from nine different remote monitoring stations produced by receivers from different manufacturers, and on the right are three spectrum displays. In some cases, the spectra are very different because some stations are far apart from the others. In both screens, the upper left corner provides a list of all on-line stations that can be selected to perform some monitoring or DF task from the control centre, and the lower left corner allows parameter entry, including start, stop and step frequencies, bandwidth, polarization, demodulation, etc.

While this example is of monitoring stations within one country, the same RMTP could be used to network stations in multiple countries, so that they could be controlled from one or more control centres. This would allow administrations in different countries to share resources, for example, to use direction finders in other countries to help improve the accuracy of locating an unlicensed transmitter.

FIGURE 3-57

Examples of measured spectra from nine (left display) and three (right display) monitoring stations



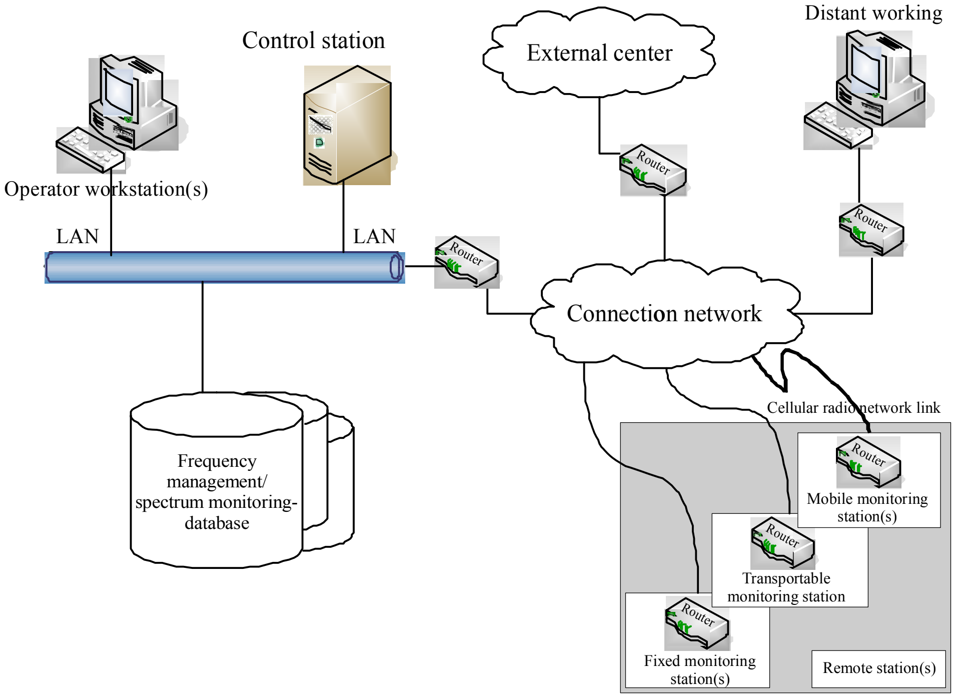
Spec-3-57

3.6.3.3 Example of a HF/VHF/UHF automated system

For spectrum monitoring in this example, there is a technical monitoring network (see Fig. 3-58) that consists of a number of remote stations connected to a control station via a standard communication network.

FIGURE 3-58

Example of HF/VHF/UHF computerized system



Spec-3-58

The various elements composing this system have the following characteristics:

a) *Operator workstations* are in charge of carrying out radio monitoring tasks described in Chapter 2 of this Handbook.

b) *Control stations* are in charge of managing and supervising the system, planning and allocating of resources, routing of messages, fault modes management and system hour management.

c) *Remote stations* could include different monitoring equipment to ensure a part or all monitoring tasks described in Chapter 2 of this Handbook.

Remote stations can be established as four types in various frequency bands as:

– Fixed manned or unmanned station

– Transportable in a mobile shelter and connected to the control station via a fixed or wireless data link

– Mobile in a vehicle and connected to the control station via a fixed or wireless data link

– Portable in a box and connected to the control station via a fixed or wireless data link.

All the stations are fully automatic and supervised by an operator in the operating control centre. For each monitoring station, two different ways of working have been developed:

– First, there is on-line control of the station, making it possible for an operator to use the remote station in a similar way as if it were a local station.

– Second, the remote station is able to operate in scheduled or batch mode, thus making it possible to load a set of parameters for an automatic measurement campaign to be performed during a given period.

An example of a HF/VHF/UHF remote station is shown in Fig. 3-59.

3.6.4 Reporting equipment and software in automated systems

Reports in modern spectrum monitoring systems are generated with the computer software. They are based on measurements, but can draw on different data records available in the spectrum monitoring and spectrum management databases. A large variety of reports should be available, including raw trace information, carrier analysis by date or band, channel occupancy and availability statistics, message length statistics, channel power statistics, system and alarm logs, and monitoring plan and schedule reports. A typical computer-generated report is illustrated in Fig. 3-60. The system should allow adaptation or customization of reports, according to the requirements of the operator.

Reports should be produced automatically from any results screen. The operator specifies the report type of interest and the measurement data to be used; the operator activates a “Report” function to generate text reports automatically on his screen. Graphical reports are often a preferred method of examining data, because they provide a view of data that summarizes the information and makes it easy to identify trends and exceptions. Through the use of colour, even more information is conveyed in a single graph.

A modern system should offer the same automated report capability whether one is in a mobile unit, fixed station or management system. The capability to remotely create a report based on data that is located at a different site is also part of a typical system software.

FIGURE 3-59

Example of HF/VHF/UHF remote station

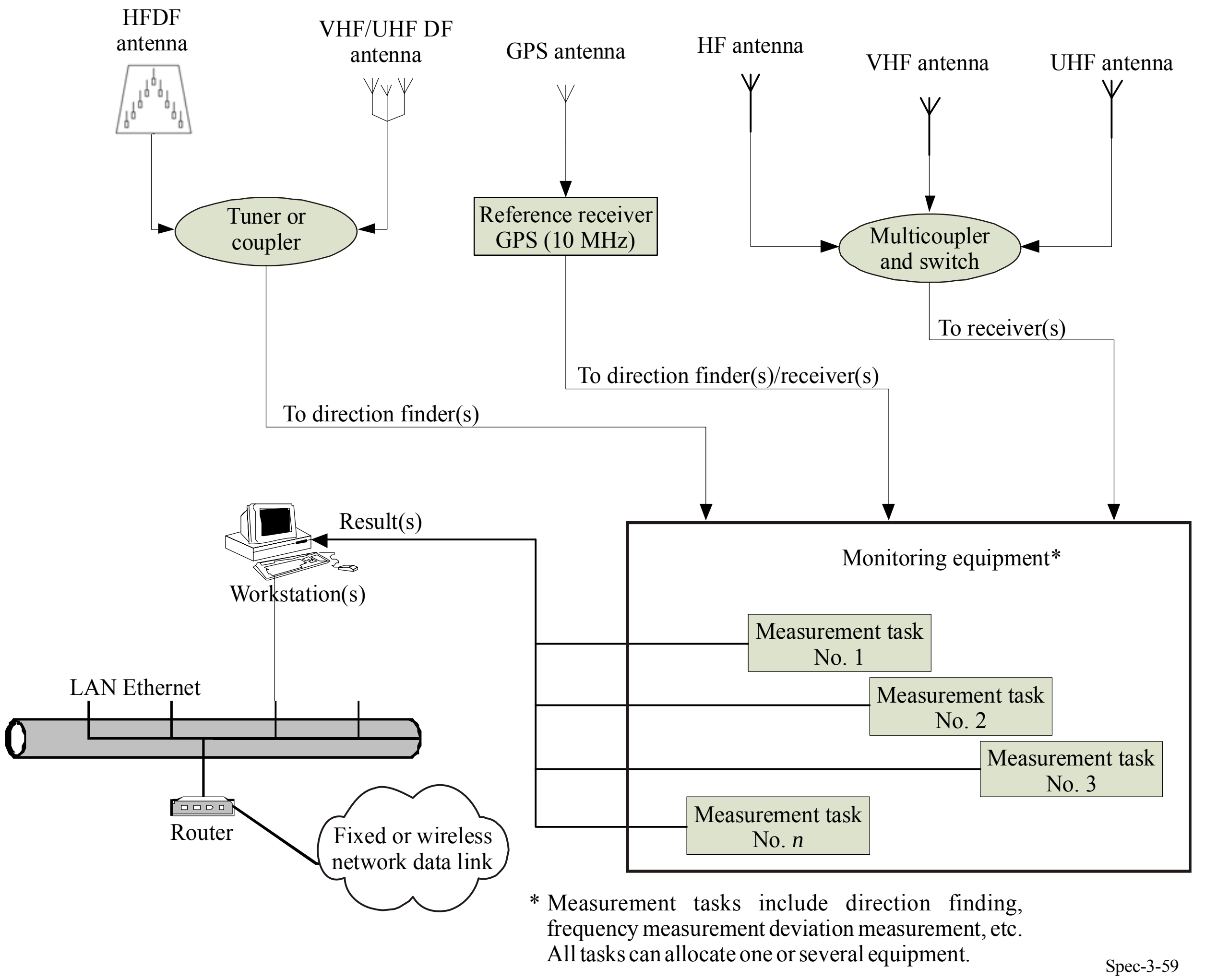


FIGURE 3-60

Portion of a typical computer-generated occupancy report

Occupancy vs. channel

Task No:	676	Storage interval:	15 s
Operator ID:	TRNI	Msg length:	15 s
Schedule time:	2/12/01 6:01:02 PM	Threshold method:	Noise riding 10 dB
Completion time:	2/12/01 6:01:02 PM	Duration:	Fixed: 30 min
StartFreq:	88.100000 MHz	Band No.	1
StopFreq:	107.900000 MHz	Bandwidth:	50 kHz
Site location:	S 23 24' 47.5" W 142 0' 59"	NumChannels:	397

Channel:	Frequency:	Max occupancy:	Avg occupancy:
•			
•			
21	89.100000	0	0
22	89.150000	4	0
23	89.200000	4	0
24	89.250000	80	53
25	89.300000	100	99
26	89.350000	76	51
27	89.400000	4	0
28	89.450000	0	0
29	89.500000	0	0
30	89.550000	0	0
31	89.600000	4	0
32	89.650000	9	0
33	89.700000	57	32
34	89.750000	14	2
35	89.800000	4	0

Spec-3-60

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ITU-R Recommendations:

NOTE – In every case, the latest edition of the Recommendation is encouraged to be used.

Recommendation ITU-R SM.1050 – Tasks of a monitoring service.

Recommendation ITU-R SM.1370 – Design guidelines for developing advanced automated spectrum management systems.

Recommendation ITU-R SM.1537 – Automation and integration of spectrum monitoring systems with automated spectrum management.

Recommendation ITU-R SM.1794 – Wideband instantaneous bandwidth spectrum monitoring system.

CHAPTER 5

SPECIFIC MONITORING SYSTEMS AND PROCEDURES

5.1 Spacecraft emission monitoring

Page

Page

5.1 Monitoring of spacecraft emissions

5.1.1 Tasks and measurements to be performed

A monitoring service responsible for the enforcement of domestic laws and regulations and engaged in international monitoring, pursuant to Article 16 of the Radio Regulations (RR), would normally participate in the monitoring of emissions from space stations as a normal and necessary extension of regular monitoring facilities, techniques and operations.

In general, the tasks carried out by a radio monitoring station for space services do not differ from those of a radio monitoring station for terrestrial services. However, radio monitoring for space services requires the use of relatively more complex measuring equipment, such as more complex antenna systems, as well as differing monitoring and measurement procedures. This is primarily because space stations are located aboard satellites whose positions are time dependent, except for those in tightly controlled geostationary (GSO) orbits. Basic knowledge of the orbits of such objects is an important precondition for any kind of observations and measurements of them.

Because space monitoring differs from terrestrial monitoring in both measurement techniques and terminology, that which provides the space function is known as a "monitoring station for space radio services". The functions of such a station can be outlined as follows:

– regular and systematic observation of the radio frequency spectrum with the aim of detecting and identifying space station emissions;

– determination of occupancy and percentage use of transponders or space station transmitters;

– measurement and recording of the characteristics of space station emissions;

– investigation and elimination of harmful interference caused by space station emissions, if appropriate, in cooperation with terrestrial and other monitoring stations for space services;

– investigation and elimination of harmful interference to the frequencies used by a space station caused by the emissions of terrestrial stations, unknown earth stations, or other satellites, e.g. by observing and measuring a transponder, interfering signal in a similar manner as for legitimate space station emissions (see §5.1.1.1 below);

– measurements and recordings for technical and scientific projects;

– detection of illicit use of transponders and identification of its source(s);

– using special satellite techniques to locate emitters on Earth;

– pre-launch monitoring, during the pre-phase of the launch of a satellite, to monitor the frequencies used for telemetry, telecommand and tracking with respect to the orbit position. This pre-launch monitoring will facilitate a saver launch and early orbit phase, including position.

If all types of spacecraft are to be observed, the antenna system must be capable of tracking low orbiting and highly elliptical orbiting satellites, as well as being able to point accurately at GSO satellites.

Satellite communications are divided into the following radio services:

– *Fixed-satellite service (FSS)*

  The FSS comprises all satellite communication services based on fixed infrastructure via private or public networks providing telephony, fax, Internet, video and data services.

– *Broadcasting-satellite service (BSS)*

  This radio service is mainly used for the distribution of TV and video signals.

– *Mobile-satellite service (MSS)*

  The MSS services are mainly used for mobile telephony and data services and for navigation and satellite fleet management.

Overall system cost must be balanced against design choices made for the provision of the above-mentioned capabilities: frequency coverage, system sensitivity, antenna slewing rate, antenna pointing accuracy, ease of changing antenna feed hardware if necessary, receiving bandwidth capability, degree of sophistication of signal analysis instrumentation and degree of automation of measurements. A highly automated and sophisticated spacecraft monitoring system, fully steerable, with continuous frequency coverage across the 1-30 GHz spectrum, for example, and sensitive enough to give carrier-to-noise ratios of at least 26 dB on all signals of interest would be ideal. However, as a practical matter in this example, incremental improvements in sensitivity come at costs that rise almost exponentially. Each administration must, therefore, analyze its own priorities and internal needs with regard to spectrum management and decide on priorities for monitoring of space services.

Table 5.1-1 provides an overview of factors to consider when conducting monitoring activities involving satellite signals. The table is organized by satellite type and signal path (uplink to satellite, downlink from satellite).

TABLE 5.1-1

Factors to be considered when conducting monitoring activities involving satellite signal

Satellite type	Satellite spacecraft emissions (downlinks)	Satellite earth station emissions (uplinks)
Geostationary satellite orbit (GSO)	Monitoring tasks are usually conducted from fixed monitoring stations, due to their superior antenna performance and system sensitivity. The antenna positioning required for GSO satellites is along the equatorial arc only	Monitoring of emissions from satellite earth stations to GSO satellites, including very small aperture terminals (VSATs) used by many businesses, are carried out by mobile vehicles operating in the appropriate frequency range. The high directivity of typical satellite earth station antennas requires the measuring equipment to be near the transmitting antenna or somewhere in the main beam
Non-GSO	Monitoring tasks are usually conducted from fixed monitoring stations with antenna tracking capability (though mobile systems with tracking capability could be used). The monitoring station antenna must continuously track the satellite position based on one of several methods of satellite tracking covered later in this Chapter	Monitoring of emissions from satellite earth stations to non-GSO satellites are carried out by mobile vehicles. As with the GSO case, the antenna directivity requires the measuring equipment to be near the transmitting antenna or somewhere in the main beam. An additional factor is that the transmitting antenna will be moving to follow the satellite orbit, complicating measurements of amplitude related-parameters.

5.1.1.1 Types of measurements

For the satellite monitoring, the following main measurements and determinations are to be carried out:

– Frequency

– Doppler frequency

– Power flux-density (pfd) with reference to bandwidth and total e.i.r.p., channel e.i.r.p. and carrier e.i.r.p

– Carrier C/N_0

– Bandwidth and carrier bandwidth

– Out-of-band spectrum measurements

- Transmission characteristics
- Identification of modulation type
- Spectrum observations recording
- Fast spectrograms to visualize fast slots drifts and sweeping signals
- Polarisation measurements
- Satellite orbit position (orbital position accuracy of at least 0.1°)
- Base band characteristics of received signals, i.e., BPSK, QPSK, QAM, FDM/FM
- Received *S/N*.

5.1.1.2 Types of interference caused by satellite systems:

- Adjacent channel interference
- Co-channel interference
- Cross-channel (cross-polarisation) interference
- Adjacent system interference.

These types of interference are produced at the input of the receiving earth station by carriers transmitted by either the satellite of the considered system (consisting of an earth station and a satellite) or by a satellite of another system

Adjacent channel interference

This type of interference is produced by carriers transmitted from the satellite to earth stations in the same system, located in the same spot beam as the earth station under consideration, which is further referred to as the victim earth station, transmitted at different frequencies but at the same polarisation.

In FDMA and TDMA access schemes, these carriers interfere with the victim carrier because of the non-ideal performance of the filter of the transmitted earth station.

Co-channel (co-polarisation) interference

Co-channel interference is produced by carriers, transmitted by the satellite to earth stations of the same system, at the same frequency and at the same polarisation as the victim carrier.

These interfering carriers are sent to earth stations, located in a different spot beam from the victim earth station in FDMA and TDMA, but they are located in the same spot beam as the victim earth station in CDMA.

In FDMA and TDMA, this interference is limited by the satellite antenna roll of the adjacent spot beam in the direction of the victim earth station, whereas in CDMA it is limited by code correlation properties.

Cross-channel interference

This type of interference is produced by carriers, transmitted by the satellite to earth stations of the same system, at the same frequency and at the orthogonal polarisation as the victim earth station carrier.

These interfering carriers are sent to earth stations located in a different spot beam as the victim earth station, if single polarisation is used, but to earth stations located in the same spot beam as the victim earth station for dual polarisation systems. For systems with single polarisation, this interference is limited by the satellite roll of the adjacent spot beam in the direction of the victim earth station and by the isolation in polarisation of the satellite antenna. In case of polarisation re-use, it is limited by the polarisation isolation of both satellite and earth station antennas only.

Adjacent system interference

This inference is produced by carriers transmitted by satellite to earth stations of another satellite communication system, transmitting at the same frequency and polarisation as the victim earth station carrier. This interference is limited by the angular separation of the two satellites from the victim's earth position.

5.1.2 Measurement techniques

5.1.2.1 General

The main factors which necessitate different techniques for the monitoring, observation and measurement of emissions from space stations as compared to emissions from fixed or mobile radio stations on or near Earth are:

– the difference between the received and the transmitted frequency, and the varying nature of the received frequency, caused by the Doppler shift effect, particularly for satellites not in GSO orbit;

– the weak pfd at the Earth receiving point, due to distance and generally low transmitter power;

– the relatively short time that a signal from a near-Earth orbiting satellite is receivable at a fixed monitoring point;

– the continual direction changes that have to be made to highly directional earth station antennas used to receive emissions from space stations not in GSO orbit.

5.1.2.2 Frequency measurements

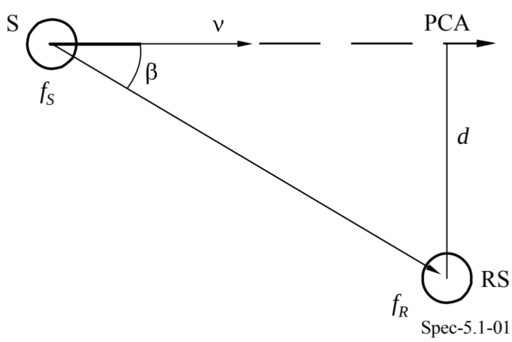
In the case of GSO space stations, the same frequency measurement methods can be applied as those used for terrestrial stations. These methods are discussed in detail in § 4.2.

5.1.2.2.1 The Doppler shift effect

When there is a relative velocity between the transmitting space station and the monitoring station, a difference of frequency proportional to the relative velocity arises between the transmitted and received signal owing to the Doppler shift effect. Equations (5.1-1) and (5.1-2) are derived from Fig. 5.1-1.

FIGURE 5.1-1

Main relations in case of Doppler shift effect



$$f_R = \frac{cfs}{c - (\nu \cos\beta)} \tag{5.1-1}$$

$$\left(\frac{\Delta f_R}{\Delta t}\right)_{max} = \frac{f_S}{c} \cdot \frac{\nu^2}{d} \tag{5.1-2}$$

where:

S : satellite

RS : receiving station

PCA : position of closest approach

f_S : transmitting frequency

f_R : receiving frequency

v : velocity of satellite

d : minimum distance at pass over

c : propagation velocity of electromagnetic waves

β : angle between flight direction and line-of-sight (LoS) direction to receive station.

The equations lead to the following findings:

– the received frequency is higher than the source frequency when the satellite is approaching the monitoring station;

– a measured frequency is equal to the correct satellite source frequency only at the time of closest approach (TCA), which coincides with the position of closest approach (PCA);

– during the TCA the maximum rate of change of frequency (MRCF) is to be observed, which gives the slope of the inflectional tangent $(\Delta f_R / \Delta t)_{max}$;

– the received frequency is lower than the source frequency when the satellite is receding from the monitoring station;

– the Doppler shift effect is proportional to the satellite's source frequency and depends on the relative velocity between the source and the monitoring station.

5.1.2.2.2 Measurement method

The achievable accuracy of a determined frequency emitted by a satellite depends on satellite orbital parameter, the propagation path, the measuring equipment and the method of evaluation. The measurement of the frequency of a non-GSO orbiting satellite is an indirect procedure, which first requires the registration of the Doppler shift, followed by the evaluation of the Doppler curve.

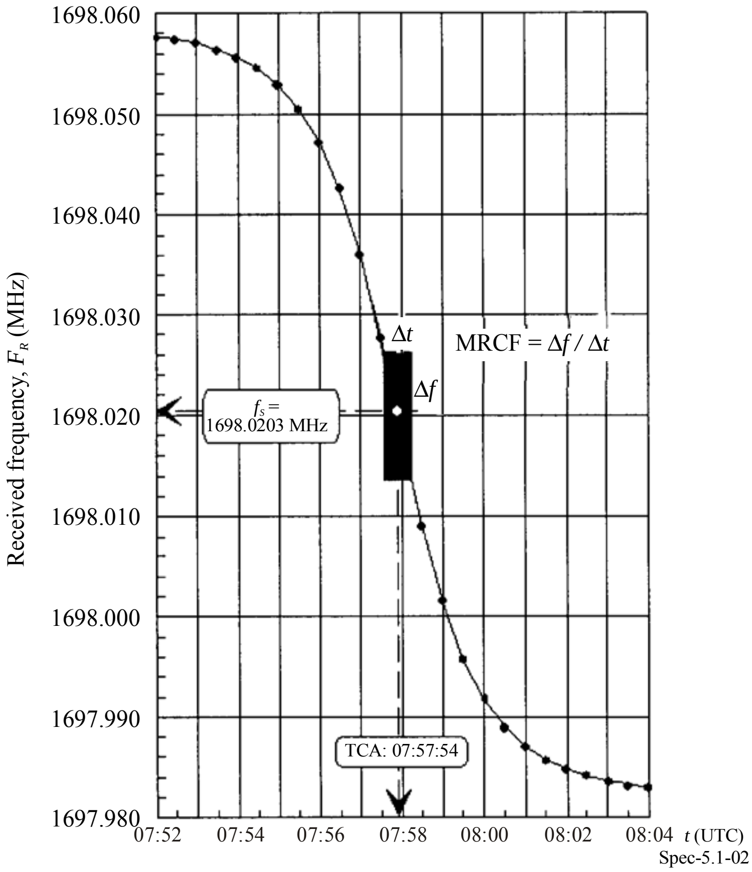
To obtain adequate measurement, an automated measuring method is preferred. See § 5.1.6.1 for details of a possible technical solution.

5.1.2.2.3 Frequency calculation procedure and measurement accuracy

By using graphical methods it is possible to determine the satellite frequency, the TCA and the MRCF (Fig. 5.1-2). The achievable frequency measurement accuracy is $\pm 1 \times 10^{-7}$ Hz.

FIGURE 5.1-2

Calculation of satellite frequency from Doppler curve



A modified method enables the degree of accuracy to be improved. By a single differentiation of the Doppler frequency curve with respect to time, a parabola is obtained, the vertex of which indicates the TCA and also the transmitter source frequency of the satellite. For the construction of the parabola, it is sufficient to utilize the individual measured values within 30 s of the TCA. The time interval between the measured values must be chosen so that the shape of the curve is clearly defined, for example, at least in intervals of 5 s. With this method and graphical evaluation methods, an accuracy of $\pm 5 \times 10^{-9}$ Hz can be obtained if a Caesium type of reference oscillator, or better, is used. Figure 5.1-3 shows the results of frequency determination performed in this manner.

Instead of time-consuming graphical evaluation methods, a software solution, which can directly process the single frequency measurement results of a frequency counter, would be best.

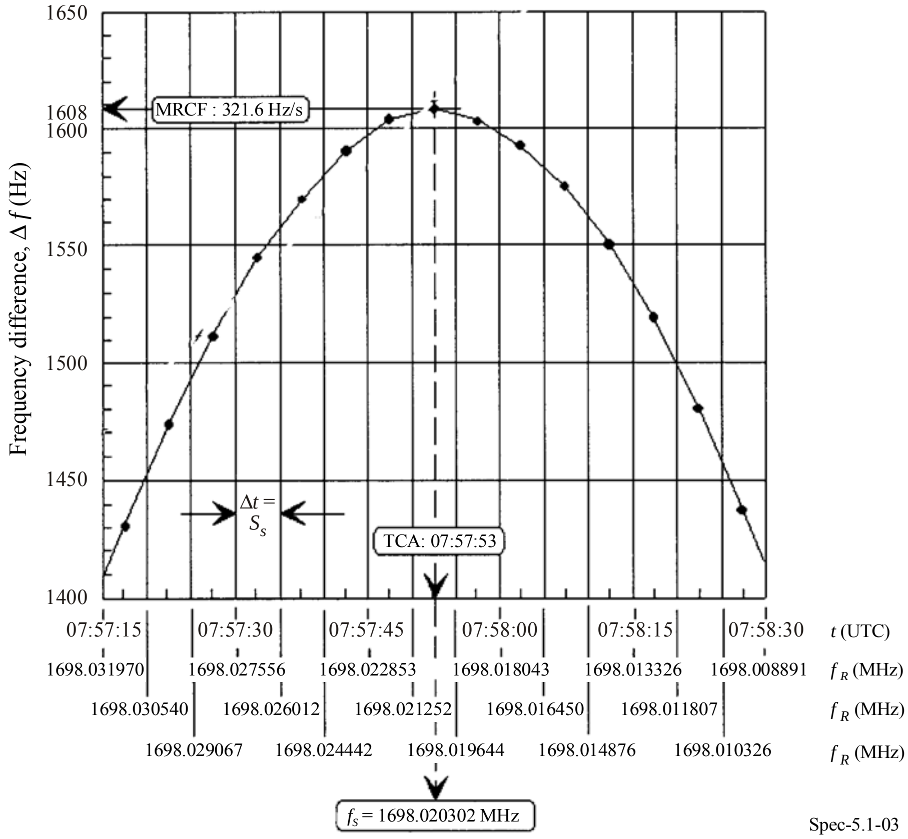
It is obvious that reliable frequency measurements can only be performed if the spectrum contains a characteristic frequency component to which the receiver can be synchronized. This, of course, also applies to the measurement of the frequencies of terrestrial stations.

5.1.2.3 Bandwidth measurements

For bandwidth measurements of GSO satellite emissions the same methods can be applied, in principle, as for measurements of terrestrial emissions. A description of these methods may be found in § 4.5.

FIGURE 5.1-3

Calculation of satellite frequency by differentiation of the Doppler curve



In cases where there is a relative velocity between the space station and the monitoring station, the apparent transmitted bandwidth as measured at the monitoring station varies because of the Doppler shift effect in the same manner as described for the carrier frequency. Two factors have to be taken into consideration:

– The entire frequency spectrum drifts during the time necessary for the bandwidth measurement.

– The frequency shift is slightly greater for signal components near the upper edge of the spectrum of the emission than for those near the lower edge. This difference could amount to hundreds of hertz for wide bandwidths. The effect causes the apparent bandwidth, as observed at the monitoring station, to vary slightly.

Automatic frequency control at the monitoring receiver can compensate for Doppler frequency shift of an emission. In this case, the normal measuring methods used to determine the bandwidth at terrestrial monitoring stations can be applied without radical changes. If the received signal is very weak, it is possible to ensure automatic correction of the receiver oscillator's frequency by using, as a reference signal, a carrier or pilot frequency emitted by the space station which is filtered by an extremely narrow bandpass filter. If the monitoring station for space services does not possess appropriate receivers with automatic frequency control, account must be taken of the frequency shift of the space station during the measurement, if necessary, by making a simultaneous Doppler frequency measurement when determining the bandwidth. It may also be necessary to make a simultaneous recording of the pfd so that the effect of pfd variations occurring during the analysis of the spectrum may be eliminated from the calculations.

5.1.2.4 Power flux-density measurements

5.1.2.4.1 Measurements in a reference bandwidth

The coordination and successful operation of space stations requires that given maximum values of pfd be not exceeded on the surface of the Earth by emissions from a space station, including emissions from a reflecting satellite. The values for individual frequency bands, space services, angles of arrival, and sharing conditions are given in RR Article 21, Section V, which should be available at the space monitoring facility. The pfd (dB(W/m^2)) is related to a particular bandwidth, in general to 4 kHz, 1 MHz, or 1.5 MHz, depending on the frequency of the fundamental emission. The indication of the reference bandwidth (RBW) is essential because the radiated power is normally not concentrated at a single frequency but is distributed within a band of frequencies.

5.1.2.4.2 Measurement of total pfd

In this case, the pfd is fully determined on the basis of the bandwidth occupied by an emission. The bandwidth of the measurement filter should be selected accordingly. Such measurements are significant if, for example, the e.i.r.p. of a space station is to be calculated. For frequency bands below 13 GHz, and provided that clear-sky conditions prevail, the total atmospheric loss may be taken as 0.1-0.2 dB for the calculations.

5.1.2.4.3 Measurement procedure

Whether the pfd in the reference bandwidth or the total pfd is to be measured, it is preferable to determine the pfd by a direct power measurement, especially at frequencies above about 1 GHz. When this method is used, the pfd can be determined by equations (5.1-3a) and (5.1-3b):

$$pfd_{RBW} = P_{SYS} - 30 - A_e - K_{BW} + K_{POL} \tag{5.1-3a}$$

$$pfd_{TOT} = P_{SYS} - 30 - A_e + K_{POL} \tag{5.1-3b}$$

where:

pfd_{RBW} : pfd in reference bandwidth (RBW) (dB(W/m^2))

pfd_{TOT} : pfd in bandwidth occupied by emission (dB(W/m^2))

P_{SYS} : system input power (dBm)

30 : factor for converting dBm to dBW

A_e : effective antenna area (see Note 2) (dBm^2)

K_{BW} : correction factor for measuring bandwidth (see Note 3) (dB)

K_{POL} : polarization correction factor (see Note 4) (dB).

The pfd value derived from equations (5.1-3a) and (5.1-3b) may be used to calculate the e.i.r.p. of the space station by using equation (5.1-4). Knowledge of the slant range to the object at the time of measurement is required for the calculation:

$$\text{e.i.r.p.} = \text{pfd} + 10 \log (4\pi d^2) + L_{ATM} \tag{5.1-4}$$

where:

e.i.r.p. : equivalent isotropically radiated power of space station (dBW)

pfd : measured pfd (dB(W/m^2))

d : distance between space station and receiving station (m)

L_{ATM} : atmospheric loss relative to free space (dB).

NOTE 1 – Input power is measured with a thermal power meter, normally connected to the IF output of the receiver and preceded by a bandpass filter of known effective bandwidth (r.m.s. measurement). The input signal is then substituted by a signal from a calibrated signal generator. Compensation for a possible Doppler shift of the incoming satellite signal should precede the IF output.

NOTE 2 – Effective antenna area (A_e) can be calculated from antenna aperture or gain by using equation (5.1-5):

$$A_e = 10 \log (A\eta) = 10 \log \left(\frac{\lambda^2}{4\pi} \right) + Gi \tag{5.1-5}$$

where:

A_e : effective antenna area (dBm^2)

A : antenna aperture (m^2)

η : efficiency expressed as a decimal

λ : wavelength (m)

G_i : isotropic antenna gain (dBi).

NOTE 3 – The bandwidth used for the measurement can be larger than the reference bandwidth, as long as the power is uniformly distributed in the measurement bandwidth. This condition can be checked by spectrum analysis. The measurement bandwidth is the effective bandwidth of the filter, which does not necessarily correspond to its 3 dB or 6 dB bandwidth. The correction factor is calculated by equation (5.1-6):

$$K_{BW} = 10 \log \left(\frac{B_M}{RBW} \right) \tag{5.1-6}$$

where:

K_{BW}: bandwidth correction factor (dB)

B_M: measurement bandwidth

RBW: reference bandwidth with same units as B_M.

NOTE 4 – In the case of matched polarization between the receiving antenna and the received signal, the polarization correction factor, $K_{POL} = 0$ dB. For linearly polarized reception of a circularly polarized emission or vice versa, $K_{POL} = 3$ dB.

Since the pfd normally varies not only with frequency but also with time, its maximum value has to be determined. This can be done by recording the output signal of the power meter over a period of time at the frequency of interest. The time constant of the power sensor used will determine the rate of power variation that can be detected. Additional information on the e.i.r.p. calculation may be found in the 2002 edition of this Handbook.

5.1.2.4.4 Measurement uncertainty

The degree of uncertainty for pfd measurements is essentially influenced by three factors:

– antenna gain uncertainty of the receiving antenna;

– uncertainty of the reference signal (power reference generator) for calibrating the measuring receiver/spectrum analyzer; and

– precision of antenna pointing/tracking.

With respect to pfd uncertainties, there is no difference between this method and the methods described in § 4.3. Whereas the uncertainty of the reference source may, to a large extent, be controlled and minimized, the actual problem lies in the exact calibration of the antenna gain of the receiving antenna. Larger parabolic reflector systems may only be calibrated after assembly at the place of installation. Accordingly, satisfactory calculation of the antenna gain must account for the specific conditions at the installation site.

The expanded measurement uncertainty (coverage factor 2) should not exceed 2 dB. A reduction in the measurement uncertainty in all frequency bands should be sought.

5.1.2.5 Polarization measurements

Knowledge of the polarization of the satellite signal is essential because the determination of this basic signal characteristic can assist in the identification of unknown emissions. Consequently, a competent antenna system should be capable of distinguishing between different types of polarization.

The technical implementation of polarization measurements has to take into account the widespread use of the dual polarization technique in the frequency bands above 1 GHz, which are used by the fixed-satellite service and the broadcasting-satellite service.

To obtain optimized receiving and measurement conditions for the satellite signal in terms of:

– maximum C/N, and

– maximum C/I by sufficient polarization discrimination between orthogonally polarized signals;

it should be possible to match the polarization of the receiving antenna at the monitoring station to that of the incoming signal. In the case of dual linear polarization, full steerability of the polarization plane is required. A polarization discrimination of at least 20 dB should be provided.

5.1.2.6 Determination of orbital positions and orbital elements

The determination of orbital positions concerns GSO satellites and the determination of orbital elements concerns non-GSO satellites.

5.1.2.6.1 GSO satellites

A GSO satellite is subject to disturbances which tend to change its position in orbit. These disturbances lead to spurious orbital plane rotation and semi-major axis and eccentricity errors. This results in that, as viewed by an observer on Earth, the satellite displays an oscillatory movement with a period of 24 h. This motion (so-called “figure of eight”) is composed of a North-South component and an in-plane component.

Space stations on board GSO satellites using frequencies allocated to the FSS or BSS have to be kept within ±0.1° of the longitude of their nominal position (see RR Article 22, Section III), except for experimental stations on board GSO satellites which should be kept within ±0.5° longitude, and for the BSS stations operating in the band 11.7-12.75 GHz which should be kept within the limits specified in RR Appendix 30. Space stations need not comply with these limits as long as the satellite network does not cause unacceptable interference to any other satellite network whose space station complies with these limits. Position determination of GSO satellites is therefore a required task of a monitoring station for space services. The orbital position is usually computed from angle measurements in the azimuth and elevation planes of the receiving antenna. Section 5.1.7.4 illustrates one example of such a measurement.

5.1.2.6.2 Non-GSO satellites

The calculation of orbital elements of a non-GSO satellite (ephemeris data) from measurements of sufficient accuracy is a basic requirement for the:

– identification of an unknown space station (see § 5.1.5);

– investigation of possible reception times; and

– predetermination of azimuth and elevation as a function of time, e.g., for computer-controlled antenna steering in cases where officially published data is not available.

A monitoring station for space services making use of passive mode measurements can provide the following timed measurement data:

– azimuth;

– elevation; and

– Doppler shift.

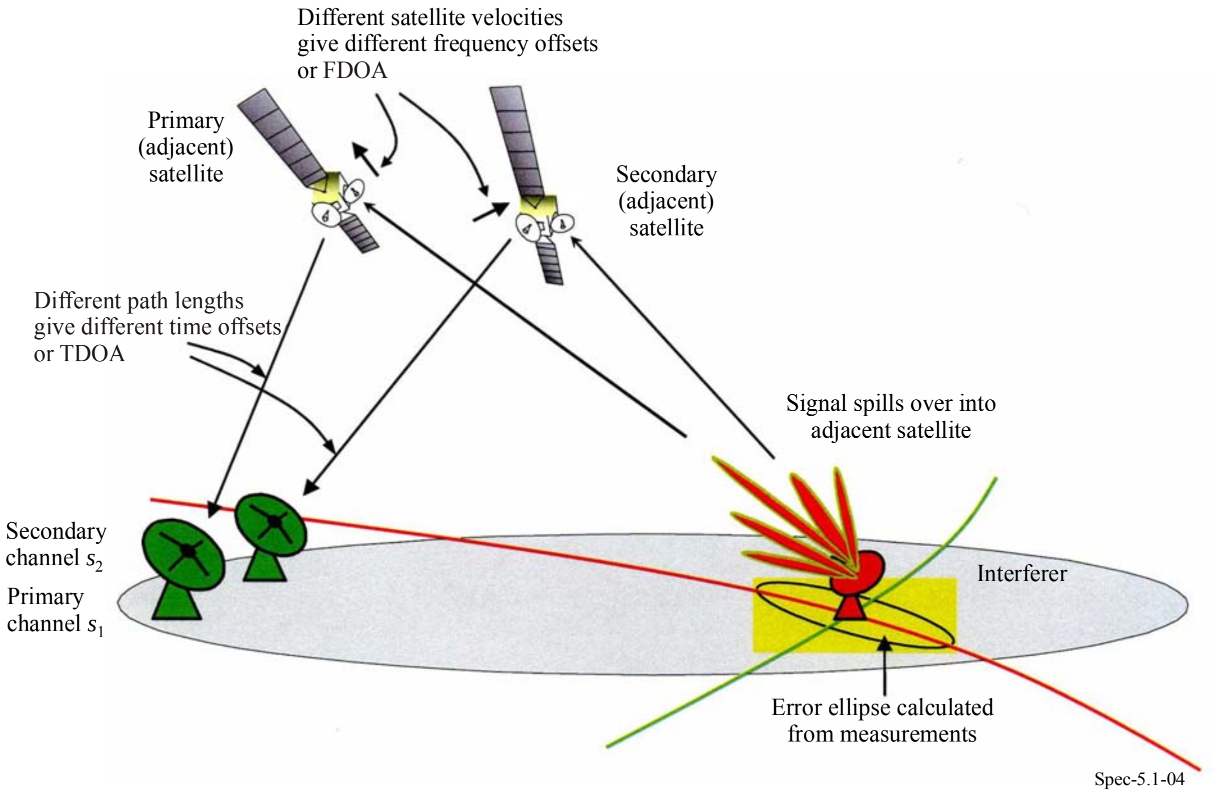
Since orbit determination requires the solving for at least six (e.g., Keplerian orbital elements), multiple measurements of the above-mentioned quantities are necessary. Typically, orbit determinations are the result of a statistical procedure in which the greater the volume of input data leads to improved accuracy of the orbital elements. When monitoring higher frequencies, i.e., above 1 GHz, methods based on the evaluation of angle measurements in the azimuth and elevation planes are preferred due to the narrower beamwidth of the receiving antenna at these frequencies.

5.1.2.7 Geolocation of transmitters on Earth using time and frequency difference measurements from two GSO satellites

Sources of interference located on Earth can affect the uplink signal received at the satellite. The receiver of the wanted signal perceives the interference as an interference of the downlink. Geolocation of radio transmitters affecting communication satellites in GSO orbit is a challenging task, which is usually accomplished through the analysis of time difference of arrival (TDOA) and frequency difference of arrival (FDOA) compound measurements. Both of these measurement types require that the transmissions be monitored through a second GSO satellite that lies within the transmitter beam. The GSO satellite carrying the unknown signal is usually referred to as the "primary satellite" and the above-mentioned second GSO satellite as the "adjacent satellite". A TDOA measurement yields the difference in the time the same signal arrives at one ground-based receiver through the primary satellite and another ground-based receiver through the adjacent satellite. An FDOA measurement yields the difference in frequency measured between the signal that separately arrives at the two receivers. Usually, the two receivers are co-located at the same geographic site, but this is not a requirement (see Fig. 5.1-4). In "distributed mode", the two receivers used for geolocation are separated from one another, but are constrained to be within the downlink beam of each space station, respectively. Distributed mode must be used when the downlink footprints are non-intersecting; indeed, these downlinks may be received on different continents. When operating in distributed mode, the raw signal measurements must be transferred to a common location for further geolocation processing.

FIGURE 5.1-4

Geolocation of transmitters on Earth using TDOA and FDOA from two GSO satellites



The arrival time varies because the transmitted signal travels different distances as it passes through the two different satellites to each receiver. The received frequency differs because, generally, there is relative motion between the two satellites causing different Doppler frequency shifts on the transmissions. Although the positions of GSO satellites are loosely described as being fixed at specific positions over the Earth's equator, they actually do move about these nominal positions within certain limits. It is these movements that induce a measurable Doppler shift in the received signals. The received frequencies can also differ as the result of drifts in the oscillators which set the retransmission frequency on the downlink of each satellite.

Single TDOA or FDOA measurements combined with the satellite and ground station configuration each describe different surfaces on which the unknown transmitter must be located. The surface of the Earth (where nearly all transmitters of interest occur) provides a third surface that constrains the unknown's location. The intersection of these three surfaces provides an estimate of the unknown signal from a single pair of TDOA and FDOA measurements. Since measurement or modeling errors can lead to errors in the geolocation, additional TDOA and FDOA measurements combined in a statistical solution can serve to reduce such errors.

5.1.2.7.1 Measuring time and frequency differences

The two time series of the transmitter signal downlinked from each of the two GSO satellites are recorded and analyzed to obtain time and frequency differences between them (i.e., TDOA and FDOA). This is done through the calculation of the cross ambiguity function (CAF) or correlation map in two dimensions. The value of CAF for a given time and frequency difference is the cross-correlation of the two recorded signals. In the special case of continuous wave (CW) emissions, no TDOA measurement can be generated since the two signals correlate for all delay time differences.

The CAF can be visualized in three dimensions where the value of the CAF is a function of both TDOA and FDOA. For the case of a single interference signal in the selected frequency range, the maximum value of CAF with respect to TDOA and FDOA selects those shifts as the TDOA and FDOA values that are presented to the geolocation algorithm that calculates the location of a single transmitter. For a CW emission, this results in a ridge along a line of constant FDOAs. Alternatively, several broadband transmitters from multiple locations will produce multiple CAF peaks. A detailed discussion of algorithms used to calculate and analyze the CAF is given by Stein [1981].

5.1.2.7.2 Geolocation algorithm

The geolocation algorithm often uses TDOA and/or FDOA measurements in an iterative least squares procedure to estimate the location where the transmitted signal originates. In its simplest form, an initial guess of the transmitter location and the given orbits of the two satellites are combined with the physical laws of satellite motion to generate predicted TDOA and FDOA measurements. The difference between the actual and predicted TDOA and FDOA measurement values (the residuals) are used to generate adjustments to the transmitter position. This adjusted transmitter location is used to generate a second set of predicted TDOA and FDOA measurements which imply further adjustments to the transmitter position and so forth. An iterative solution is required because the problem is inherently nonlinear. Iterations continue until the adjustments in the transmitter position are sufficiently small, at which point the geolocation solution is said to have converged.

Because TDOA and FDOA measurements over time are linked to the transmitter location through modeled physical laws, geolocation solutions are also available for other combinations of measurement types. For example, geolocation of CW transmitters are possible from a series of FDOA measurements, with reduced accuracy compared to what would have been available with corresponding TDOA measurements that are accessible from a broadband signal. Alternatively, use of a third satellite to generate a second set of TDOA and/or FDOA measurements can also provide improved solutions, however, this comes at the expense of greater use of receiver antenna resources. TDOA-only solutions are possible by using a third satellite, but the surfaces of constant TDOA derived from two satellite pairs are nearly parallel making their practical use more dependent on TDOA measurement precision or take more time when gathering measurements.

In practice, the accuracy of the satellite ephemeris of each of the two satellites limits the accuracy of the geolocation solution. Improved geolocation performance is achieved through TDOA and FDOA measurements of separate transmitter signals, sometimes referred to as reference locators, which originate from known locations and pass through the same pair of satellites as the signal of interest. These reference locators are used to refine the orbital ephemeris of one or both of the satellites which, in turn, improves the accuracy of the estimate of the location of the transmitter signal of interest.

5.1.2.7.3 Uncertainty analysis

The goal of uncertainty analysis of a geolocation problem is to provide a realistic appraisal of the accuracy of a geolocation solution.

Providing accurate uncertainty analyses can sometimes be complex and difficult. The precision of the individual TDOA and FDOA measurements are both proportional to the square root of the *S/N* obtained in the correlation solution. The precision of TDOA and FDOA measurements are also proportional to the signal bandwidth and measurement time, respectively. The least squares geolocation solution provides formal error estimates and confidence intervals of the location of the transmitter of interest that are based on the uncertainties assigned to the TDOA and FDOA measurements. The reliability of these TDOA and FDOA uncertainties can be checked statistically against their corresponding measurement residuals. Alternatively, if a sufficient number of TDOA and FDOA measurements are available, the uncertainties in the TDOA and FDOA measurements can be estimated by the same solutions procedure. An example of error analysis is given by Bardelli *et al.* [1995].

Two caveats must also be given. First, the uncertainties in the TDOA and FDOA measurements may be large enough so as to invalidate the assumption that the solution is linear in the spanned region of the parameter space. This means that the formal errors generated by the geolocation algorithm that are based on linear statistical analysis are less accurate. Monte Carlo techniques may be employed to generate better uncertainty estimates in these cases.

Secondly, formal uncertainties account for random error and only partially for any systematic errors. Systematic errors can arise, for example, through incomplete modeling of the physics of the TDOA and FDOA measurements or in the force model used to produce the satellite ephemeris. The impact of systematic errors can be assessed by very thorough simulation of the geolocation technique and all of its systematic error sources.

There are several potential inaccuracies resulting in a location error. The error can be substantially reduced by using reference transmitters whose geographical coordinates are exactly known (see Fig. 5.1-5).

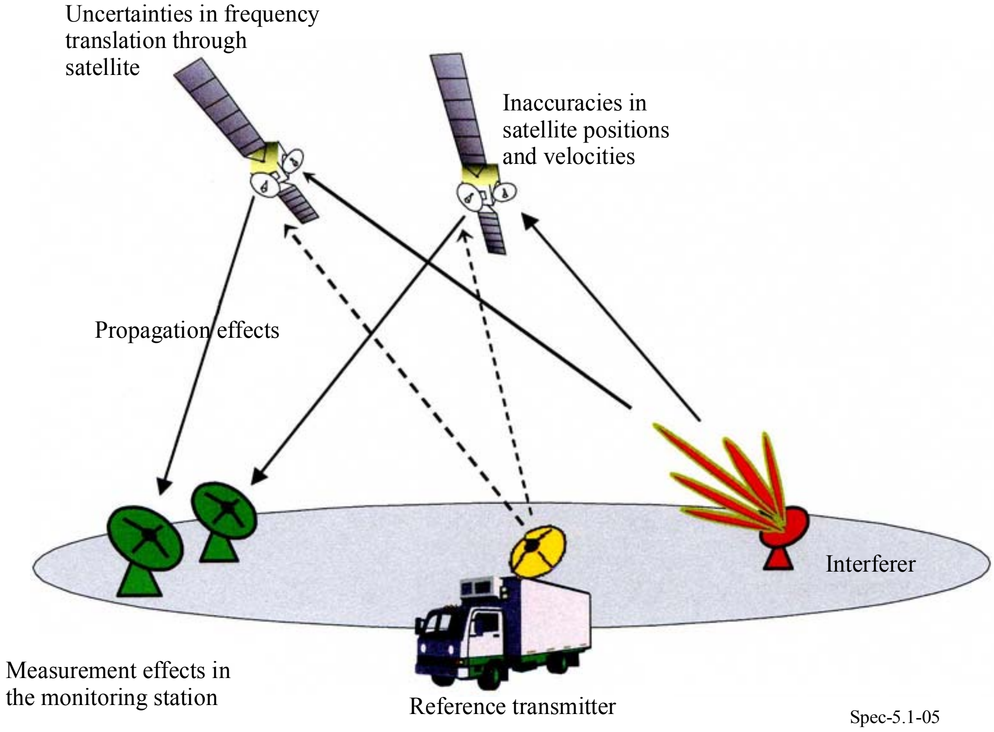
Reference stations deployed over a huge area can eliminate errors due to ephemeris inaccuracies, whereas the use of reference stations located in the vicinity of the interferer can minimize the location error (see § 5.1.5.4.5 and § 5.1.5.4.6).

5.1.2.8 Geolocation of transmitters on Earth using a single GSO satellite and inverse Doppler shift

The location of a transmitter (or interference) on the surface of the Earth may be determined under certain conditions using the transmitted signals relayed through a single GSO communications satellite. The small Doppler shift on the signal carrier frequency, which is induced by the slight motion of the satellite relative to the Earth during an orbit can be exploited to estimate the location of the transmitter to the point (within tens of kilometres) that mobile units may be deployed to pinpoint transmitter or interference location. The technique uses measurements of the carrier frequency giving infrequent, short transmissions distributed over several hours. Super resolution techniques and signal processing are used to estimate the small Doppler shift in the transmitted signals with the needed degree of accuracy. Predictions of the position and velocity of a satellite can be refined using a reference transmitter.

FIGURE 5.1-5

Geolocation of transmitters on Earth using TDOA and FDOA from two GSO satellites using a reference transmitter



Non-zero inclination and eccentricity of a GSO orbit induces some motion in the satellite relative to the surface of the Earth. This motion induces a small Doppler shift, which can be exploited to estimate the location of the transmitter. The technique even makes use of observations of infrequent and short transmissions scattered over a period of several hours. The carrier frequencies of the transmissions must be measured with very high precision in order to use this method. A non-linear iterative estimation technique is then applied. See § 5.1.2.8.3 and Fig. 5.1-6 for a description of GSO satellite excursions.

For all these reasons, the implementation of the geolocation method using one satellite is very difficult. Moreover, it imposes assumptions on the transmitter itself that are generally not met, such as:

– ultra stable local oscillator of the transmitter during a long period of time;

– emission of the transmitter during a long period of time.

5.1.2.8.1 Geolocation algorithm

The geolocation algorithm utilizes a mathematical expression (f_R) to predict the carrier frequency of a signal that is relayed through a GSO satellite. The expression incorporates the known position and velocity of the satellite and the location of the receiver, as well as the unknown location of the sought transmitter. The effects of uplink Doppler shift, frequency translation within the satellite transponder, and downlink Doppler shift must be taken into account.

All vector quantities are expressed in the three-dimensional Earth-centered Earth-fixed Cartesian coordinate system:

$$f_R = \left[f_T \cdot \left(1 + \frac{\vec{v}_S \cdot (\vec{r} - \vec{r}_S)}{c \cdot \|\vec{r} - \vec{r}_S\|} \right) + \Delta_f \right] \cdot \left(1 + \frac{v_D}{c} \right) \qquad (5.1\text{-}7)$$

where:

f_R: carrier frequency of the received signal

f_T: carrier frequency of the transmitted signal

v_S: velocity vector of the satellite at the observation time

r_S: position vector of the satellite at the observation time

r: position vector of the transmitter

Δ_f: frequency translation in the satellite transponder

v_D: scalar range rate between the satellite and the receiver

c: propagation velocity of the signal.

Equation (5.1-7) is a function of known and unknown parameters. The known parameters consist of the position and velocity of the satellite, frequency translation, and the range rate between the satellite and receiver. The satellite position and velocity and range rate are dependent on time. The unknown parameter set consists of the location and carrier frequency of the transmitter. Measurements of the actual carrier frequency of the signal at the receiver are made at several observation times. The geolocation algorithm estimates a set of unknown parameters such that the sum of square errors between the measured carrier frequency and the carrier frequency predicted from the expression is a minimum.

The geolocation algorithm uses a linearized version of the received frequency expression, which is a first-order multi-dimensional Taylor series expansion of equation (5.1-7). A set of linear equations can be formed using this expression and assembled as the matrix equation:

$$E = A\Delta \tag{5.1-8}$$

where E is the column vector of measurements of the carrier frequency of the received signal at each of the observations times, and $A = [A_f A_x A_y A_Z]$ where each column vector A_i is the derivative of the expression with respect to the parameter i, computed at each observation time, and Δ is the vector of errors between the true parameter values and their initial estimates. The matrix equation is solved for the vector Δ in a linear least squares sense and this error vector is used to iterate and refine the initial parameter estimates. Since the linear equation used is only an approximation to the model, several iterations of the process are performed, using the most recently obtained parameter estimates for each step. The parameter values converge to the final frequency and location estimates.

5.1.2.8.2 Frequency (Doppler) measurement

Since a GSO satellite moves slowly relative to a fixed Earth point, the Doppler shifts observed in a communications link are small, of the order of tens of Hertz. Accurate geolocation is therefore dependent on very accurate carrier frequency estimations (rubidium standard is sufficient).

The MUSIC (multiple signal classification) algorithm may be used for frequency estimation. The resolution of the frequency estimator is limited only by machine precision and not by the length of the data set. The accuracy of the estimates is constrained by the *S/N*. The MUSIC algorithm produces a much more precise frequency estimate than fast-Fourier-transform-based algorithms.

5.1.2.8.3 Position and velocity correction

Accurate geolocation results are dependent upon accurate knowledge of the position and velocity vectors of the satellite at every time of observation. These vectors are typically computed using an orbit propagation model and a set of six orbital elements that describe the orbit of the satellite. These elements are periodically updated based on observations of the satellite and the updated element sets available. Orbit propagation algorithms model the gravitational effects of the Earth, Sun, and Moon to predict the position and velocity of the satellite for times later than the time at which the elements are computed. There are forces that affect the motion of a satellite that are not modeled. Therefore, the resulting position and velocity estimates become less accurate as the time difference between the prediction time and the time the element set was updated becomes large. The frequency translation within the satellite transponder is also imperfectly known.

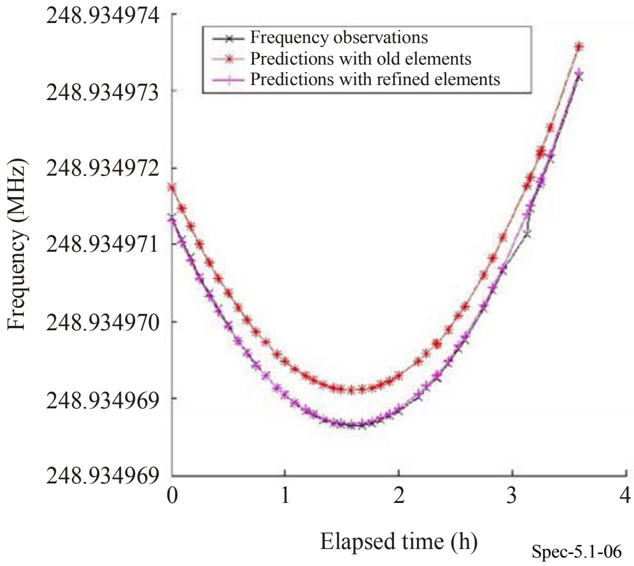
It is necessary to refine the satellite position and velocity predictions and the translation frequency to improve the accuracy of location estimates. A reference transmitter at a known location and with a known carrier frequency can be used to refine these values. The reference transmitter should relay signals through the satellite during the same period that signals of interest are observed. The carrier frequency of each of the reference signals observed at the receiver is computed in the same manner as a target signal. These observed reference frequencies are then compared to frequencies that are predicted by evaluating the expression with the known location of the reference transmitter and initial estimates of the set of orbital elements and the translation frequency to refine the results. Figure 5.1-6 illustrates the improvement in frequency predictions obtained with the refined orbital elements and the refined translation frequency.

5.1.2.9 Frequency occupancy measurements and GSO orbit position occupancy measurements

Preparations in the planning of new satellite systems should include specific investigations into the occupancy of the downlink frequencies by other satellite systems. This applies in general, since it cannot always be assumed that utilization of frequencies has been subject to coordination or notification. Such occupancy measurements are therefore valuable in order to avoid unexpected interference.

FIGURE 5.1-6

Improved frequency predictions with orbital element refinement



Automatic radio frequency spectrum recording equipment has proved to be very useful for monitoring low orbiting satellite emissions. Using non-directional or hemispheric-shaped beam antennas, the results obtained over a period of several days permit the determination of the occupancy of the frequency band by satellite emissions. In addition, the approximate determination of the satellite frequencies is possible, as are the expected times of reception and the computation of the period of revolution with a good degree of accuracy. One example of a frequency spectrum record is given in § 5.1.7.1.

General frequency occupancy monitoring methods using low-gain antennas are as a rule, not suitable for frequency bands above about 3 GHz. For low pfd signals, directional antennas with adequate antenna gain are required. In the case of GSO space stations, however, occupancy measurements are possible which:

– determine the positions occupied by space stations; and

– provide frequency and time-related data regarding the occupancy of frequency bands at occupied positions.

In order to identify occupied positions, an inter-active process is recommended to steer the directional antenna used for reception along the GSO orbit within its half-power beamwidth, during which measurements are continuously taken from the analyzer used for the signal processing to monitor crossing of the threshold values. After scanning the orbit segment visible to the radio monitoring station, the analyzer is switched to the next frequency sub-band and the whole process is repeated.

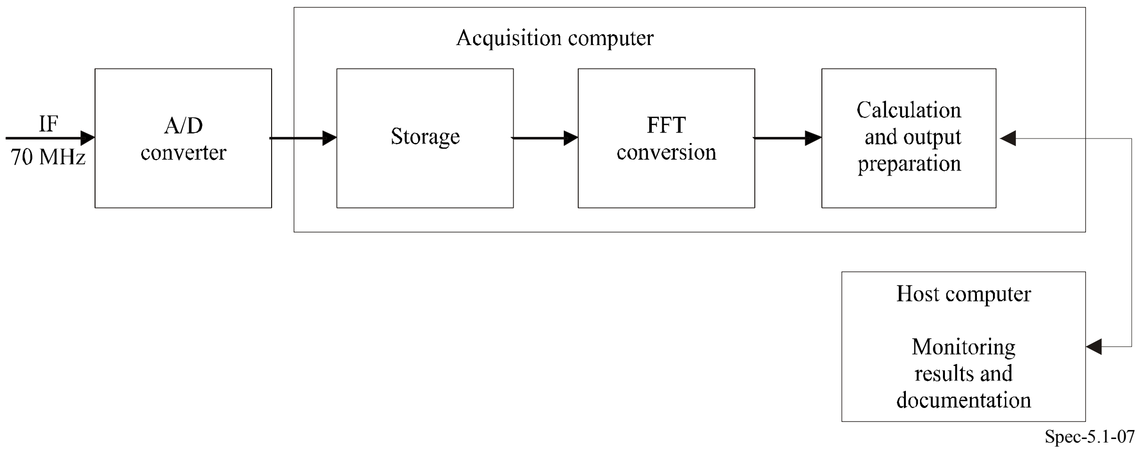
The time and frequency-related occupancy measurements for a pre-determined position allow for variations, which should be coordinated precisely with the target selected. One example is illustrated in § 5.1.7.3.

5.1.2.10 Measurements below the noise floor

Often there is a need to analyse weak radio signals or parts of signals which are hidden below the noise floor. Especially space radio emissions suffer from this situation. Recommendation ITU-R SM.1681 – Measuring of low-level emissions from space stations at monitoring earth stations using noise reduction techniques was developed to solve this problem. Figure 5.1-7 shows the typical block diagram for such measurements.

FIGURE 5.1-7

Block diagram for monitoring below the noise floor



The measurement of low-level emissions below the noise floor is based on an integration method which subtracts the noise spectrum from the signal.

The IF signal is sampled by an analogue/digital converter and stored on a hard disc. This measurement is repeated typically 10 000 times in order to acquire 10 000 recorded samples. Immediately thereafter, the antenna is pointed to an adjacent orbit position with the satellite outside the antenna beam thus receiving the noise only under the same environmental conditions. Another 10 000 samples are taken and stored on the hard disk. Both 10 000 sample lines are linearly averaged and subtracted from each other. This results in a noise reduction of typically 10 to 20 dB.

It should be noted that an excellent frequency stability of the whole receiving path is necessary. Also, any noticeable satellite Doppler frequency shift must be eliminated or deducted.

5.1.3 Equipment and facility requirements

The purpose of the following paragraphs is to highlight some system characteristics. Further details regarding figure of merit, antenna systems, antenna steering and auto-tracking are contained in the Handbook on Satellite communications (fixed-satellite service), and in the publications listed in the Bibliography.

5.1.3.1 General

The technical concept of a radio monitoring station for space services is essentially determined by the tasks to be performed in accordance with the specific needs of the administration. New developments in the field of space services should be taken into consideration during the planning of the concept. Some important aspects are listed in Table 5.1-2.

TABLE 5.1-2

Tasks and their sphere of influence with respect to the technical concept of the monitoring station for space services

No.	Task	Sphere of influence
1	Which part of the frequency spectrum should be able to be monitored?	Number and kind of antenna systems
2	Which satellite systems should be included in the monitoring? Which power flux-densities do these systems produce at the locality of reception? What *C/N* should be achieved?	Figure of merit of the receiving system (antenna gain, system noise temperature)
3	Should position determination of GSO satellites be possible?	Pointing accuracy, kind of antenna steering, receiver concept
4	Should determination of orbital elements of non-GSO satellites be possible?	Pointing accuracy, kind of antenna steering, acceleration and antenna steering velocity, receiver concept
5	Should determination of polarization characteristics and measurements in case of dual polarization systems be possible?	Antenna feed system

The required measurement accuracies, e.g. for frequency and pfd measurements and in particular for angle measurements for the determination of the position of GSO space stations or the orbital elements of non-GSO satellites, are of special importance.

In general, as in more conventional monitoring stations, equipment for monitoring signals from space stations must have adequate flexibility to tune over a wide range of frequencies, in contrast to the spot frequency coverage that suffices for the needs of a research or operational space agency.

5.1.3.2 Figure of merit of a space monitoring system

The achievable *C*/*N* on reception of an emission from space depends on the following factors:

– the pfd of the signal at the reception site;

– the gain of the receiving antenna; and

– the system noise temperature of the receive system.

The figure of merit, *G*/*T*, of a receiving system is the ratio between the gain of the receiving antenna in the direction of the received signal and the receiving system noise temperature as set out in equation (5.1-9).

$$\left(\frac{G}{T}\right) = G - T_{RS} \tag{5.1-9}$$

$$\left(\frac{G}{T}\right) = \left(\frac{C}{N}\right) - \text{pfd} - 10\log\left(\frac{\lambda^2}{4\pi}\right) + 10\log\left(kB\right) \tag{5.1-10}$$

where:

- G/T: figure of merit (dB(K^{-1}))
- G: antenna gain (dBi)
- T_{RS}: system noise temperature of receiving system (dB(K))
- C/N: wanted carrier-to-noise ratio in measurement bandwidth, B (dB)
- pfd: pfd in measurement bandwidth, B (dB(W/m^2))
- $\lambda^2/4\pi$: effective area of an isotropic antenna (m^2)
- k: Boltzmann's constant (1.38×10^{-23} J/K) (W/Hz)
- B: measurement bandwidth (Hz).

In the case of the fixed-satellite service, the link conditions for a planned system are known exactly. The required G/T for a given C/N can be calculated by using equation (5.1-10). The measurement bandwidth is equivalent to the receiving bandwidth. It is up to the system developer to decide whether a required G/T should be achieved by means of an increase in the antenna gain, or a reduction in the noise temperature.

Such clarity of conditions cannot be expected for the space monitoring activity. The method used is, however, similar. The desired G/T is calculated on the basis of the lowest pfd values of those space stations for which the technical analysis of their emission characteristics is regarded as necessary for the monitoring station.

Direct measurement of G/T of a space monitoring system is preferred to taking the ratio of separately measured G and T, because the opportunity for error is reduced. Separate measurements of G and T also require the use of a signal generator, which unnecessarily introduces an additional factor of uncertainty. The sun, rather than a radio star, is often used for G/T measurements for pfd calibration purposes at monitoring stations because of its much stronger signal. Should, however, the receiving system be sufficiently sensitive, use of radio stars would be better.

5.1.3.2.1 Terms defining *G/T*

The figure of merit is usually determined at 5° elevation and expressed in (dB(K^{-1})) units i.e., G/T (dB(K^{-1})) = 10 log (G/T numeric).

$$G/T\ (\mathrm{dB}(\mathrm{K}^{-1})) = \text{Antenna gain (dBi)} - 10 \log (\text{system noise temperature (K)}) \qquad (5.1\text{-}11)$$

or

$$G/T\ (\text{numeric})\ \frac{8\,\pi\, k r_1 r_2 f^2 (y_{sun} - 1)}{s c^2\, y_x} \qquad (5.1\text{-}12)$$

where:

- k: Boltzmann's constant (1.38×10^{-23} J/K)
- r_1: correction factor for atmospheric attenuation; for angles ≥ 5°, where:

$$r_1 = \text{antilog}\, \frac{\dfrac{A}{\sin\theta}\,(\mathrm{dB})}{10}$$

- A: one-way atmospheric absorption in decibels for a vertical path and θ is the Sun's elevation angle at the time of measurement
- r_2: correction factor for receiving antenna half power beamwidth relative to the angular diameter of the Sun where:

$$r_2 = 1 + \frac{401.4}{\vartheta_h^2} \text{ and } \vartheta_h^2 \text{ is the antenna half power beamwidth (min)}$$

f: frequency (Hz)

y_{sun}: measured values, expressed in numeric units, where:

$$y_{sun} = \text{antilog} = \frac{Y_{sun}(\text{dB})}{10}$$

s: Sun flux density obtained from a national standards laboratory; if the Sun flux density, s, at the frequency (f) of direct interest is not available, the following interpolation equation should be used, instead of linear interpolation, to obtain greater accuracy:

$$s = \left(\frac{s_1}{s_2}\right)^{R_2}$$

where:

s_1: flux at lower frequency (f_1), (J/m^2)

s_2: flux at higher frequency (f_2), (J/m^2)

$$R_2 = \frac{\log(f / f_2)}{\log(f_1 / f_2)}$$

c: velocity of light (3×10^8 m/s)

y_x: measured values, expressed in numeric units, where:

$$y_x = \text{antilog} \frac{Y_x(\text{dB})}{10}$$

5.1.3.2.2 *G/T* measurement procedures

A receiver of the type usually found at monitoring stations, having an IF output voltage indicator, e.g., voltmeter or oscilloscope, is required. It is highly desirable that the indicator has a voltage resolution of 0.1 dB (1%) or better. The receiver must be stable and have no significant gain changes during the measurement period.

For the measurements:

– the receiver automatic gain circuit should be switched off;

– the antenna should be pointed towards the Sun and maximum signal obtained. The Sun should have an elevation angle greater than about 30° to avoid atmospheric effects and to ensure that the correction factors r_1 and r_2 are minimally affected;

– the antenna should then be slewed, in azimuth only, away from the Sun, e.g., more than a few degrees. The IF voltage level should be noted. This voltage corresponds to the cold sky reference value;

– the antenna should then be returned in azimuth towards the sun and the voltage noted. The difference in readings equals Y_{sun} (dB); and

– the antenna should then be slewed, in elevation coordinate only, down from the Sun to 5° elevation and the voltage noted. The difference between this voltage level and the cold sky level is Y_x (dB) for x° of elevation. It should be noted that 5° of elevation (x°) is a common reference standard.

The *G*/*T* can then be evaluated using the measured values of y_{sun} and y_x and applying the correction values r_1 and r_2. The Sun flux density, s, can be obtained from a national standard laboratory.

Using the equation for *G*/*T*, the root-sum-square uncertainty of the measurement is of the order of < 0.5 dB.

It is necessary that the measurement procedures be carried out on a bright, sunny day.

5.1.3.3 Antenna systems

The antenna gain should be as high as possible in order to provide a good minimum sensitivity limit for the measuring equipment.

Helical antennas or dipole antenna arrays are suitable for the 100-1 000 MHz frequency range. As individual antennas, they provide a gain of about 12 to 16 dBi.

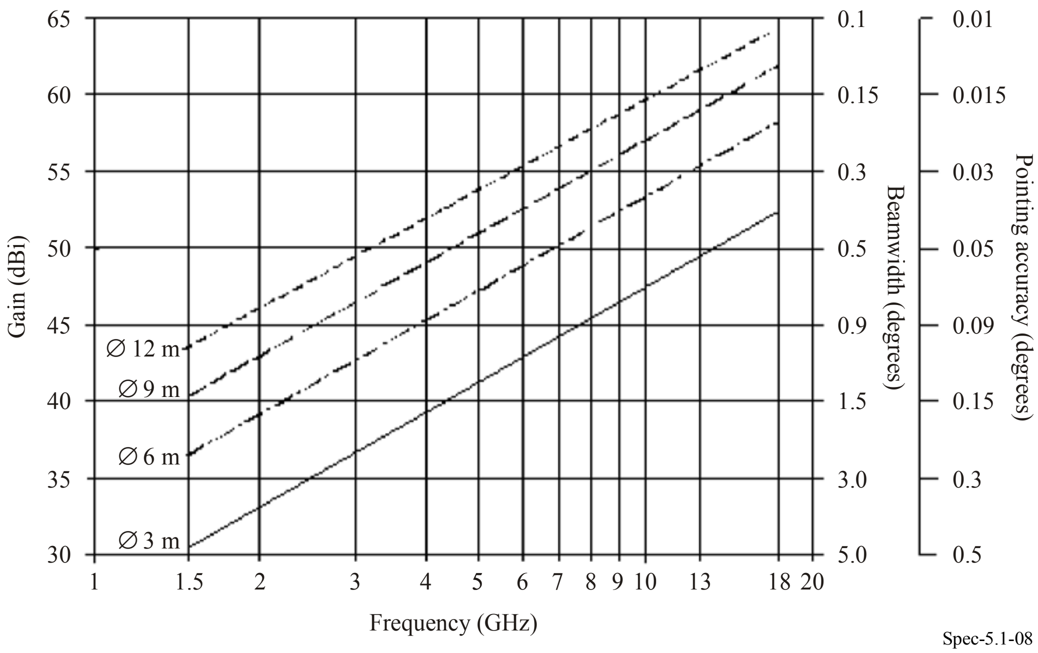
For the frequency range from 1 to 26.5 GHz, one parabolic reflector with one broadband feed at the prime focus is adequate. If optimised polarization and directivity characteristics are required, a design, which uses interchangeable feed system, is preferred. Examples for such technical solutions are given in § 5.1.6.1.

Figure 5.1-8 illustrates the antenna gain as a function of frequency for the different diameters of the parabolic reflector, assuming a typical antenna efficiency of 55%. The diameter of the reflector should be a minimum of 3 m. In this case, antenna gains ranging from 31 dBi at 1.5 GHz to 53 dBi at 18 GHz may be obtained. Extrapolation to higher frequencies is applicable. Generally, antennas with a diameter ranging from 6 m to 12 m are used.

In some cases, the use of log-periodic antennas may be of advantage. Antennas of this type provide good general coverage over a 10 to 1 frequency range and have been used for satellite monitoring on frequencies between 50 and 5 000 MHz. The disadvantage in this case is a frequency-independent and near-constant antenna gain, generally ranging below 10 dBi.

FIGURE 5.1-8

Antenna gain, 3 dB beamwidth and pointing accuracy as a function of frequency for the different diameters of the parabolic reflector and an antenna efficiency of 55%



Spec-5.1-08

5.1.3.4 Antenna steering

The antenna drive system should allow either manual or computer-controlled adjustment. If accurate position determination of GSO satellites is required or if the calculation of orbital elements of a space station based on angle measurements is seen as a required task, then autotracking is necessary. Step-track or monopulse tracking are the two possible solutions.

The step-track technique is based on measurements of the strength of the received signal in positions around the expected satellite position. By computation the optimum is found stepwise. The monopulse technique is based on the analysis of the wave type arriving in the tracking receiver. Only when the antenna is pointed directly towards the satellite, the expected wave type (waveguide mode) is produced. Other wave types produce the tracking information for proper pointing. The monopulse tracking is usable for GSO and non-GSO satellites and have no impact on the power measurements.

5.1.3.5 Antenna beamwidth necessary for angle measurements

The intention in this sub-section is to establish a relationship between the half-power (3 dB) beamwidth of an antenna and the achievable pointing accuracy. This is of interest with respect to auto-tracking techniques in those cases where the monitoring of the station-keeping of GSO space stations or the calculation of the orbital elements of non-GSO satellites are seen as a required task of a radio monitoring station (see § 5.1.2.6). Pointing accuracy is a measure of how well an antenna system determines the look angles (azimuth, elevation) of an object. In this respect, there is a difference between space monitoring and earth stations of the fixed-satellite service, since in the case of the latter, even a smallest possible relative alignment error (relative to the space station) is significant.

A relationship between the half-power beamwidth of an antenna and the maximum achievable pointing accuracy can be established:

$$R = n \cdot \theta_0 \tag{5.1-13}$$

where:

R: angle measurement error (degrees)

n: improvement factor

θ_0: half-power beamwidth (degrees).

For optimised narrow-band antennas, $n = 0.01$. For a broadband antenna of the kind generally used by a radio monitoring station for space services, a factor of 0.1 seems to be realistic if a monopulse system is used and 0.15 if a step-track system is used. The remaining variable, the half-power beamwidth is a function of the diameter of the reflector.

The suitable half-power beamwidth should be selected by taking into account the smallest longitudinal position tolerance of $\pm 0.1°$ as defined in the Radio Regulations. A tolerance of $\pm 0.1°$ of the longitude defines an angular segment of the equatorial orbital plane. In the restrictive case where a monitoring station is operated on the equator, position keeping would have to be checked by angle measurements in only the elevation plane of the antenna. When the monitoring station is shifted to the South or North, a rotation takes place in the azimuth plane of the monitoring antenna. In the case of 50° latitude, for example, this means that the longitudinal station-keeping tolerance of a GSO space station is predominantly measured as angular difference in the azimuth plane of the antenna. It reaches the value $\pm 0.13°$ for a longitudinal difference of 0° between monitoring station and sub-satellite point and drops to $\pm 0.085°$ for a longitudinal difference of 60°. The corresponding measurement error in this example is $\pm 0.01°$, i.e., smaller by a factor of 10 compared to the allowable tolerance.

Figure 5.1-8 contains values for the half-power beamwidth and the pointing accuracy of an antenna as a function of frequency and reflector diameter. It is clear that full implementation of position monitoring as a monitoring task is subject to restrictions, especially in the case of lower frequency bands. Less stringent requirements allowing the use of smaller antenna systems are permissible in such cases where only greater divergences or deviations in position-keeping, for example in investigations of harmful interference, are to be identified.

5.1.3.6 System polarization

For polarization measurements (§ 5.1.2.5) the characteristics of the antenna system should be carefully considered. As circular and linear polarizations are used in the frequency bands above 1 GHz and use of dual polarizations in the frequency bands of the fixed-satellite service is a standard technique, it is necessary that the polarization of the receiving system can be adapted to that of the received signal and that a sufficient polarization discrimination is achieved.

Apart from enabling the polarization characteristics of the received signal to be obtained, such a system will also provide for maximum antenna gain and maximum reduction in the crosstalk signals between the two orthogonal polarization planes, which is a requirement for most of the measurements indicated in § 5.1.2.

5.1.3.7 Receivers

For economic reasons and because general coverage is required at monitoring stations, the extremely low noise figures of the fixed-frequency receivers used for space research and operational purposes are not reached by tunable monitoring receivers. Nevertheless, the noise figure of the receiving system for a monitoring station for space services affects the total system noise figure. Its reduction to the lowest possible value is an important goal during the design phase of a monitoring station for space services. This is true even though it is possible in nearly all cases to improve the *S/N* by narrow band filtering of a part of the emission spectrum.

For frequencies below about 3 GHz, standard monitoring receivers may be used. Above about 3 GHz a microwave receiver system of modular design should be used to meet the various requirements. The conventional concept, where the receiver comes as a self-contained unit, cannot be used, as, due to the high cable losses in the microwave range, the front end of the receiver must be situated close to the antenna, whereas the low-frequency modules and the control facilities can be located in the operating room. An example of a receiving system specifications for C and Ku bands is given in Table 5.1-3.

TABLE 5.1-3

Example of receiving system characteristics

Tuner and synthesizer	
Frequency range	1-18 GHz with several overlapping tuners
Receiving frequency bandwidth	Centre frequency: ± 50 MHz
Frequency error	$< \pm 2.5 \times 10^{-8}$
IM-free dynamic range	> 66 dB (1 MHz bandwidth)
Oscillator phase noise	<–90 dBc (Hz) (10 kHz from carrier)
Broadband receiver	
Minimum tuning step	1 kHz
IF filter bandwidth	0.05/0.3/1.25/2.5/5/10/20/40 MHz

In the case of automatic methods for Doppler shift measurements, where a frequency counter is required, the receiver has to deliver a noise-free output signal, which accurately represents the satellite carrier frequency. For this purpose, the receiver must provide phase-locked synchronization to the satellite carrier frequency. The bandwidth of the loop should be able to be switched between a few hertz and a few hundred hertz. The output frequency of such a phase-locked circuit may also be used as a pilot frequency for the adjustment of the frequency of a second receiver during bandwidth measurements, as outlined in § 5.1.2.3.

For more general purposes, if a satellite signal without a carrier has to be received, and if the pfd of this signal is sufficient, an automatic frequency tuning device may be used to avoid distortion of bandwidth and pfd measurements due to Doppler shift in the received signal frequency.

The following receiver outputs should be provided to facilitate the taking of measurements: wideband and narrow-band intermediate frequency outputs, video frequency, audio frequency and baseband (AM/FM) outputs. The intermediate frequency should be the same for all the receivers of a measuring installation so that the same auxiliary equipment may be used with all the receivers.

5.1.3.8 Peripheral equipment

5.1.3.8.1 General equipment

Table 5.1-4 contains a list of some peripheral equipment, which is necessary for the above-mentioned measurements, and other useful equipment, which can be added to the receiving system.

TABLE 5.1-4

Peripheral equipment

Necessary peripheral equipment		Additional peripheral equipment	
Type of equipment	**Function**	**Type of equipment**	**Function**
Frequency/time standard	Central reference	TV demodulator	Demodulation of FM- and digitally-modulated TV carriers
Frequency counter	Doppler shift frequency measurements	TV decoder	Decoding of TV baseband signals (NTSC, PAL, SECAM, HDTV)
Time divider	Timing pulse for frequency counter		
Signal analyzer	Spectrum analysis, band-width measurements	Sound carrier demodulator	Demodulation of TV sound subcarriers, tunable
Power meter	pfd measurements		
Signal generator	Reference pfd measurements	Modulation analyzer	Identification of types of modulations, modulation measurements
Recorder	General purpose		
Digital oscilloscope	General purpose		

5.1.3.8.2 Analyzer

The spectrum analyzer has proven to be one of the most powerful instruments not only for general monitoring, but also for space monitoring purposes. To enable it to be used for monitoring tasks, the spectrum analyzer should be able to work interactively with other equipment under computer control.

To perform real time spectrum display and power measurements, a digital FFT or vector analyzer can be used. The bandwidths and the appropriate filter curves for the different modulations (FM, QPSK, etc.) can be chosen by programming digital filters. FFT analyses show a real-time spectrum and do not need a significant period of time to sweep over the signal bandwidth like conventional spectrum analyzers.

5.1.3.9 Broadband RF or IF monitoring channel

It is recommended for the technical design of the receiving system of a monitoring station for space services to allow for the broadband monitoring of the radio frequency spectrum. Simultaneous analysis of a minimum bandwidth of 500 MHz should be provided for.

5.1.3.10 Radio-frequency spectrum recording equipment

The technical characteristics of the recording equipment for space monitoring (see § 5.1.2.9 for reference) correspond to those required for terrestrial monitoring purposes. Since non-directional antennas of preferably linear polarization have to be used, the loss in antenna gain has to be compensated for by selecting a small bandwidth for the recording equipment. As a general rule, and particularly for graphical recording units, the total analyzed spectrum bandwidth should not exceed 2 MHz.

5.1.3.11 Computer requirements

Computer requirements should be seen as an integral part of a monitoring station for space services. They can be used, for example, for:

– calculation of orbital elements;

– calculation of antenna pointing angles from orbital elements;

– antenna steering;

– storage of measurement results; and

– evaluation of measurement results.

5.1.4 Documentation and database support to space monitoring

5.1.4.1 General considerations of documentation and database

Successful operation of a monitoring station for space services depends on the continual update of paper or electronic documentation. Preferably these would take the form of a database system containing not only the data officially published by the ITU, i.e.,

– BR International Frequency Information Circular (BR IFIC) on CD-ROM;

– Space Network List (Online or on CD-ROM);

– Space Radiocommunication Stations on DVD-ROM; and

– Radio Regulations, paper or CD-ROM;

but also a survey of all satellites in orbit, together with some of their most important orbital elements (time of revolution, inclination, apogee, perigee). The data of earth stations licensed by the administration are valuable in earth station geolocation, especially in identifying the unauthorized users of the spectrum.

To facilitate monitoring operations, it is necessary to establish a database in order to record two kinds of information. One is general information of all satellites of interest, and the other is the characteristics of the satellites that will be obtained by monitoring.

5.1.4.2 General information database of existing satellites

The general information database of existing satellites mainly describes the characteristics and the licensed space service of a satellite within the monitoring capacity of the station. The most important information includes:

– satellite orbital information, including nominal longitude of a GSO satellite, longitude tolerance, ephemeris information of a non-GSO satellite, etc.;

– transponder information, including number of transponders, bandwidth of transponders, frequency range, beacon frequency, maximum antenna gain;

– satellite beam information, including beam coverage, service area, maximum power (dBW/m^2).

Additionally, the following satellite information is useful for the geolocation of earth stations:

– geographic information, including longitude, latitude and altitude, etc.;
– antenna information, including antenna size, gain, antenna pattern, etc.;
– other information, including frequency assignment, bandwidth, polarization, transmitting power, service type, modulation type, work time, etc.

Sources for the above information can be satellite operator(s), the administration(s), and public media.

5.1.4.3 Monitoring information database

The monitoring information database is used to record the measurement result of space monitoring station. The measurement result should include some key parameters, such as frequency, polarization, bandwidth, pfd, modulation type, etc. A long term occupancy analysis of spectrum can facilitate spectrum planning.

To facilitate data exchange between monitoring stations, the parameters of monitoring itself, such as position of antenna, antenna parameters, measurement time and weather, etc., should be recorded in the database.

5.1.4.4 Using documentation and databases to facilitate monitoring

In monitoring, documentation and databases support the following aims:

– Identifying space stations

Space stations can be identified through a comparison between the general information database and monitoring data. A detailed introduction to the process of identifying space stations will be given in the following section.

Identifying illegal emissions

Monitoring engineers can identify illegal emissions through comparison of corresponding entries in the general information database which have been approved by the administration. This can be achieved automatically by monitoring systems. This is only applicable when the approved data of the carriers is available to the administration.

Facilitating the geolocation of emissions

Database systems can remarkably improve the efficiency of geolocation missions. Analysis can be performed based on the information in the database, including:

– adjacent satellite analysis;
– reference signal selection;
– potential interferer analysis.

In addition, Geographic Information System (GIS) plays an important role in space monitoring, a joint system of station database and GIS database can give the monitoring engineer an overview of the use of the spectrum. Such a joint system can be used in the analysis concerning potential interferers to space stations.

5.1.5 Identification of space stations and geolocation of earth stations

The identification of a space station is generally based on the comparison of the measured emission and orbital characteristics with those found in the reference database and documentation. Reference characteristics consist of a list of the emissions and orbital characteristics of all space stations, which have been published or made available to the monitoring service. The unknown station is identified by the iterative elimination of those stations, which do not correspond to the measured characteristics. Reference characteristics are given in Table 5.1-5.

With the wide use of GSO satellites, it is necessary for administrations to be able to identify earth stations transmitting toward GSO satellites, to acquire complete information of the use of earth stations and eliminating harmful or illegal emissions. When using the geolocation method described in § 5.1.2.7, positional inaccuracies typically can be tens of kilometres. This accuracy may be sufficient when identifying emissions from legitimate users, as for illegal emissions, other terrestrial monitoring means may be required to finally pinpoint and eliminate the interference.

TABLE 5.1-5

Reference characteristics

Emission characteristics	Orbital characteristics
Frequency	Ephemeris data, or, if not available:
Bandwidth	– period of revolution
Type of modulation	– angle of inclination of orbit
Polarization	– perigee and apogee distances
e.i.r.p.	– equator crossing time and longitude of crossing

5.1.5.1 Monitoring results to be used for identification

5.1.5.1.1 Evaluation of frequency band recordings

With reference to § 5.1.2.9 and to the example given in § 5.1.7.1, approximate values for the following space station characteristics can be obtained from frequency band recordings:

– frequency;

– expected time of reception for non-GSO satellites; and

– period of revolution.

5.1.5.1.2 Calculation of period of revolution

For the calculation of the period of revolution with an accuracy level of several seconds, it is possible to obtain an initial approximate value by measuring the TCA times of two successive paths. A refined result is then based on additional TCA measurements over a period of one or two days.

5.1.5.1.3 Direction-finding (DF)

To complement the determination of the exact TCA of a satellite to a monitoring station, a curve can be plotted to show the change in direction of arrival of the signal with time, as determined by DF bearings or orientation of a highly directional receiving antenna. The maximum angular rate of change will occur when the satellite is nearest to the monitoring station during a particular pass, and the information obtained by this method should agree with the information obtained from the Doppler shift curve.

DF measurements are well suited for the determination of the TCA in cases where a carrier frequency does not exist within the spectrum. However, DF measurements require sufficient pfd at the receiving point.

5.1.5.1.4 Calculation of ephemeris data from antenna angle measurements

If a monitoring station is equipped with an auto-tracking antenna system, angle measurements in the azimuth and elevation planes may be used to calculate the ephemeris data of the unknown satellite [Montenbruck, 1989] and [Montenbruck and Pfleger, 1991]. Software to carry out the calculations is commercially available.

The accuracy in determining the ephemeris data depends on:

– overall angle measurement accuracy (§ 5.1.3.5);

– orbit segment used for angle measurements;

– type of orbit of the satellite.

A significant operational problem is the need to point the antenna quickly at a non-GSO satellite soon after its entry into the visibility range of the monitoring station. While the need to obtain accurate angle measurement requires highly directional antennas, their use increases the difficulty of searching for and finding a LEO satellite, since the portion of the orbit that can be used for measurements is less than the total visible orbit. One example illustrating the calculation of orbital elements on the basis of angle measurements is found in § 5.1.7.2.

5.1.5.1.5 Emission characteristics

Measurements of the emission characteristics as outlined in the sections above may be sufficient for the identification of a space station. This is particularly the case for those space stations which are operated in accordance with the Radio Regulations and whose emission characteristics are notified or published.

5.1.5.2 Identification procedure

If the measured emission characteristics do not result in the identification of a space station, the measured ephemeris data, or parts thereof, may be of help.

When comparing the measured ephemeris data with the published reference data, the orbiting objects with the most similar data are selected first. Subsequent step-by-step comparison of the data should result in a significant reduction in the number of objects to be considered. Finally, by calculating the visibility times and the TCA for the remaining objects and by comparing them with the monitored results, it should be possible to achieve correct identification.

5.1.5.3 Other possibilities for identifying space stations

The procedures that have been discussed so far for the identification of space stations have been based on comparing the measured and observed signal characteristics with published information, and by comparing the measured ephemeris data or parts thereof (time of revolution, inclination angle, TCA) with published ephemeris data. This procedure is, however, time consuming and requires access to the ephemeris data of the objects in orbit.

In some cases, particularly when non-compliance with the Radio Regulations or where cases of harmful interference are observed, an additional procedure may be useful. In these cases, the monitoring station for space services could log all possible information concerning frequency and bandwidth measurements and other emission characteristics, together with ephemeris data, or parts thereof, and request identification based on this data from identification and tracking centres or from satellite network operators.

5.1.5.4 Operational considerations regarding the geolocation of uplinking earth stations toward GSO satellites

At present, there are commercial geolocation systems available from different manufacturers, these systems use the principles described in § 5.1.2.7 to geolocate uplinking earth stations toward GSO satellites, and are adopted by some satellite operators and administrations. Certain operational considerations of these systems are presented in this section.

At the outset, the operator of the geolocation system should first determine the nature of the unknown signal. This can be done in two ways: by means of other monitoring facilities, or obtaining information from the satellite operator. Next, an adjacent satellite is required for the test. The operator may have multiple choices when evaluating candidate adjacent satellites. He should also input other required information into the geolocation system. Usually a number of reference signals are required to either cancel the drifts in the oscillators on board the two satellites, or be used in the geolocation algorithm to correct position fix inaccuracies as a result of ephemeris errors.

5.1.5.4.1 Acquisition of necessary information

The operator should identify some useful information regarding the signal under test. For example, the satellite carrying the unknown signal, the frequency plans of its transponders, the centre frequency, bandwidth, duty cycles (for intermittent signals) and the frequency mobility characteristics of the unknown signal. Based on this information, the operator will select the appropriate observing parameters to optimize the likelihood of successful geolocation.

The above information can be acquired by other monitoring means, or, if the unknown signal is creating harmful interference, provided by the victim.

It is also helpful to record the interfered with transponder of the satellite with a spectrum recorder as soon as possible after the interference is reported to the monitoring station in order to "see" the activities of the interferer and the transponder occupancy.

5.1.5.4.2 Adjacent satellite selection

There may be more than one suitable satellite that can be used as an adjacent satellite. The primary consideration is to ensure that the selected adjacent satellite has the proper uplink and downlink connectivity.

From the known downlink frequency and polarization of the unknown signal, the operator may deduce what are the corresponding uplink frequency and polarization of the unknown signal. In the case where either hemispherical or spot uplink beams are used, the uplink beam pattern may limit the geographical region from which the unknown signal is likely to originate. The operator should keep in mind, however, that large uplink antennas residing outside of the main beam pattern of the satellite uplink beam interference may cause interference as well.

When considering the unknown signal's uplink frequency and polarization, as well as the beam coverage of the primary satellite's uplink antenna, the candidate adjacent satellite(s) can be determined. The criteria for selecting the adjacent satellite are the following:

– Same uplink frequency coverage as the primary satellite.

– Same uplink polarization as the primary satellite.

– Similar uplink beam coverage as the primary.

– Angular separation from the primary satellite along the geostationary arc.

– Transponder does not use on-board processing (OBP).

The primary selection criteria listed above are ordered roughly according to their relative importance. The first two criteria, uplink frequency, uplink polarization and downlink beam coverage, are absolute prerequisites for successful measurements.

Once the operator has identified one or more candidate adjacent satellites based on the above-mentioned criteria, secondary criteria can be used to help make a final selection. The secondary criteria include:

– Availability of adequate reference signals for the primary/adjacent satellite pair.

– Quality of the ephemeris data available for the adjacent satellite.

– Presence/absence of signals in the transponder of the adjacent satellite corresponding to the frequency of the interfering signal.

In making the final choice of adjacent satellite, the operator should keep in mind that the optimum geometric solution will be obtained for satellites with good quality current ephemeris data and an adequate selection of reference signals for the satellite pair to be used.

Reference signals may appear on either the primary or adjacent satellite. If adequate reference signals are available on the primary satellite, this criterion need not drive the selection of the adjacent satellite. Dedicated reference transmitters, fixed or transportable, can also be used to improve the geolocation results.

An additional factor that may influence the selection of an adjacent satellite is the orientation of the FDOA lines for the chosen satellite pair at the time of measurement. Unlike the TDOA lines, the orientation of the FDOA lines for a given satellite pair can vary significantly over the course of one orbital period (1 day).

The best choice is to find an adjacent satellite without signals in the vicinity of the interfering signal and the reference signals. To observe the actual transponder activities it is recommended to record the transponder of the adjacent satellite using a frequency spectrum recorder facility.

If the measurements are taken when the FDOA lines are nearly parallel to the TDOA lines, the resulting area will be highly elongated along the lines of constant TDOA. In such circumstances, the operator should consider either choosing a different adjacent satellite or scheduling additional measurements at a time when the FDOA line orientation is more favourable.

5.1.5.4.3 Reference signals

An ideal reference signal is a full-time broadband signal uplinking from a precisely known geographic location, which produces a strong correlation between the two satellites being used. This precise location can be obtained from the earth stations database, but it is preferable to double-check using a portable GPS receiver. In cases when reference signals are abundant, the operator should try to use reference signals:

– uplinking from a relatively small antenna;

– which are well distributed geographically;

– with suitable modulation;

– whose frequency is from unused transponder sections of the adjacent satellites.

5.1.5.4.4 Ephemeris data

The quality of the ephemeris data for both the primary and adjacent satellite will directly impact the quality of the result. In most cases, the error in the ephemeris can be eliminated to a large extent by using two or more reference signals (see § 5.1.2.7.2 for detailed information). If the ephemeris data is particularly bad, as may be the case immediately following orbital manoeuvres or when the epoch of the ephemeris data is several days prior to the date of the measurements, position uncertainties as large as several hundred kilometers may result. In this case the operator should strive to either obtain better ephemeris data or use an alternate adjacent satellite.

The operator of the geolocation system can acquire ephemeris data as follows:

– Data requested from satellite operator(s)

– Download published data from websites.

Then check the ephemeris data with a geolocation measurement of a known (e.g., reference) station. If the quality of the result is not sufficient, an ephemeris error compensation can be applied. This is one possibility to compensate satellite ephemeris errors. With three or more reference stations geolocation measurements can be carried out. The ephemeris error compensation corrects the ephemeris data with an inverse calculation of the geolocation measurements.

5.1.5.4.5 Establishment of dedicated supplementary reference transmitters

The operator of the geolocation system may find the number and the geographic distribution of reference signals not sufficient to yield accurate results in some circumstances. On some satellites, most of its users are located in one or two major cities, which significantly limits the number of reference signals available for geolocation. Therefore, it is necessary for administrations to establish a number of dedicated supplementary reference transmitters to provide the operator of a geolocation system with more choices in terms of reference signals. These transmitters should:

– meet the technical requirements of satellite operators;

– be able to point to any visible GSO satellites along the geostationary arc;

– be well distributed geographically;

– have relatively small antenna sizes;

– use suitable modulation type(s).

It is advisable for administrations to cooperate in establishing dedicated supplementary reference transmitters at different locations, and use them as a reference when necessary.

Before using the dedicated supplementary reference transmitters to transmit toward a certain satellite, prior consent of the satellite operator is required. And certain technical tests may also be required before transmitting.

5.1.5.4.6 Transportable reference transmitter

Generally, it is very hard to find a transmitter uplinking to a GSO satellite, especially in urban areas. Two major factors are responsible for these difficulties, one being the blockage of radio waves by buildings, the other is the usually high directivity of antennas with very weak side lobes in the terrestrial direction. Therefore it would be useful, with the help of transportable transmitters, to use the TDOA and FDOA measurements to help pinpoint the transmitter, responsible for the harmful interference.

As mentioned in the previous section, before transmitting towards a certain satellite, prior consent of the satellite operator is required, since certain technical tests may be required before transmission.

Theoretically, given a satellite pair, two earth stations transmitting at different frequencies produce the same TDOA values and two FDOA values with very little difference. The closer the reference transmitter is to the unknown interferer, the better the accuracy of the geolocation algorithm.

Before using the transportable reference transmitter, the operator should take full advantage of all fixed reference transmitters to minimize the inaccuracies of the results and the size of the resulting area. Then, prior consent should be obtained from the satellite operator to transmit, taking into account the technical parameters of the transmission. Finally the following two steps should be applied:

Step 1: move the transportable reference transmitter to the centre of the resulting area, and transmit the reference signal as agreed to by the satellite operator. Then the operator of the geolocation system should be notified so as to carry out the geolocation measurements. He should also be notified of the accurate position of the vehicle.

Step 2: The geolocation measurements should yield a new result when the transportable reference transmitter is used.

The results will be refined after Step 2, and these Steps can be repeated to obtain even better results.

The operator of the transportable reference transmitter should keep close contact with the operator of the geolocation system. In practice, the selection of the route and the transmission will be affected by many other factors, such as traffic regulations, and the operator should take note of these factors.

5.1.6 Technical solutions by examples

5.1.6.1 Example of a space radio monitoring station

This sub-section describes the most important parts of a space radio monitoring station. Typically, it is made up of four major technical parts:

Part 1: Antenna system (see § 5.1.6.1.1)

One or more different antennas to cover all telecommunication and space radio frequency bands of interest (directional and omni-directional antennas).

Part 2: Receiving facilities (see § 5.1.6.1.2)

Feed systems, polarization unit, down-converters, calibration systems, reference frequency source.

Part 3: Monitoring equipment (see § 5.1.6.1.3)

Both automatic measurement systems and manual measurement and analytic facilities like signal analyzers, receivers, spectrum recording systems and modulation analyzers which are part of the monitoring equipment.

Part 4: Control facilities (see § 5.1.6.1.4)

The control facilities include the hardware and software for control of antenna positioning, the settings of the receiving system and the settings of the monitoring equipment to facilitate automatic measurement procedures.

General

Location of the monitoring station:

The monitoring station should be as far away as possible from urban and industrial areas with man-made noise, cell phones and RLANs. Fixed links should not cross the location of the site. A protected area around the monitoring station should be declared and kept free from terrestrial transmitters and fixed links.

The landscape around the monitoring station should be flat without line-of-sight obstructions due to hills and buildings.

Site configuration:

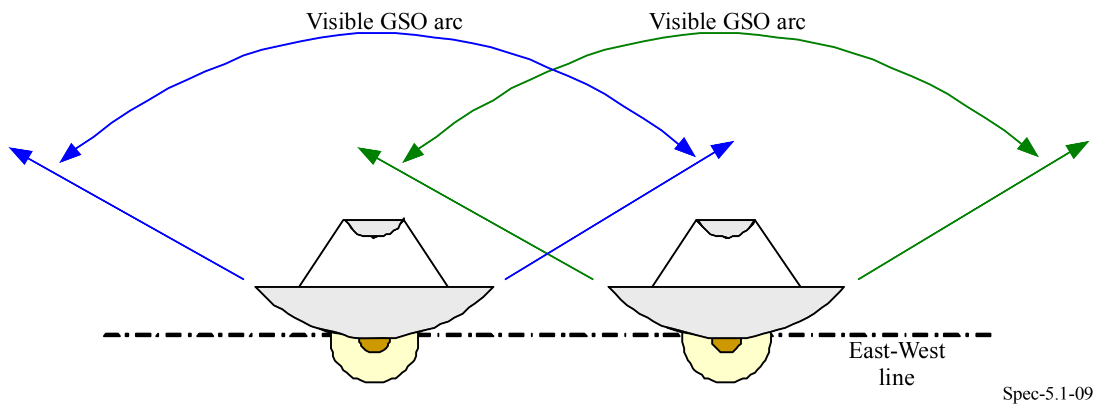
The location of the antennas and the buildings depends mainly on the monitoring target (GSO or non-GSO satellite) and which part of the geostationary orbit is of interest. Future extensions should be foreseen.

For flat and open conditions the antennas can be arranged in a line, e.g., an East-Westline.

The distance between antennas should be sufficient in the direction towards GSO satellites, and the visible angle of the geostationary arc has to be free of obstacles (see Fig. 5.1-9).

FIGURE 5.1-9

Separation of GSO satellite monitoring antennas



For the unhindered reception from non-GSO satellites the area around the antenna must be free of obstacles in all directions (antennas, buildings), this at least up to the lowest required elevation (see Fig. 5.1-10).

FIGURE 5.1-10

Elevation of non-GSO satellite monitoring antennas

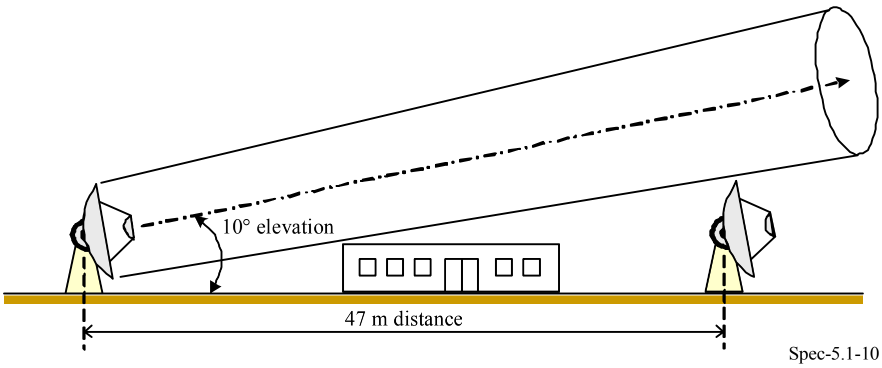


Table 5.1-6 shows the ideal distance between two antennas (9 m diameter each) for clear LoS to the satellites. The elevation angle is the lowest angle for an unblocked view to the satellite.

In order to optimize the number of antennas needed without significant deterioration of their performance, a combination of receiving bands shall be preferred,. A geolocation measurement system requires two antennas, both covering the desired frequency band.

For example a combination of 3 antennas (1 C/Ku, 1 L/S and 1 Ka) offers the capacity to receive, for example, broadcast links, networks and optionally satellite control and test signals. It is also possible to combine 4 or 5 frequency bands using only one antenna. This can be achieved by using a Cassegrain antenna with a beam waveguide system and two cabins or by using a revolving feed system.

TABLE 5.1-6

Distance between two antennas (of the same size) for clear LoS to the satellites

Elevation (degrees)	**Distance (m)**
5	99
10	47
15	30
20	22
25	18
30	16

The disadvantage of such a multiband antenna is that only one frequency band can be used at the same time.

5.1.6.1.1 Antenna system

Antenna types

– Limited motion antenna
– Turning-head antenna with continuous azimuth travel range of >180°
– Full-motion antenna with elevation axis above azimuth axis
– Full-motion antenna with elevation axis above azimuth axis above tilt axis
– Full-motion antenna with slant axis above azimuth above tilt axis
– Full-motion antenna with X-Y mounting
– Hexapod.

Monitoring GSO or non-GSO satellites requires different types of antennas. The most commonly used antenna types are described below.

Antennas for GSO satellite monitoring

When monitoring GSO satellites, antennas with slow azimuth and elevation velocity can be used.

Usable tracking systems:

– Computer tracking with two line elements (TLE)
– Step track
– Monopulse tracking.

FIGURE 5.1-11

Nine-metre limited motion antenna with Kingpost pedestal and motorized jackscrews in azimuth and elevation

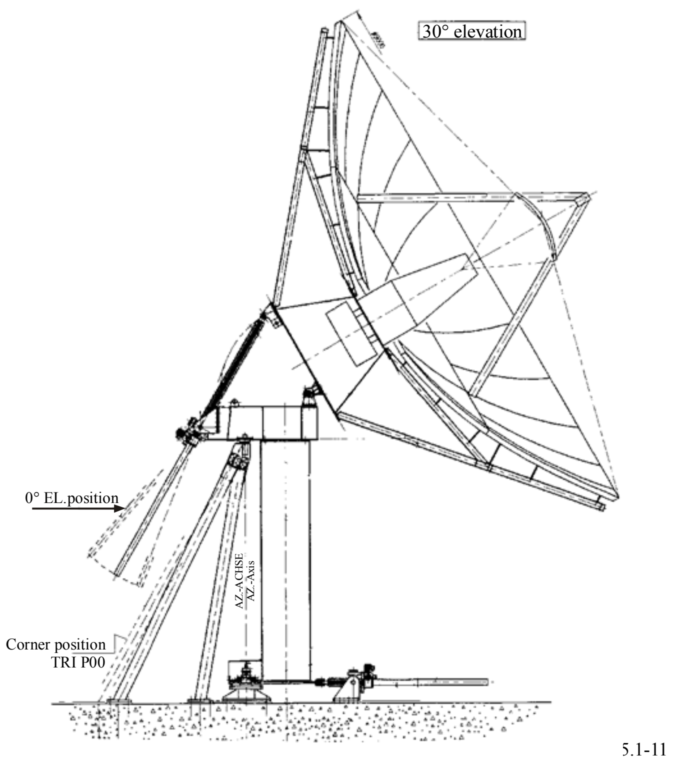
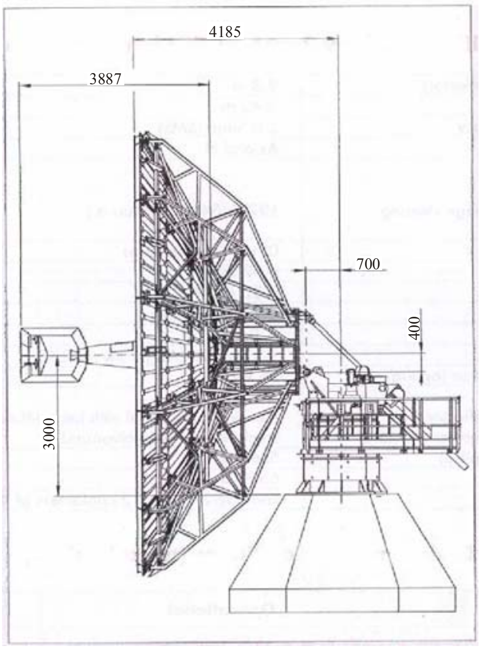


FIGURE 5.1-12

Example of a 9.3 m turning-head antenna



9.3 m antenna roof top version (0° elevation)

Spec-5.1-12

Antennas for non-GSO satellite monitoring

Full motion antennas with a faster velocity and a tracking system must be used. Depending on the antenna pedestal type (elevation above azimuth or X-Y mounting), the required velocity and acceleration are different.

Usable tracking systems:

– Computer tracking with two line elements (TLE).

– Monopulse tracking.

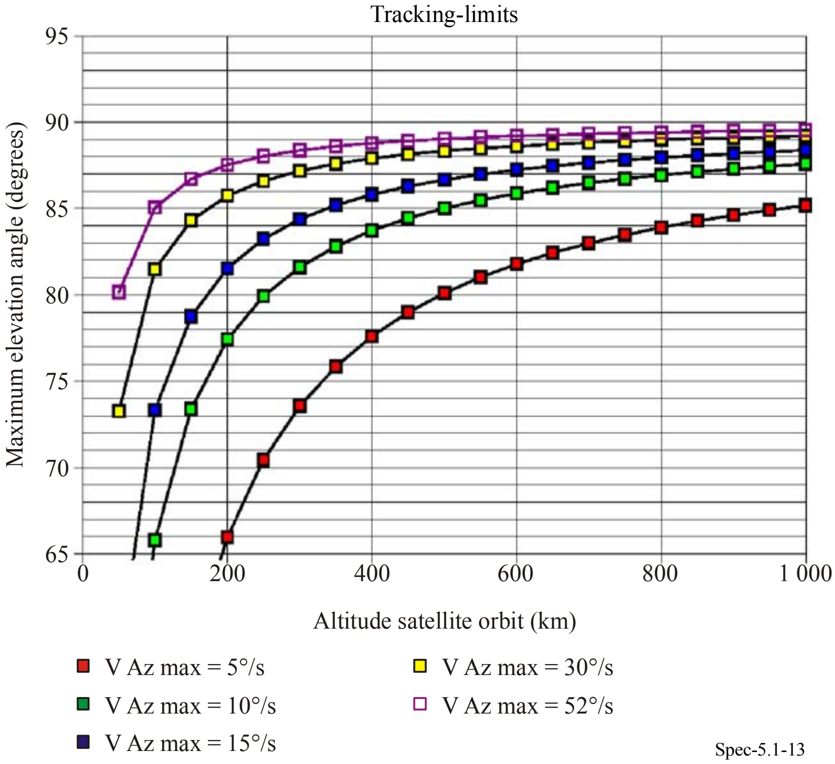
Antennas with elevation axis above azimuth axis

This type of antenna can be used for all types of satellite with orbits of up to 85° elevation. At its zenith, this antenna type has a keyhole. It provides different options for the mounting of the receiving equipment, e.g., a cabin direct at the dish.

Tracking satellite orbits of up to 85° elevation with this type of antenna requires an azimuth speed of around 15°/s, depending on the satellite altitude. Especially when considering low, orbiting satellites with high elevation angles, there is a risk of losing contact with the satellite if the azimuth speed is not sufficient. The diagram in Figure 5.1-13 shows the relation between the satellite orbit, the azimuth speed and the elevation angle.

FIGURE 5.1-13

Relationship between satellite orbit, elevation angle and azimuth velocity for the antenna type elevation axis above azimuth axis



To be able to reduce the azimuth speed, antennas can be used with a so-called tilt axis. Tilt axis systems shift the whole antenna pedestal slantwise. This enables satellite tracking without interruption even at lower azimuth velocity. The satellite orbit must be well-known (e.g., two-line elements) for the advanced calculation of the tilt angle. Tilting cannot be used for satellites with unknown orbit data. These satellites can, for example, be tracked by means of monopulse tracking.

FIGURE 5.1-14

Twelve-metre Cassegrain beam waveguide antenna with an elevation above azimuth pedestal and two cabins for the receiving facilities at the rear side of the dish

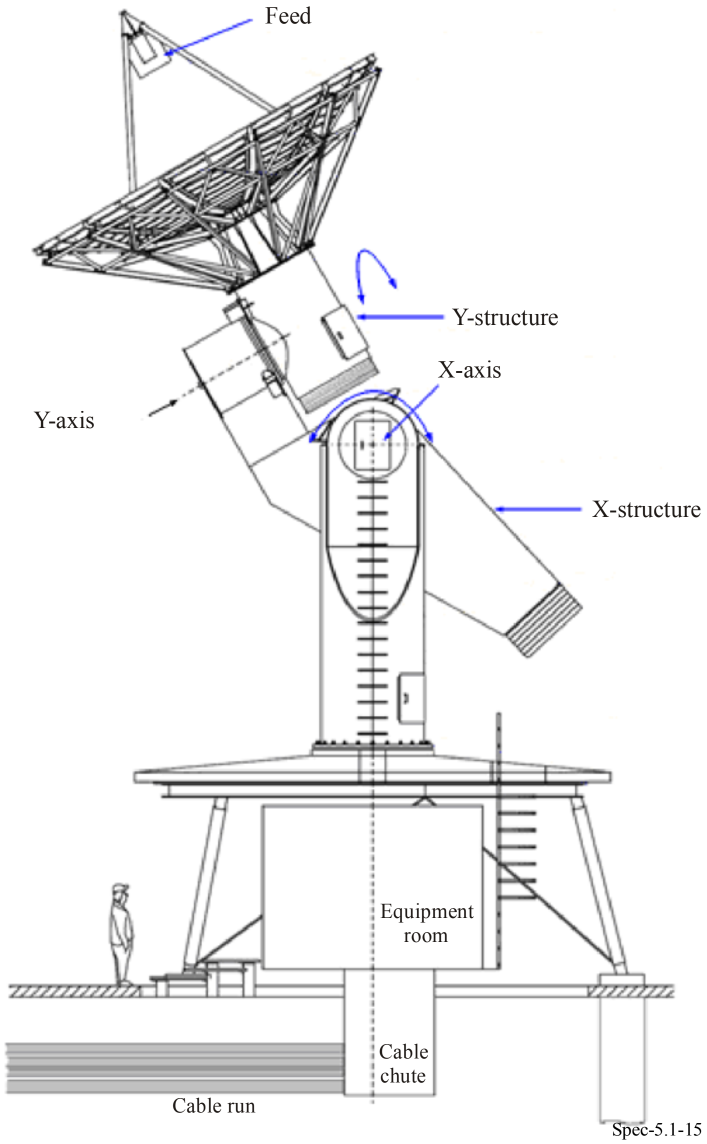
Spec-5.1-14

X-Y antenna

This type of antenna has the advantage that it can track any type of orbit without keyholes in the zenith. The special axis construction needs only slow velocity and acceleration (≤ 3°/s). Its disadvantage is that the reverse side of the antenna provides only limited space for receiving equipment.

FIGURE 5.1-15

Seven metre X-Y prime focus antenna



Antenna specifications

Table 5.1-7 provides practical technical specifications for satellite-monitoring antennas. As the requirements depend on the station, the figures in the table should be regarded as typical minimum specifications. The actual parameters, however, should be determined by the specific measurement requirements.

TABLE 5.1-7

Practical technical specifications for satellite monitoring antennas

	Parameter		Performance		
			L/S/C Band	**Ku Band**	**Ka Band**
a.	Frequency range		L band: 1 452-1 492 and 1 530-1 800 MHz S band: 2 100-2 300 MHz 2 500-2 690 MHz C band: 3 400-4 200 and 4 500-4 800 MHz	10.70-12.75 GHz	17.30-21.20 GHz
b.	Maximum signal level at the input of the low-noise amplifier (LNA) (dBm)		≤ –30	≤ –30	≤ –30
c.	pfd measurement performance (*C/N* at least 23 dB)		–155 dBW/m^2 in 4 kHz bandwidth	–165 dBW/m^2 in 4 kHz bandwidth	–160 dBW/m^2 in 4 kHz bandwidth
d.	pfd measurement accuracy (dB)		±1	± 1	± 1
e.	Figure of merit (*G/T*) (dB/K)		L = 20 S = 23 C = 28	37	33
f.	Reference frequency accuracy		Aging: one part in 10^{10} per day, Temperature: one part in 10^9, 0° to 50° total change.		
g.	Polarization		X, Y, left-hand circular (LHCP), right-hand circular (RHCP)	X, Y, LHCP, RHCP	X, Y, LHCP, RHCP
h.	Frequency resolution (kHz)		1	1	1
i.	Dynamic range (dB)		≥ 60	≥ 60	≥ 60
j.	Antenna	Dish diameter (m)	≥ 9 m	≥ 9 m	≥ 4.5 m
		Pointing accuracy (degrees)	0.15-0.04	0.02-0.017	0.025-0.02
		Beam width (degrees)	1.6-0.5	0.22-0.18	0.27-0.22
		Step-track speed for GSO satellites	0.02-2°/s, manual drive and auto step track (depending of the antenna's location longitude and latitude)		
		Coverage for GSO satellites (degrees)	EL: 0 to 90, AZ: ± 60		
		Coverage for non-GSO satellites (degrees)	EL: 0 to 85, AZ: ± 270 (total azimuth coverage 360), store at 90		

NOTE 1: The frequency ranges in this Table and in § 5.1, such as L, S, C bands, are not defined in the ITU Radio Regulations, but are widely used in the satellite communication community. These frequency ranges may be defined slightly differently, depending on the source.

NOTE 2: For the measurement of out-of-band emissions, the listed commercial frequency bands (see a.) must be enlarged. Strong terrestrial emissions have to be blocked with filters.

5.1.6.1.2 Receiving facilities

The advantage of a beam waveguide system is that the beam can be directed to different locations with low insertion loss. The feeds can be accommodated in equipment cabins providing sufficient space for the installation and maintenance of equipment and air conditioning. The feed systems for satellite-monitoring antennas are relatively unique, since these antennas are used for receiving only, and generally cover a wide frequency range (see Figs. 5.1-16 to 5.1-23).

FIGURE 5.1-16

Example of separated feeds with moveable feed and select reflector layout for 3 frequency bands into a 12 m beam waveguide antenna

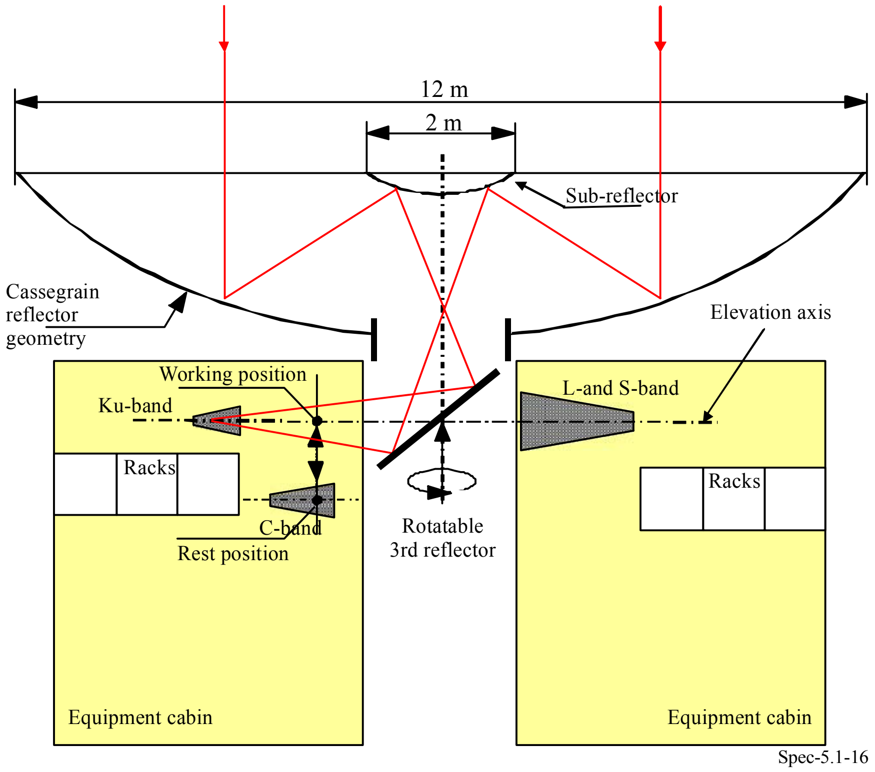
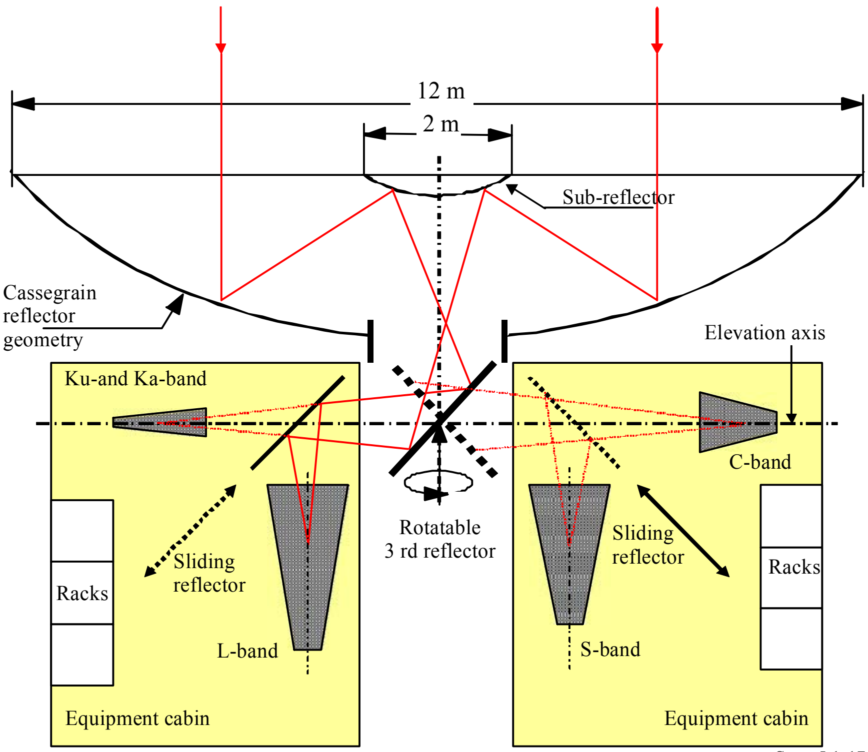


FIGURE 5.1-17

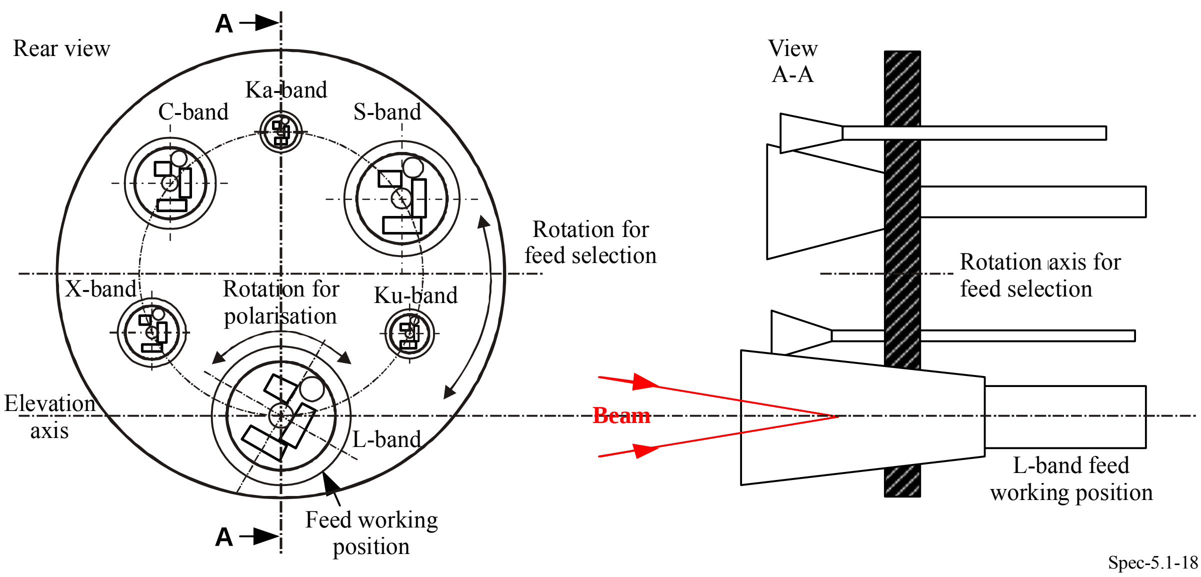
Example of fixed feeds with moveable select reflectors layout for 5 frequency bands into a 12 m antenna



Spec-5.1-17

FIGURE 5.1-18

Example of multifeed revolver system with 6 feeds for a beam waveguide antenna



Spec-5.1-18

Example: Multifeed revolver system with 8 feeds for a prime focus antenna

Frequency range: 1-26.5 GHz without frequency gaps.

Feeds 1 up to 6 (frequency range 1-12.75 GHz) are crossed dipoles with cavity design.

Feeds 7 and 8 (frequency range 12.5-26.5 GHz) are horn antennas.

Outdoor case dimension: around 700 mm × 700 mm × 500 mm [$W \times D \times H$].

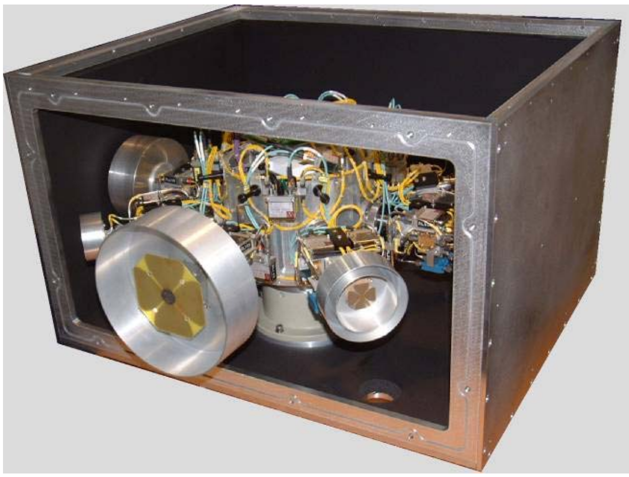
FIGURE 5.1-19

Multifeed mounted in prime focus

Spec-5.1-19

FIGURE 5.1-20

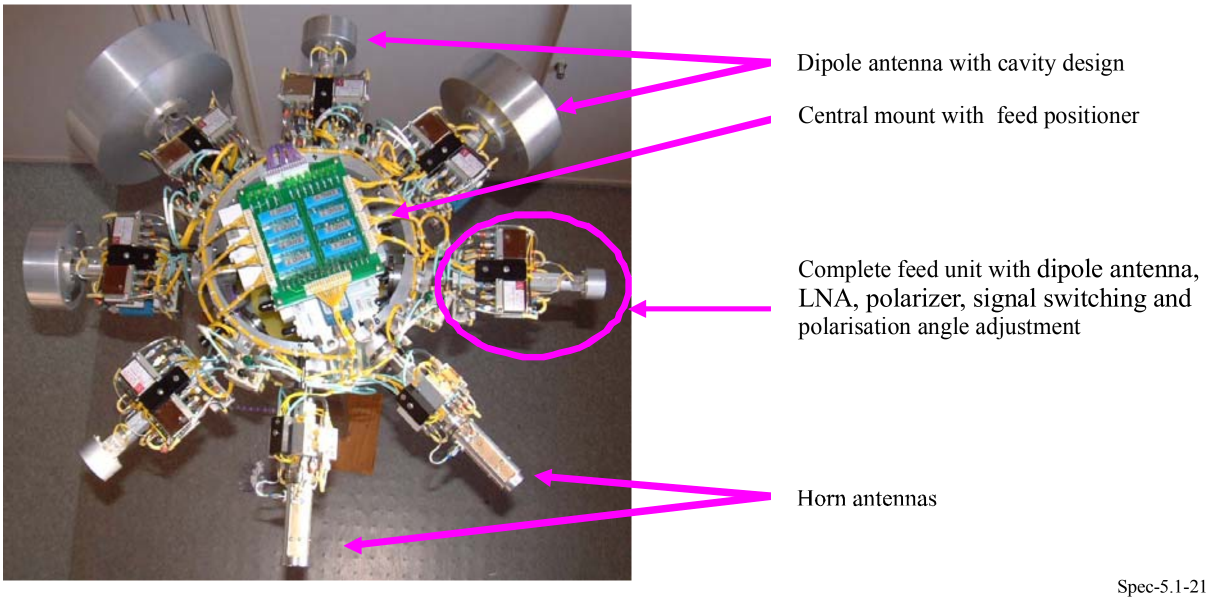
Multifeed in open outdoor case



Spec-5.1-20

FIGURE 5.1-21

Feed without outdoor case mounted around feed positioner



Spec-5.1-21

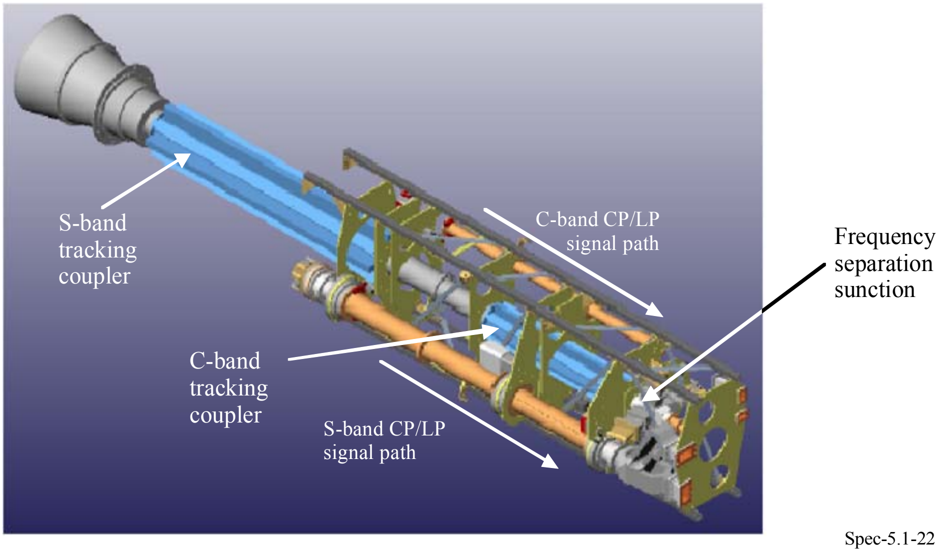
All feeds designed with coaxial technique for linear and circular polarisation and polarisation angle adjustment of ±95°.

FIGURE 5.1-22

Example of a combination of 3 frequency bands into a 12 m antenna

Feed system for Cassegrain antenna configurations 11 m and larger. CP/LP switching, independent LP polarisation adjustment and monopulse tracking in both bands.

S-band: 2.1-2.7 GHz
C-band: 3.4-4.8 GHz



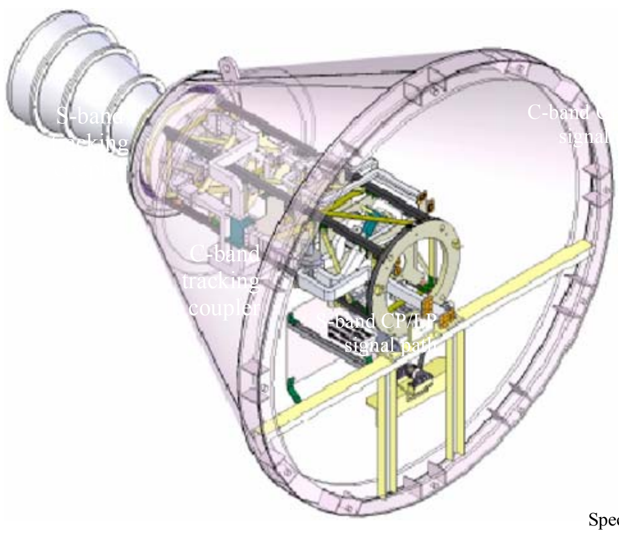
Spec-5.1-22

FIGURE 5.1-23

Example of feed with 2 closely spaced frequency bands

Feed system for Cassegrain antenna configurations 9 m and larger.

C-band: 3.4-4.2 GHz, CP/LP
X-band: 7.25-8.4 GHz, CP
Ku-band: 10.9-12.75 GHz, CP/LP



Spec-5.1-23

Receiving equipment

The receiving equipment comprises the following items in Table 5.1-8:

TABLE 5.1-8

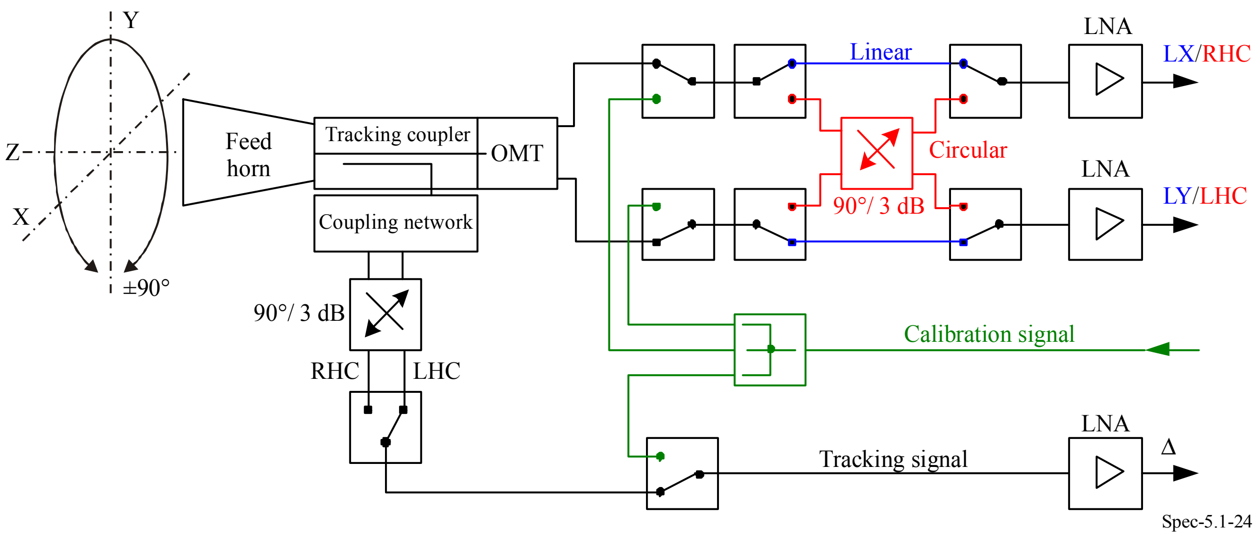
Receiving equipment of an antenna system

Feed	Horn-, dipole- or cross dipole-antenna and the coupling network
Tracking coupler	Coupling out the TE21 mode for the monopulse antenna tracking
Polarisation adjustment	Rotator for the adjustment of the polarization angle
Ortho mode transducer (OMT)	Separation of the polarisation planes X and Y in two channels
LNA	First amplifier with a noise figure as low as possible
Polarizer	Combine the X and Y channels into RHCP and LHCP in the case of circular polarisation
Down converter	Converts the RF signal into a broadband IF and/or a narrowband IF, e.g., 70 MHz IF
Switching and post amplifying	Switches the different signal paths and amplifies the IF for the transmission to the main building

Depending on the type of antenna, these components may be spatially separated.

FIGURE 5.1-24

Block diagram example of a feed system with tracking coupler and polarizer

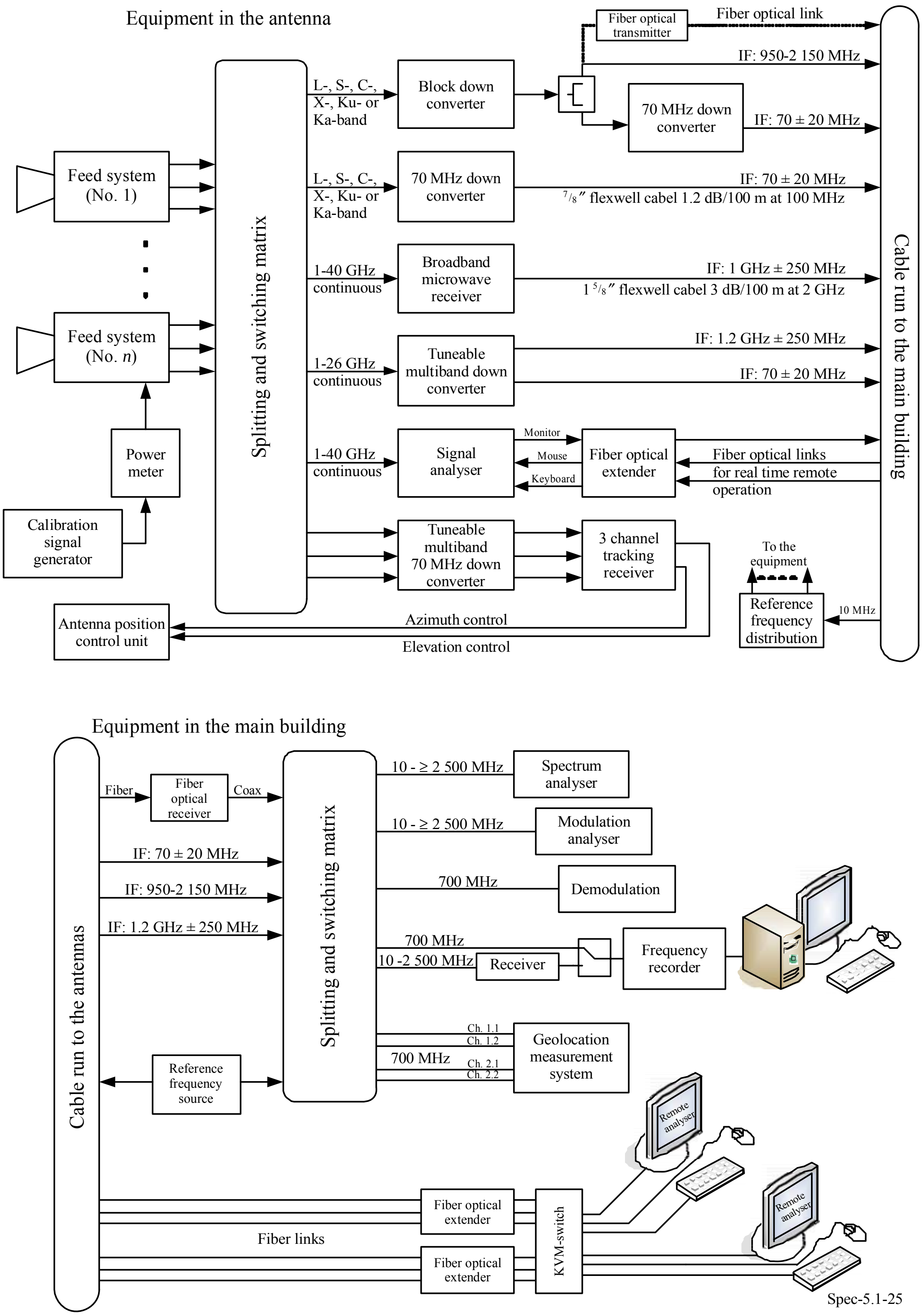


5.1.6.1.3 Monitoring equipment

The following diagrams, as in Fig. 5.1-25, show examples for the integration of monitoring equipment.

FIGURE 5.1-25

Integration of monitoring equipment



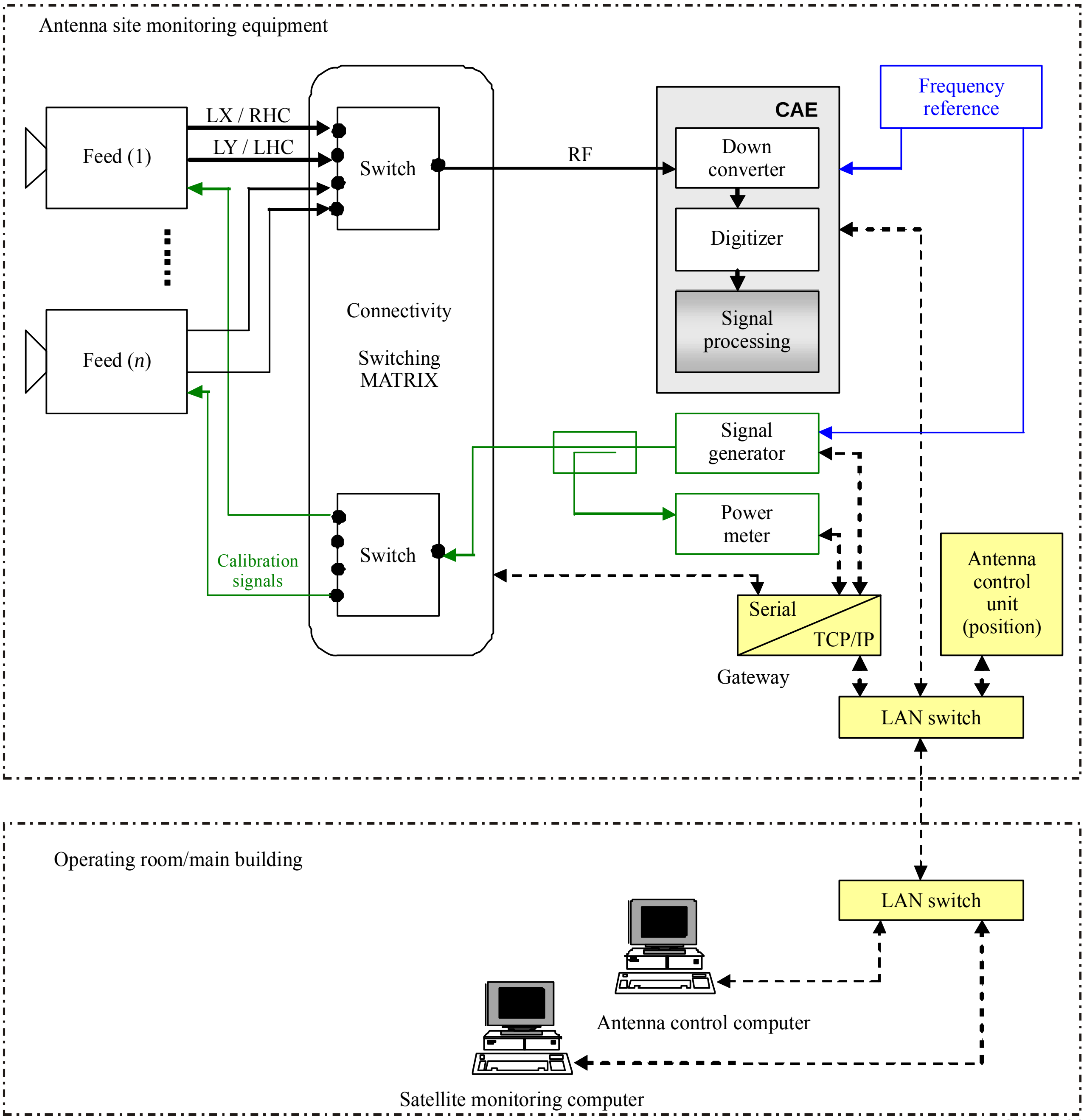
Spec-5.1-25

Automated satellite monitoring system

Figure 5.1-26 shows an automated monitoring system for carrier acquisition. The carrier acquisition equipment (CAE) hardware architecture for satellite monitoring uses a calibration system and injection points is also shown in the Figure. The power meter controls the calibration signal from the signal generator.

FIGURE 5.1-26

Example of an automated satellite monitoring equipment



Spec-5.1-26

The CAE is capable of:

- acquiring satellite frequency bands in L, S, C, Ku and Ka;
- detecting all carriers above noise floor (typical 6 to 10 dB above noise floor);
- getting RF parameters for each carrier;
- giving a full carrier classification, including all digital parameters used by the modulator and the standard that is used.

The CAE shall be able to analyse and classify carriers up to the 80 MHz bandwidth; this covers most of the civilian transponders.

When satellite traffic is known, the CAE detects unwanted carriers and optionally localizes the transmitters using FDOA and TDOA methods.

For automated satellite monitoring, the following measurements should be carried out:

- RF measurements:
  - Carrier power at equipment level
  - Carrier e.i.r.p at satellite level
  - Carrier C/N_0
  - Carrier frequency by barycentre, recovery, carrier shape, peak search methods
  - Carrier bandwidth: *x* dB method, β% of total power method, derived from symbol rate calculation
  - Spectrum observations and analysis tools (markers, zoom, spectrogram, selectors)
  - Transponder e.i.r.p. at satellite level.
- Digital measurements:
  - Carrier characterization
  - Modulation type
  - Bit rate (transmission rate)
  - FEC rate
  - Reed Solomon rate
  - Standard used
  - Carrier demodulation diagram.
- Carrier detection based on power density detection (typically 6 to 10 dB above noise floor):
  - Subsequent database update
  - Inside defined carrier detection (carrier rejection capability shall be better than 13 dB).
- Spectrum observations, virtual spectrum observations by simulating end-user *G/T*.
- Fast spectrograms to visualize fast slots drifts (e.g., MF TDMA access).
- Orbital parameters (orbital position accuracy of at least ±0.1°).
- Calibration should be used to determine the gain of the reception chain.

The software system on the satellite monitoring computer should perform both interactive and automated measurements.

Interactive measurements allow the operator to investigate signals rapidly. Interactive measurements include observation of multiple bands in multiple formats, hand-off signals for carrier measurements and control of the spectrum analyser and optionally of the receiver, tape recorder, printer and plotter.

Automated measurements should be triggered under event occurrence (see Note 1) or scheduled in background without an operator present. A task scheduling shall allow coordinating signal presence, carrier measurements, spectral occupancy and statistical measurements.

NOTE 1 – For example, an automated target signal and reference signal recording may be started immediately after an unwanted signal detection. This paves the way for the geolocation module.

Figure 5.1-27 gives an example of a monitoring screenshot of showing spectrum and spectrogram information.

FIGURE 5.1-27

Example of a spectrum monitoring screenshot on the satellite monitoring computer

Spec-5.1-27

5.1.6.1.4 Control facilities

Operational modes of an antenna control system

For space radio monitoring a simple efficient control of the antennas is required for their operation. A large number of different operational modes should be available to allow for an efficient pointing of the antenna at difficult satellites constellations. The most common antenna control functions are listed in Table 5.1-9.

TABLE 5.1-9

Operational modes of an antenna control system

Modes	Description	Comment
PRESET	Movement to predefined position Input: Az and El values	
GEO PRESET	Movement to predefined position Input: Satellite position, e.g., E19.2°	Set the antenna to a GSO orbit position without user calculation of Az and El values
POSITION	Movement at user-defined angle around the actual antenna position	Move the antenna in Az und El with 4 arrow buttons or with knobs for manual antenna adjustment
RATE	Movement at user-defined constant velocity	Mostly for calibration and test measurements
PROGRAM TRACK	Tracking of an object along a pre-defined path with Az, El, data and time data records	
TLE TRACK	Tracking of an object along a pre-defined path with TLE orbital data sets from NORAD	
STAR TRACK	Tracking of astronomical targets	Option for calibration and test measurements
AUTO-TRACK	Tracking of an object using tracking error signals (monopulse tracking)	Needs a monopulse tracking coupler in the feed system and a monopulse tracking receiver
STEP TRACK	Tracking of an object using a step track receiver	Needs a step track receiver but without additional components at the feed system
ORBIT PREDICTION TRACKING	Intelligent step track	Option to improve the step tracking pointing accuracy
MEMORY TRACK	Tracking using last stored satellite position data	
SECTOR SCAN	User defined sector is scanned horizontally / vertically	Helpful to find a satellite, e.g., a high-inclination satellite
SEARCH SPIRAL	Pulsating spiral around last actual position	Helpful to find a satellite, e.g., a high-inclination satellite
GEOSYNC	Pointing to a pre-defined geo-synchronous orbit and movement on the GSO arc	Manuel movement with East/West buttons along the GSOarc

Monitoring and control system

The monitoring and control (M&C) system is a central computer-based system for the control of all facilities in the monitoring station. A graphical user interface (GUI) represents an abstracted clearly arranged overview of the equipment and switching status on every operator’s place (see Fig. 5.1-28). For the prevention of access collisions on the equipment, the system should have an assignment and locking mode. The measurement units can depend on the M&C development system and the requirements are completely controlled or, only for manual use, are connected at the signal path of the M&C. To allow for an efficient workflow, two monitors should be used for the operation of the antenna positioning and the device control.

The following equipment is controlled and inspected:

– Antenna control system for pointing and searching functions.

– Antenna tracking system with monopulse or step track receivers.

– Feed system with polarisation switching and polarisation angle adjustment.

– Down-converters, filters and post-amplifiers.

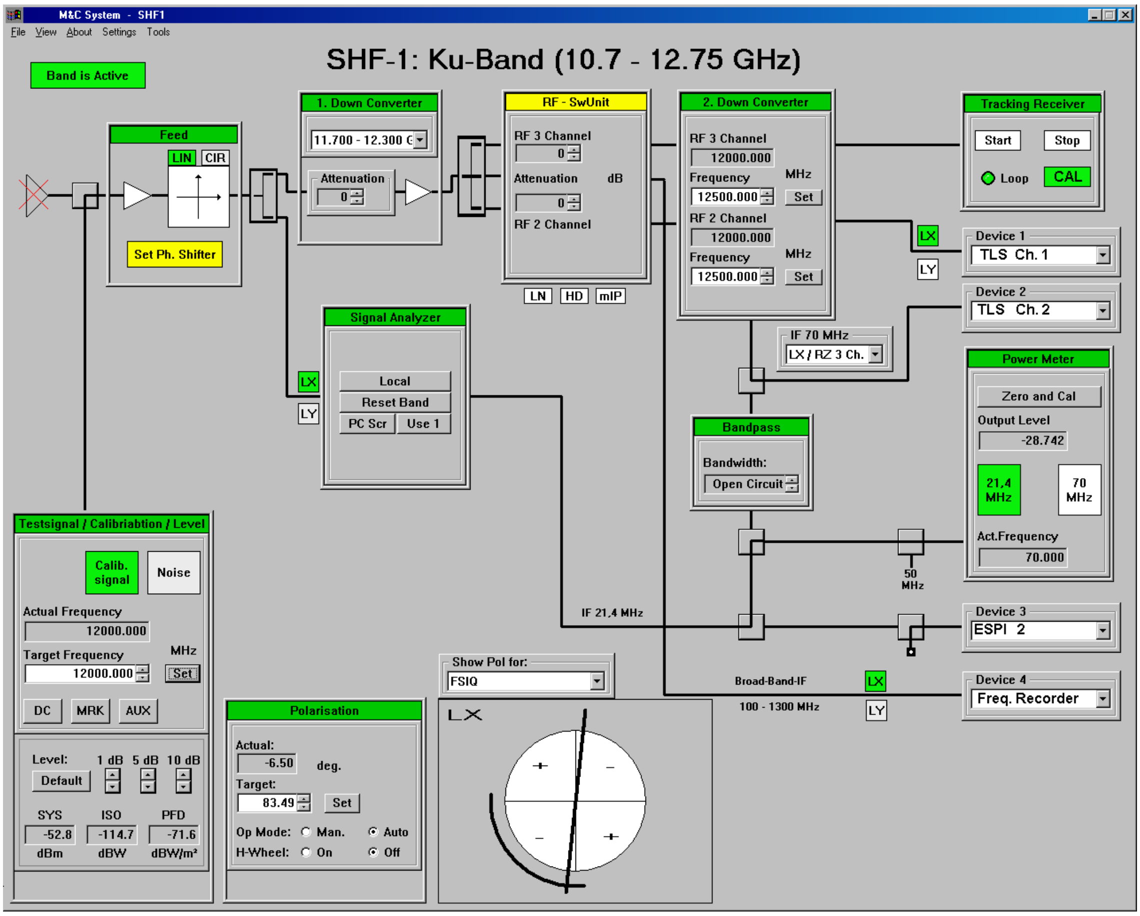
– All switching units for connection and distribution of the RF an IF signals.

– Connection and settings of the measurement and analytic units.

– Launching automated measurement software.

FIGURE 5.1-28

Example of a GUI screen of an M and C system



Spec-5.1-28

FIGURE 5.1-29

Geolocation measurement system

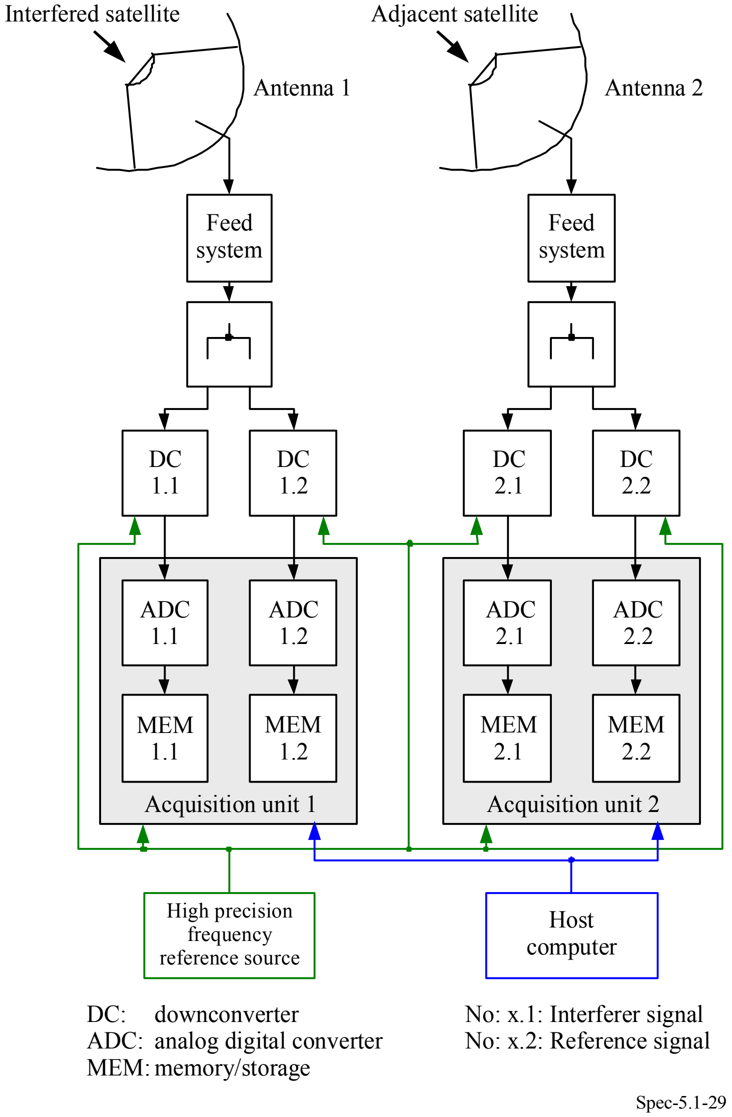
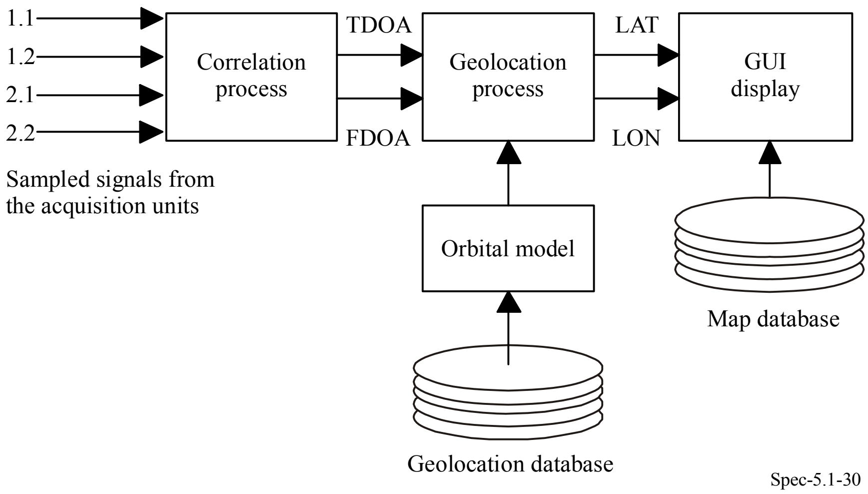


FIGURE 5.1-30

Geolocation calculation procedure in the host computer



TDOA: Time difference of arrival
FDOA: Frequency difference of arrival
LAT: Latitude
LON: Longitude
GUI: Graphical user interface

Notes:

Signals 1.1 and 1.2 received by antenna 1 from the interfered satellite.
Signals 2.1 and 2.2 received by antenna 2 from the adjacent satellite.
Signals 1.1 and 2.1 are interferer signals, 1.2 and 2.2 are the reference signals.

5.1.6.2 Process for radio monitoring of GSO satellites

An automated system for radio monitoring of GSO satellites is described below. It attempts to minimize the number of operators in their task, when measuring the orbit and radio wave quality, by using various techniques.

The automated monitoring system is equipped with a computer program which has the following functions:

– Control, to establish operation priority.
– Registration, to schedule single measurements.
– Error detection of the system software with a reporting function for operators.
– Searching and measuring.
– Calibration of the system and inspection - to check whether the monitoring facility operates properly.
– Reporting of measurement results to operators.
– Storing of registered satellites and measurement results in the database.

Operators of the space radio monitoring station should prepare the monitoring schedule so that monitoring tasks are routinely performed according to the monitoring plan.

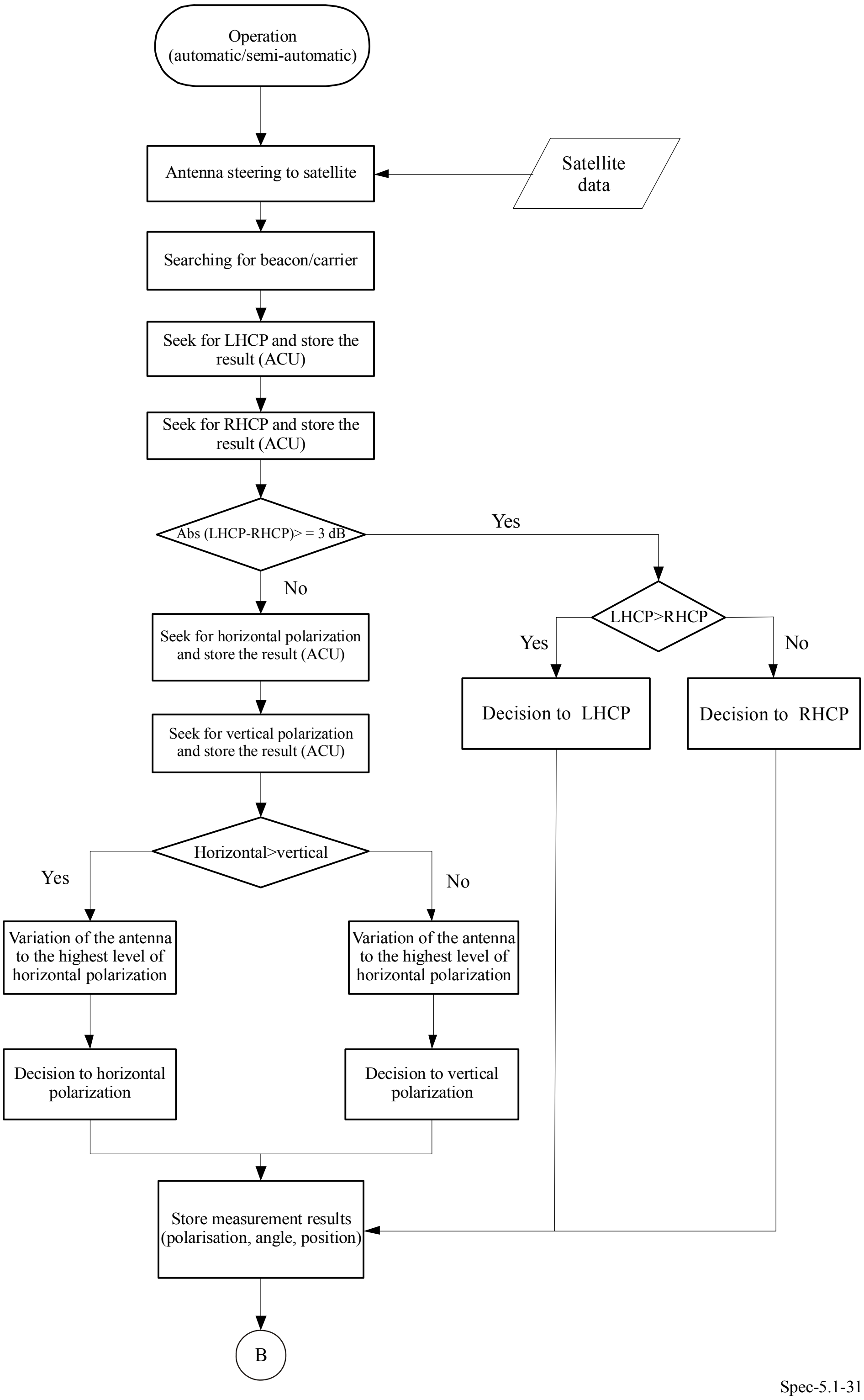
For detecting sources of harmful interference, monitoring new satellites and measuring the frequency spectrum occupancy in detail, the semi-automatic and manual modes can be operated simultaneously.

The specified items in the monitoring schedule include such items as monitoring time, automatic or semi-automatic mode selection, satellite name, number of monitoring times, task priorities, etc.

Figure 5.1-31 shows an example of the sequential process of monitoring.

FIGURE 5.1-31

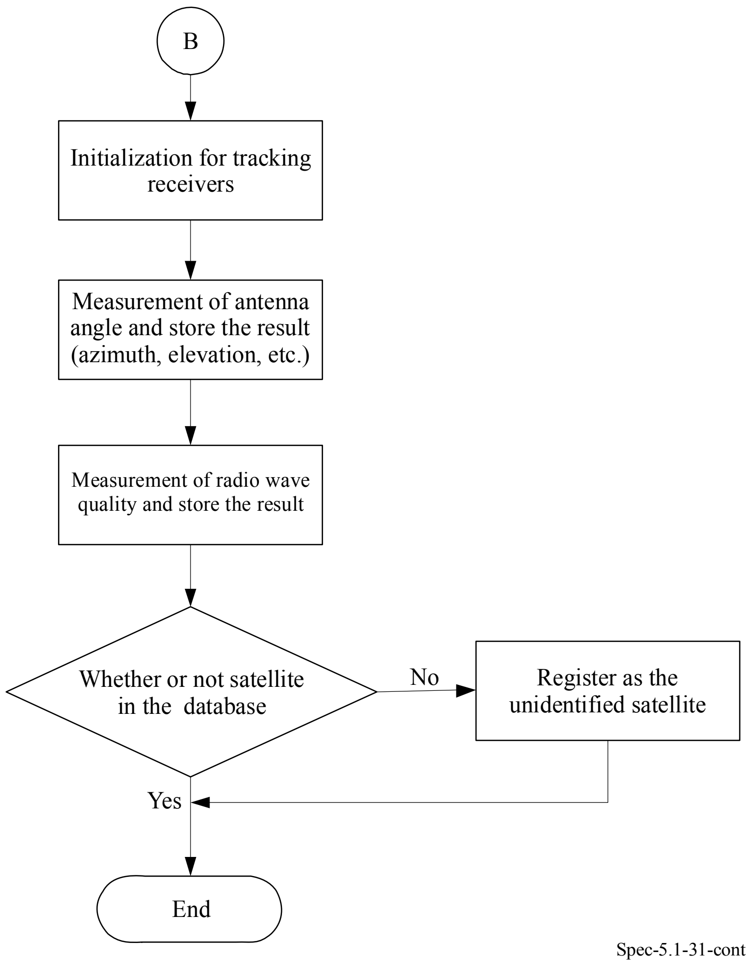
Sequential process of monitoring



Spec-5.1-31

FIGURE 5.1-31 (*cont.*)

Sequential process of monitoring



Measurement items of the scheduling process include satellite orbital position, polarization, centre frequency, pfd, occupied bandwidth and so on. It is important for space radio monitoring facilities to include techniques for fast tracking, choosing polarization by means of comparison algorithms, locating centre frequencies for measuring occupied bandwidth, and measuring carrier power.

The polarization is determined by repeatedly checking incoming measurements against the polarization criteria.

Usually, the monopulse tracking method is preferred but other methods, such as step tracking, are also used.

Satellite identification is verified by comparing measurement result with the satellite database.

Repetition of measurements and corrections are required in order to improve the accuracy and reliability of the measurement results.

Measurement tasks should be performed with high reliability, considering the propagation characteristics at high frequencies and the weak signal received on Earth from the satellite. The monitoring stations should verify whether the satellite is operated following appropriate technical standards and regulations.

Moreover, operators register or renew the operational schedule for any new monitoring requests and special tasks. Storing of the standard procedures which are often used will simplify the registration process.

5.1.6.3 Precise orbital longitude monitoring (radio interferometry)

5.1.6.3.1 Introduction

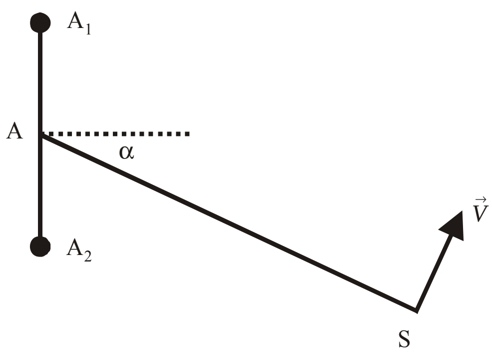
Precise monitoring of satellite longitudes will become more important as the geostationary orbit is more densely populated with an ever-increasing number of satellites. A proposed technique for such monitoring is radio interferometry. Developments are under way to establish interferometer-based monitoring, as described in [Kawase, 2005; Kawase, 2007].

5.1.6.3.2 General principle

An interferometer with two antennas A_1 and A_2 has a basic geometry as shown in Fig. 5.1-32. The antennas span a baseline A_1A_2, and its middle point is A. Signals from satellite S are received at an incidence angle α. The phase-difference between A_1 and A_2 is referred to as the "interferometric phase". $\vec{V}$ is a unit vector, perpendicular to line AS and lying in the plane containing A_1, A_2, and S. A satellite's motion along $\vec{V}$ is detected by the interferometer, while motions perpendicular to $\vec{V}$ are not detected. This selective detection is the basis for longitude monitoring.

FIGURE 5.1-32

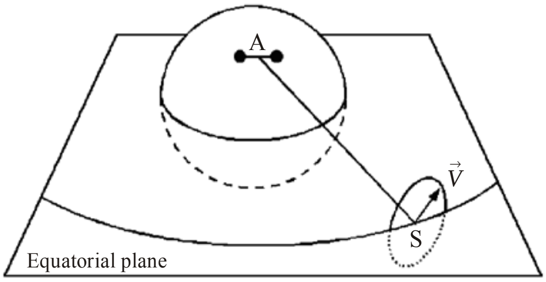
Interferometer geometry



The interferometer is situated in an earth station, as shown in Fig. 5.1-33. The baseline is placed horizontally, and its orientation is rotated. Thus, the vector $\vec{V}$ rotates and sweeps out giving a tilted disk.

FIGURE 5.1-33

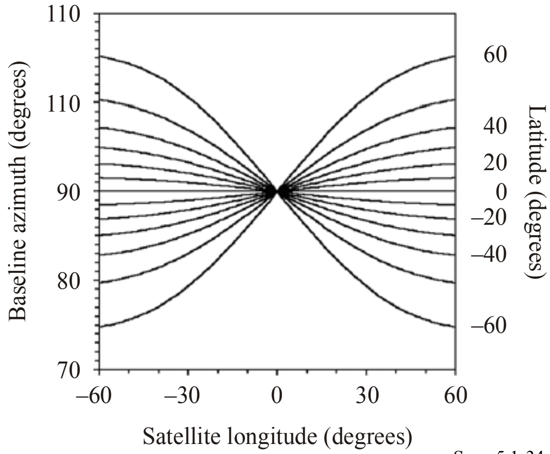
Satellite-station geometry



$\vec{V}$ lies in the equatorial plane with a particular orientation from the baseline. This particular baseline orientation is East-West (azimuth 90°) if the satellite and the station are at the same longitude. Generally, the orientation differs from East-West, depending on the satellite-station geometry, as shown in Fig. 5.1-34. In choosing this particular baseline orientation, the interferometer has sensitivity only for satellite motions in the equatorial plane.

FIGURE 5.1-34

Particular baseline orientation
(Station's longitude is zero)

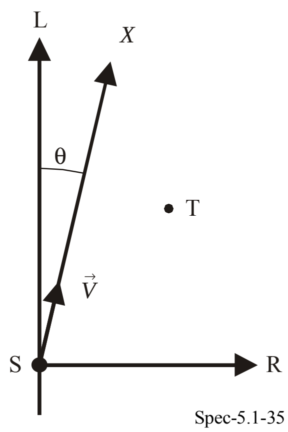


Spec-5.1-34

Assuming that the satellite has a nominal stationary position at point S, as in Fig. 5.1-33, the true satellite position T will be close to S, and T is projected onto the equatorial plane, as shown in Fig. 5.1-35. Position T is measured relative to S, with radial and longitudinal coordinate axes (R and L). Vector $\vec{V}$ defines the "detection axis" X, the X-axis deflects from the L-axis by an angle θ, this angle depends on the satellite-station geometry.

FIGURE 5.1-35

Coordinate axes in the equatorial plane



Spec-5.1-35

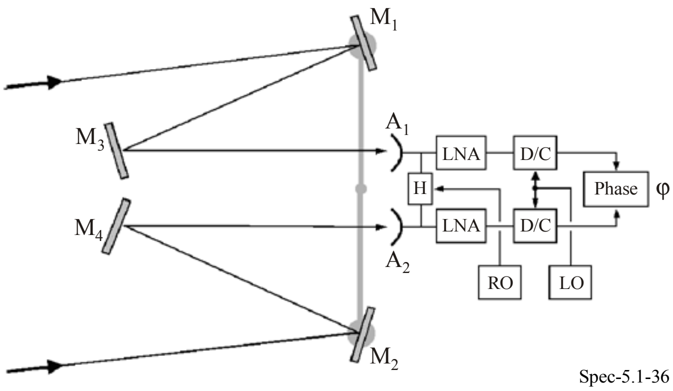
Practically, the angle θ is small. For example, if a station in Japan monitors satellites at 10º or higher elevations, θ is less than 7º. Hence, disregarding R axis components of satellite motion and equating $X/\cos\theta$ to the L axis, leads to accurate longitude monitoring. Monitoring errors are within 0.0006º for mean longitude if the satellite stays within an orbital slot at least for a few days, and within a 0.2% relative error for eccentricity.

5.1.6.3.3 Interferometer installation

The interferometer uses plane mirrors to establish the baseline, as shown in Figs. 5.1-36 and 5.1-37. An incident wave in 11-GHz frequency bands is reflected by mirrors M_1 and M_3 before being directed to antenna A_1, and the same occurs for M_2, M_4 and A_2. Phase delays over the reflected paths are geometrically calculated and removed from the interferometric phase, and this allows M_1M_2 to be the interferometer baseline. The baseline must be re-orientated to monitor satellites at different orbital positions. This can be achieved by changing the positions of M_1 and M_2 and repointing the mirrors, without moving the phase-critical microwave components and cables. M_1 and M_2 are movable, as they are mounted on a rotary arm. A common local oscillator (LO) is for the interferometric phase-connection, and a common reference oscillator (RO) is for compensating for equipment delay variations. Placing the antennas side-by-side allows the LO and RO to distribute their common signals through short cables, thus ensuring stable phase measurements. The mirrors are 2 m^2, the antennas are 1.8 m in diameter, and the baseline (rotary arm) length is 13 m.

FIGURE 5.1-36

Interferometer diagram



Measured interferometric phase φ (rad) is converted to the satellite longitude l (degrees) in reference to nominal longitude, as follows:

$$M = \frac{\lambda}{2\pi}(\varphi - \varphi_S - \varphi_C)\frac{r_S}{B\cos\alpha\cos\theta} \qquad (5.1\text{-}14)$$

$$l = \frac{180}{\pi}\frac{M}{R_S} \qquad (5.1\text{-}15)$$

where:

R_S: nominal orbital radius, 42165×10^3 (m)

λ: wavelength of received signal (m)

r_S: distance AS (m)

B: baseline length A_1A_2 (m)

α: incidence angle

θ: X-axis deflection

φ_S: interferometric phase for satellite at nominal position (rad)

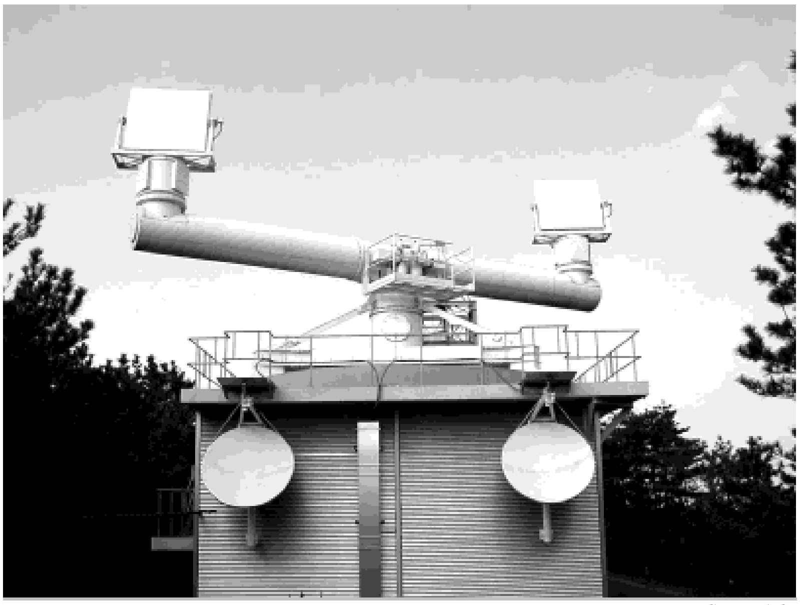
φ_C: correction to interferometric phase (rad)

l: satellite longitude (degrees (positive refers to East longitude and negative refers to West))

φ: measured interferometric phase (rad).

FIGURE 5.1-37

Interferometer site in Japan



Spec-5.1-37

The constant φ_S is calculated from the satellite-interferometer geometry. Small errors in positioning A_1, A_2, M_3, and M_4 may cause a near-constant phase error, but this is corrected by φ_C.

Phase ambiguity of 360º in measured phase leads to a 0.1º ambiguity in satellite longitude. Resolving this ambiguity and determining the correction constant φ_C is achieved by the following: the baseline arm is rotated around its fixed centre C over one revolution. As a result, the phase $\varphi - \varphi_S$ changes, as shown in Fig. 5.1-38, with 360º to 0º- phase leaps. These leaps are reconnected, as shown in Fig. 5.1-39.

FIGURE 5.1-38

Phase changes as the arm rotates

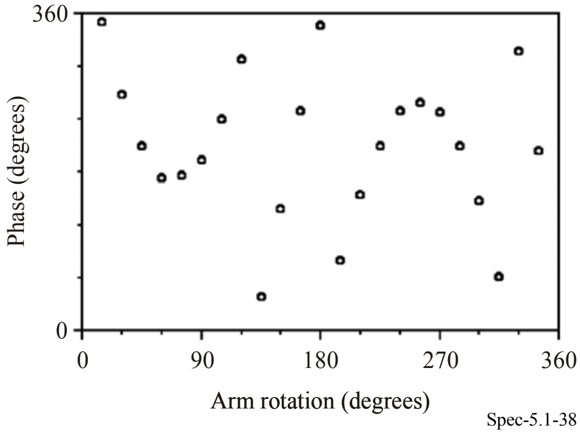
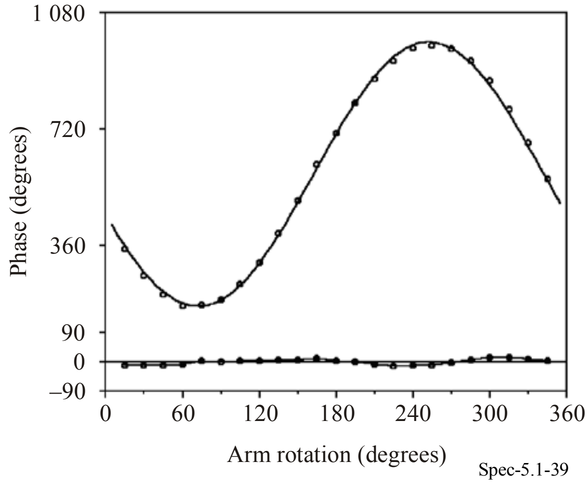


FIGURE 5.1-39

Phase reconnection and model-fitting



The phase angle $\varphi - \varphi_S$ is modelled as a function of the arm-rotation angle, with satellite azimuth, satellite elevation, and φ_C included as parameters. The model's function is fitted to the reconnected phase, as shown in Fig. 5.1-39 (solid curve). The azimuth and elevation thus estimated enables the ambiguity resolution and the phase correction, φ_C. The baseline arm undergoes this one-revolution operation once before any unknown satellite is monitored.

5.1.6.3.4 Monitoring example

Figure 5.1-40 is an example of longitude monitoring. The interferometer is calibrated by using optical tracking and orbit determinations. Figure 5.1-41 is for a longer time span, where the East-West-keeping manoeuvre occurs at the point marked "*". Satellite longitude occupancies are thus precisely determined. If there are two satellites operating closely to each other, their longitudes can each be monitored separately. Then, by subtracting, their differential longitude can be plotted, as shown in Fig. 5.1-42. Differential monitoring eliminates atmospheric fluctuations that are common to closely located satellites, and so the data noise in Fig. 5.1-42 is less than that shown in Fig. 5.1-41. This is useful for precise longitude monitoring for closely operating satellites.

FIGURE 5.1-40

Longitude monitoring, interferometer (-) and optics (o) satellite at 144° E

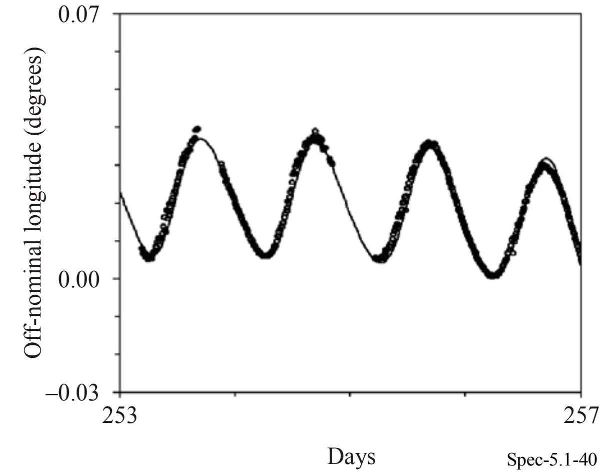


FIGURE 5.1-41

East-West correction during the monitoring satellite at 124° E

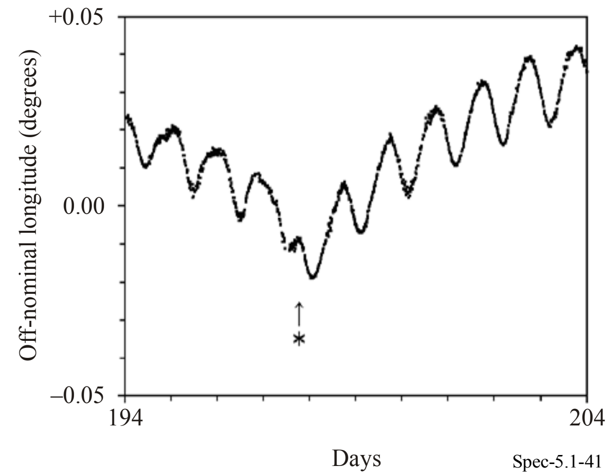
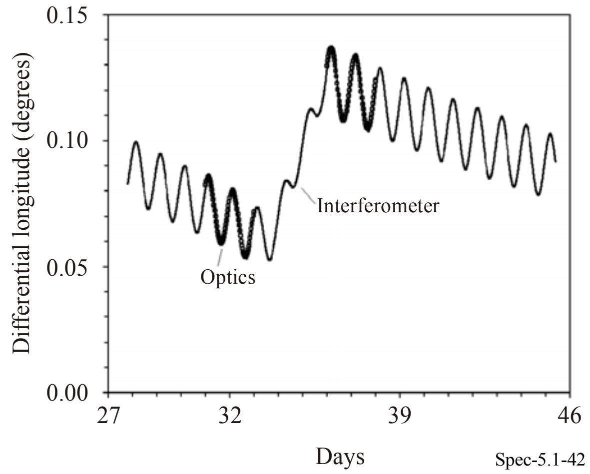


FIGURE 5.1-42

Monitoring differential longitudes two satellites at 110° E



5.1.6.3.5 Summary

Radio interferometry can be especially used for monitoring geostationary satellite longitudes. Small aperture antennas suffice, and the use of movable mirrors ensures stable phase measurements. This monitoring technique is useful when the satellites operate closely together in the geostationary orbit.

5.1.7 Monitoring results by examples

5.1.7.1 Frequency band recording in the VHF band

Radio frequency spectrum recording systems are particularly suitable for the monitoring of frequency bands for occupancy by emissions from low-orbiting space stations in frequency bands below 1 000 MHz, with an omni-directional antenna.

The structure of the occupancy pattern (Doppler curve) depends on the orbital elements of the satellite and is of fingerprint quality. In addition to the receive frequency, the period of revolution (PERIOD_{raw}), taken as the average of several consecutive revolutions, and the expected times of reception may be different. In order to determine the period of revolution with a satisfactory degree of accuracy (PERIOD_{fine}), an iterative method is recommended using registrations taken over a period of several days on the basis of the following equations:

$$\text{PERIOD}_{raw} = T_2 - T_1 \qquad (5.1\text{-}15)$$

$$\text{PERIOD}_{fine} = (T_x - T_1)/n \qquad (5.1\text{-}16)$$

T_x is the centre point of the receiving window one day or several days later. The divisor, n, is a fictitious number of revolutions in the case of equation (5.1-16). It is systematically altered until the minimum divergence between the desired result for the PERIOD_{fine} and PERIOD_{raw} is achieved. In this way, the measurement error of the time of revolution may be reduced after a period of only 24 h to some tenths of a minute. The time of revolution and the characteristics of the recording pattern are reliable for the identification of a satellite.

Another method is the use of an adjustable time line grid as an overlay in the spectrogram of the recorded satellite emissions over a period of two or more days. If the time lines match the satellite emissions the PERIOD_{raw} is found. In the example shown in Fig. 5.1-43, PERIOD_{raw} = 112 min.

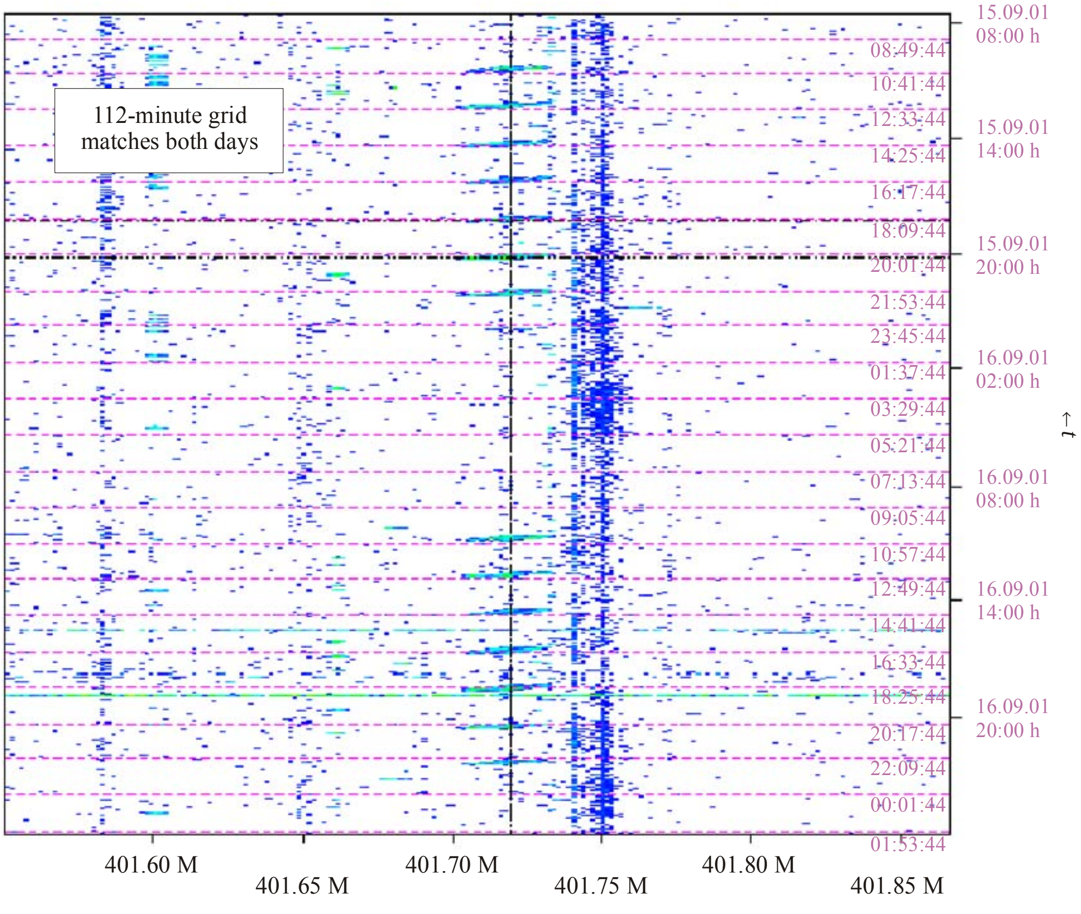
To find out the exact period time, a search of the NASA database is necessary as a second step.

With the result of 112 min, it can search for satellites with a revolution period close to 112 min. Figure 5.1-44 illustrates the NASA-SSR database with marked satellites close to 112 min periods. With the related two-line-elements, the visibility time for these satellites, for the location of the monitoring station, has to be calculated. The frequency recorder system can display these visibility windows as an overlay in the spectrogram of the received satellite emission.

If the visibility windows match all the recorded satellite emissions, the satellite is identified. Figure 5.1-45 illustrates the visibility windows for the S80/T satellite with a revolution period of 111.9 min. After the orbit data are known now, a directional antenna can track the satellite with these data for further measurements.

FIGURE 5.1-43

Frequency occupancy registration, approximate determination of time of revolution



Spec-5.1-43

FIGURE 5.1-44

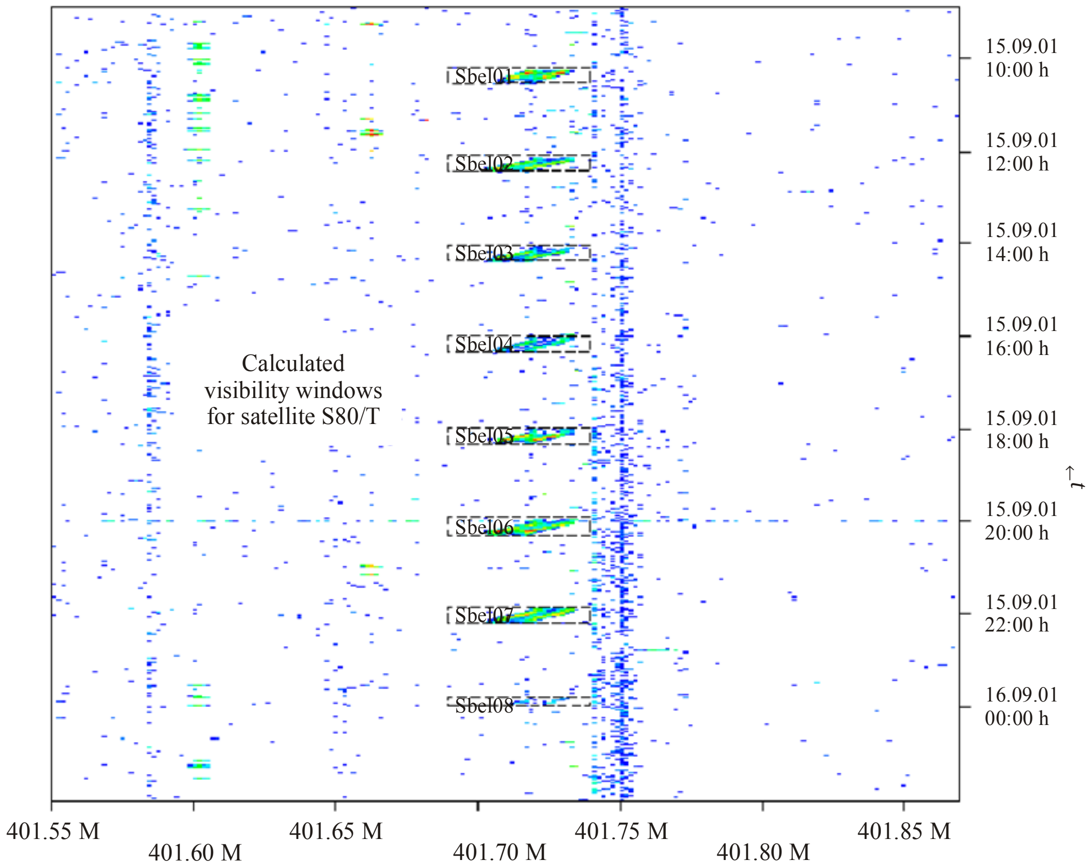
Search in NASA-SSR

INT-ID	CAT	SRC	PERIOD	INCL	APOG.	PERIG.	RCS	NAME	DATE
1990-114F	21033	CIS	113,7	82,6	1410	1386	2,2032	COSMOS 2119	22.12.90
1989-074B	20233	CIS	113,7	82,6	1410	1386	1,7514	COSMOS 2039	14.09.89
1988-002F	18793	CIS	113,7	82,6	1411	1384	1,9042	COSMOS 1914	15.01.88
1987-074A	18334	CIS	113,7	82,6	1409	1387	2,1058	COSMOS 1875	07.09.87
1987-026B	17583	CIS	113,7	82,6	1411	1385	2,2787	COSMOS 1828	13.03.87
1985-003C	15471	CIS	113,7	82,6	1413	1383	1,3662	COSMOS 1619	15.01.85
1992-052A	22076	US	112,4	66	1344	1332	10,6361	TOPEX/POSEIDON	10.08.92
1990-013C	20480	JPN	112,2	99,1	1744	912	0,3319	JAS 1B (FUJI 2)	07.02.90
1990-013B	20479	JPN	112,2	99,1	1743	912	0,4893	DEBUT (ORIZURU)	07.02.90
1992-052C	22078	FR	111,9	66,1	1325	1305	0,4416	S80/T	10.08.92
1992-052B	22077	KOR	111,9	66,1	1325	1307	0,2912	OSCAR 23 (KITSAT 1)	10.08.92
1994-046A	23191	US	110,6	70	2156	355	3,8606	APEX	03.08.94
2000-075C	26621	SWED	110,5	95,4	1799	701	0,1528	MUNIN	21.11.00
1989-086A	20305	CIS	110,4	82,6	1251	1238	11,6301	METEOR 3-3	24.10.89
1995-059B	23711	US	109,7	100,5	1493	934	13,2018	SURFSAT	04.11.95
1994-003B	22970	GER	109,4	82,6	1208	1185	7,6481	TUBSAT B	25.01.94
1994-003A	22969	CIS	109,4	82,6	1208	1186	41,1628	METEOR 3-6	25.01.94
1991-030A	21232	CIS	109,4	82,6	1208	1188	9,5992	METEOR 3-4	24.04.91
1991-056A	21655	CIS	109,3	82,6	1206	1187	7,8738	METEOR 3-5	15.08.91
1988-064A	19336	CIS	109,3	82,5	1208	1184	8,0195	METEOR 3-2	26.07.88

Spec-5.1-44

FIGURE 5.1-45

Visibility windows in the frequency occupancy registration



Spec-5.1-45

5.1.7.2 Calculation of orbital elements from antenna angle measurements

The identification of a satellite is made easier, and in some cases only possible, by the use of orbital elements calculated from antenna angle measurements. The question of whether or not a sufficiently accurate determination may be obtained depends largely on the angle measurement accuracy of the antenna available and the length and type of the tracked orbit arc. The following example should allow specific conclusions to be drawn regarding the achievable calculation accuracy, which may not at the same time be universally applicable. It is based on a comparison between the ephemeris data of the space station NOAA10, published with a good degree of accuracy and therefore used as reference data, with the ephemeris data obtained from antenna angle measurements and on a comparison between the visibility times and the azimuth and elevation calculated on the basis of both sets of ephemeris data for a path approximately 24 h later.

The antenna angle measurement accuracy of the available 12 m parabolic reflector antenna using the monopulse technique is approximately 0.12° in the 1 700 MHz frequency band used (see also § 5.1.3.5). The maximum elevation angle of the tracked orbit above the horizontal plane was approximately 60°.

Three sets of antenna angle measurement data (azimuth/elevation/time) are used for an initial mathematical determination of the orbit, followed by calculation of the orbital elements. In order to improve the results, a parametric calculation is then made, with the aim of obtaining a solution, which corresponds as closely as possible to the antenna angle measurement values for the series of measurements [Montenbruck, 1989] and [Montenbruck and Pfleger, 1991].

Table 5.1-10 and Fig. 5.1-46 illustrate the results of these comparisons. When used as an identification aid, the elements in Table 5.1-10 can considerably facilitate the identification of a satellite. However, when the ephemeris data as a whole are used for the predetermination of azimuth and elevation as a function of time, deviations growing with interval to the epoch are observed. This is due to the limitations in accuracy when computing the orbital elements from the angle measurements of a single satellite path. The satellite pick up during the following paths, however, is remarkably improved. The divergence of azimuth and elevation for a satellite path 24 h later (after 14 revolutions) and based on the initial orbit determination is presented in Fig. 5.1-46. The calculated curves are shifted by –1 min to compensate for time delay.

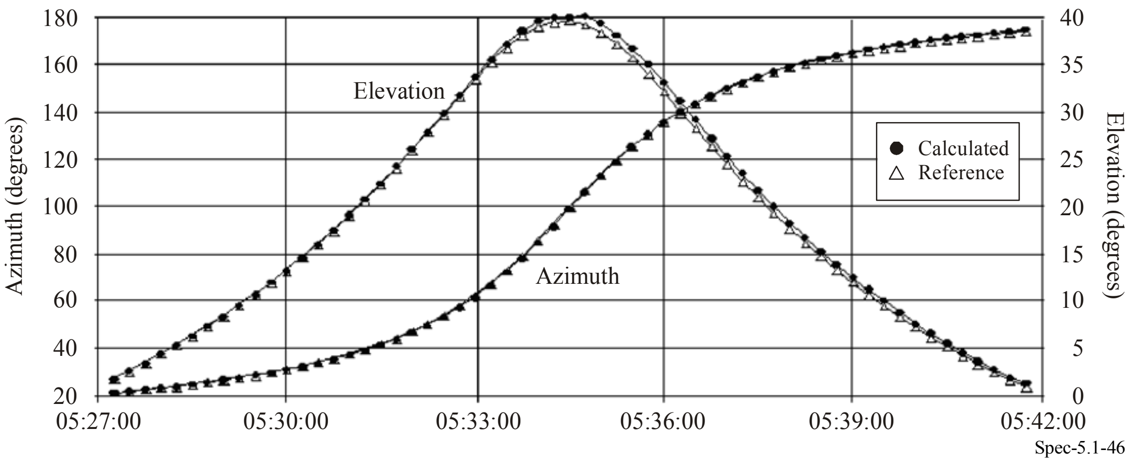
TABLE 5.1-10

Comparison between reference orbital elements and computed orbital elements (initial orbit determination)

Orbital elements NOAA10	Reference elements	Computed elements
Perigee (km)	807	808
Apogee (km)	825	830
Semi-major axis (km)	7 187	7 190
Eccentricity	0.0012156	0.0015
Inclination (degrees)	98.5121	98.78
Time of revolution (min)	100.781	100.85

FIGURE 5.1-46

Comparisons between antenna angles computed from reference orbital elements and from measured orbital elements

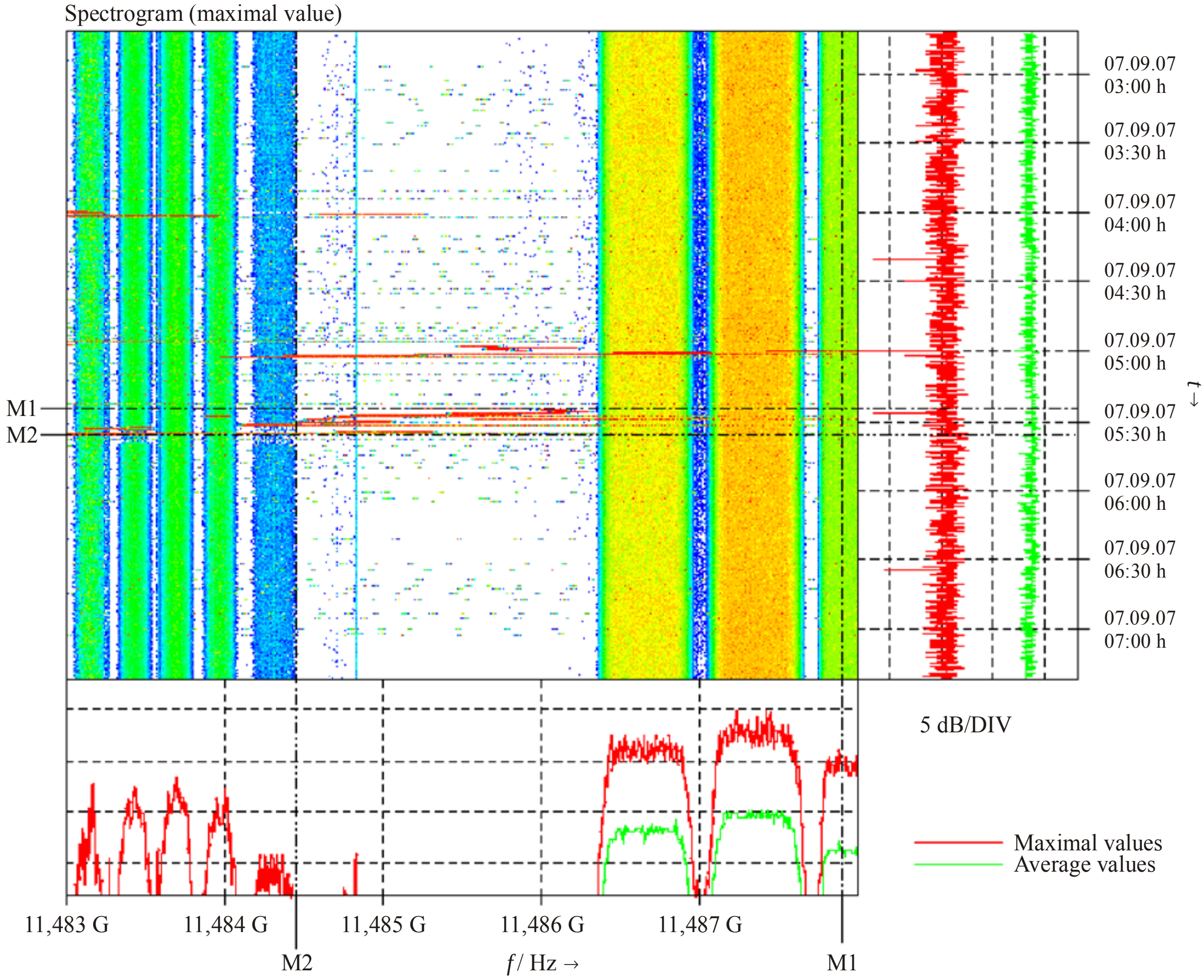


5.1.7.3 Transponder occupancy measurements

Figure 5.1-47 illustrates the result obtained from a transponder occupancy measurement with a frequency recording system. The spectrogram shows satellite transponder occupancy with an unused transponder section in the middle of the displayed frequency range and a temporarily appearing high-power interfering signal.

FIGURE 5.1-47

Transponder occupancy measurements



	Level	Frequency	Time	Samples	Dead T.
M1	–65,0 dBm	11,487915 GHz	05:23:50 h	399	40 ms
M2	–81,0 dBm	11,484453 GHz	05:35:15 h	399	30 ms
Δ	16,0 dB	3,4614 MHz	–00:11:25 h		

-·-·-·- Marker 1

-··-··-··- Marker 2

Spec-5.1-47

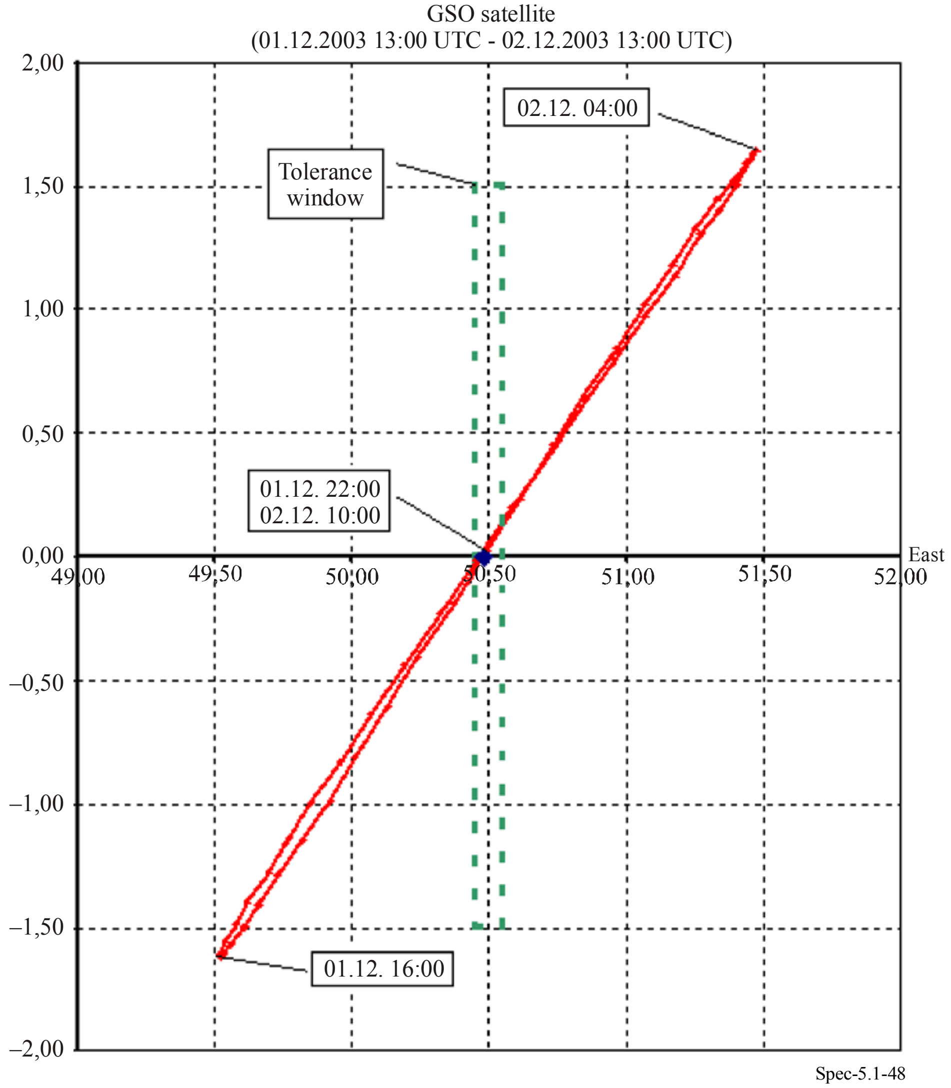
The interferer crosses the whole transponder fast up and down. The signal, received with a directional antenna, is connected to the frequency recorder in the IF range. The signal is, digitized and represented online, using an FFT in the form of a spectrogram in the frequency recorder. The spectra are stored continuously on a hard disk and are available for further offline processing. The different colours represent the power level in the spectrogram. The displayed power level range is adjustable by the colour range settings. The spectrogram can be changed in the frequency range and in the recorded time range by zooming in so that a short observation period can be represented in great detail or by zooming out for a long observation period, which provides a general view. The position of the frequency marker line and the time marker line is on the right-hand side and below the spectrogram displayed for the respective spectrum.

5.1.7.4 Inclination of GSO satellites

The plot in Fig. 5.1-48 was obtained by observing the position of a GSO satellite at 30 min intervals by using a 12 m parabolic antenna with a half-power beamwidth of 0.15°. Based on a monopulse tracking procedure the antenna pointing data are acquired automatically by initially manually locating the satellite. The satellite positions are recorded over a 24 h period and the results are calculated to produce the figure "8". The information obtained shows the satellite's excursion from its nominal orbital position and provides a reference for future observations.

FIGURE 5.1-48

Inclination of geostationary satellites (figure "8")



5.1.7.5 Result and presentation of a geolocation measurement

Figure 5.1-49 is obtained from a TDOA and FDOA geolocation measurement of an unknown uplinking earth station. The result is usually presented in the form of an elliptical area, which can be overlaid on a digital map application for better understanding. The shape and the orientation of the ellipse may vary significantly due to the number of measurements made, the measurement time of the day, the modulation type of the signal under test, the correlation *S/N*, etc. The factors needed to define the ellipse include:

– The length of the semi-major axis.

– The length of the semi-minor axis.

– Angle of semi-major axis (or semi-minor axis) with respect to a reference direction.

– Coordination of the centre.

– Confidence level.

FIGURE 5.1-49

Geolocation results of an earth station transmitting to a GSO satellite (1)

Spec-5.1-49

The geolocation ellipse result in Fig. 5.1-49 can be found in Table 5.1-11.

TABLE 5.1-11

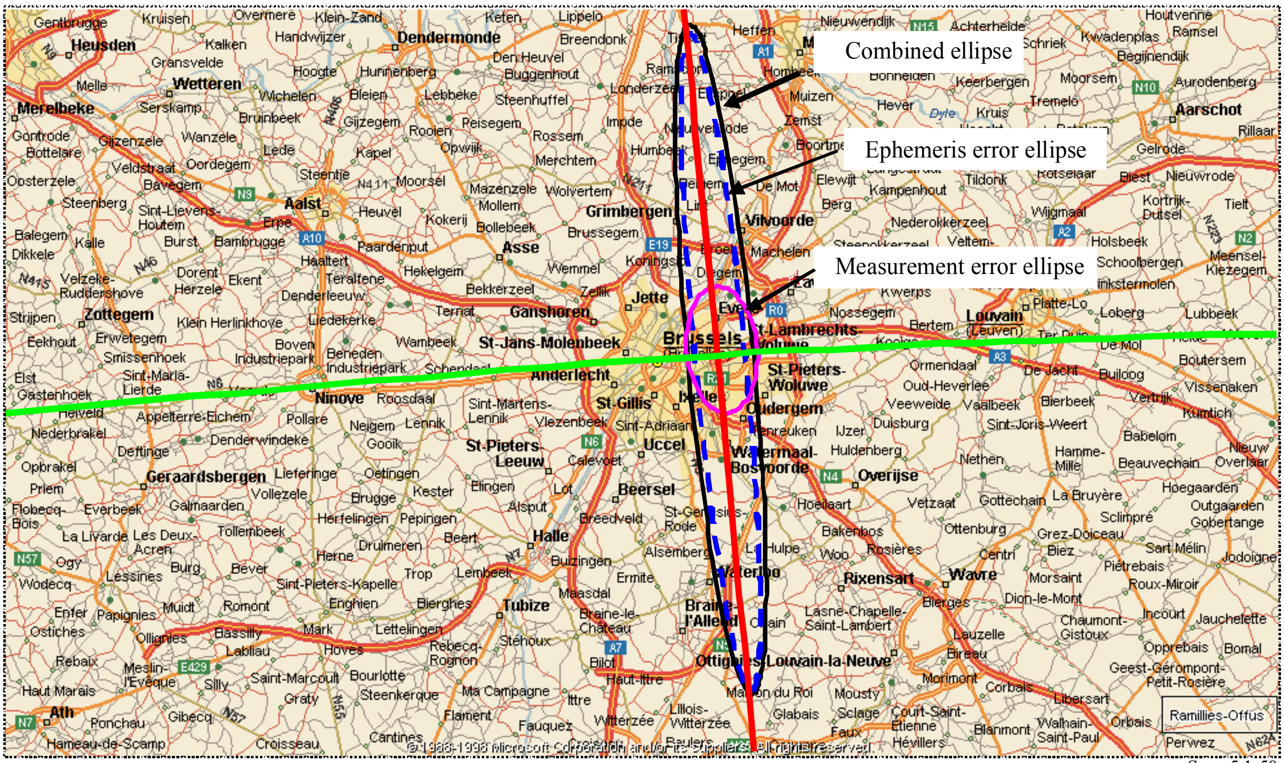
Geolocation ellipse result corresponding to Fig. 5.1-49

Latitude (degrees)	N 38.793
Longitude (degrees)	W 77.168
Semi-major axis (km)	8.679
Semi-minor axis (km)	3.338
Angle (degrees)	51.5
Confidence level (%)	95

Figure 5.1-50 shows the representation on a map of a geolocation measurement with the error ellipse. The huge ellipse for the ephemeris error shows inaccuracies in a satellite's position and velocities. In this case, an ephemeris error compensation measurement should be carried out.

FIGURE 5.1-50

Geolocation results of an earth station transmitting to a GSO satellite (2)



Spec-5.1-50

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ITU-R Recommendations

NOTE – In every case, the latest edition of the Recommendation is encouraged to be used.

Recommendation ITU-R BO.650 – Standards for conventional television systems for satellite broadcasting in the channels defined by Appendix 30 of the Radio Regulations.

Recommendation ITU-R S.446 – Carrier energy dispersal for systems employing angle modulation by analogue signals or digital modulation in the fixed-satellite service.

Recommendation ITU-R S.484 – Station-keeping in longitude of geostationary satellites in the fixed-satellite service.

Recommendation ITU-R S.673 – Terms and definitions relating to space radiocommunications.

Recommendation ITU-R SM.1681 – Measuring of low-level emissions from space stations at monitoring earth stations using noise reduction techniques.

ANNEX 1

MONITORING SYSTEM PLANNING AND TENDERS

Page

Page

A1 Topics to be considered by Regulatory Authorities before issuing a tender

A National Radio Regulatory Authority has to interpret and implement the provisions of the ITU Radio Regulations (RR), which have the force of an international treaty. It also has to implement the national statutory provisions of the national laws and the Rules framed there under relating to radiocommunications. Compliance of the provisions of the authorizations/licenses by various wireless users, spread all over the country, has also been enforced. The Monitoring Organization is the field organization of the national Authority, which provides practical data relevant to spectrum management, including control and regulation of wireless networks, with a view to ensuring interference-free operations of all networks.

The Monitoring Organization is entrusted with all necessary responsibilities for effecting coherent and extensive usage of radiocommunications in the country. The following aspects relate to planning, coordination and regulation of the spectrum in the national context:

a) Optimizing the utilization of radio spectrum by following the latest international standards and practices for spectrum management and wireless monitoring functions.

b) Utilization and protection of orbit/frequency resources for national satellite and other space systems by publishing, notifying and registering national systems with ITU and ensuring continued protection from new systems of other countries.

c) Identifying the spectrum needs for new wireless networks, and assigning suitable frequency(ies), power, bandwidth, emission, hours of operation, and other technical parameters with appropriate operational, regulatory and administrative provisions to them.

d) Authorizing the installation and operation of wireless stations by specifying all the necessary technical and operational parameters, such as frequency of operation, power, emission, hours of operation, etc.

e) Establishing regulations, technical parameters and standards governing the use of each frequency band or specific frequency by stations of different radio services, having regard to current international regulations and agreements.

f) Undertaking special coordination work for use of radio systems/equipments in special situations such as natural calamities, etc.

g) Maintaining and updating all information on authorized radiocommunication systems such as frequencies, location of stations, power, call signs, etc.

Radio Monitoring supports all these functions as it is an important part of the spectrum management process. It plays a significant role in the planning, engineering, electromagnetic compatibility and in ensuring compliance with licensed/authorized parameters. In fact, monitoring is known as the eyes and ears of spectrum management.

The other Chapters of this Handbook on Spectrum Monitoring provide many detailed descriptions of all types of monitoring stations, equipment and procedures. This Annex provides an overview of what sort of planning, studies and procedures are required when developing either a nationwide monitoring system or a fixed or mobile monitoring station.

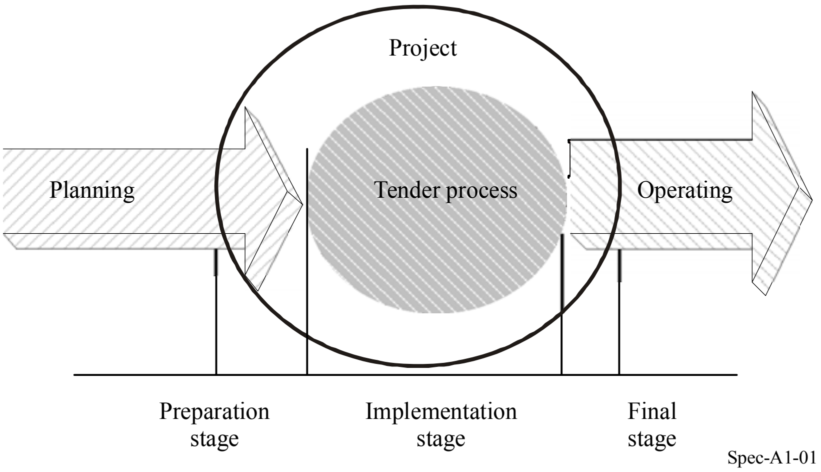
If the radio-frequency spectrum is to be used equitably, economically, efficiently and rationally, it is required that appropriate frequency repeatability be ensured, as well as the adoption of appropriate equipment and monitoring systems.

A2 General overview of a tender process

When a national administration decides to create its nationwide monitoring system, a new local monitoring station, or just a single mobile measuring system, the work of the established project for the execution of the assigned goal is divided into three stages (see Fig. A1-1).

FIGURE A1-1

Three stages of an established project



Preparation stage – Planning:

– Concept for a radio monitoring system.

– Feasibility study.

– Business plan.

– System planning.

– Specifications for the systems.

Implementation stage – Tender process:

– Invitation to start public purchase tenders (consideration of the competence of the bidders, disqualification clauses for non-fulfilment of contract).

– Invitation for bids (including clarification of the specifications to the bidders).

– Submission of proposals by the bidders.

– Evaluation of received proposals (request for clarifications inclusive).

– Decision for award of contract.

– Signature and entry into force of the contract.

Final (termination) stage – Acceptance procedure, operation:

– Factory, provisional and final acceptance procedures.

– Training, maintenance and spare parts supply.

– Starting up of the operation.

A3 Preparation stage: planning

This section describes the various stages, which may lead to tendering for a complete new monitoring system or part(s) of it, resulting finally in the procurement of equipment.

In the case that only a part of an existing monitoring system or an individual piece of equipment needs to be replaced, some of these stages are not needed.

In the case that a complete new monitoring system is needed, a number of fundamental requirements have to be worked out in order to arrive at a monitoring system which responds to the monitoring needs of the regulatory body, available budget, etc.

The following stages are described below:

– Concept for a radio monitoring system

– Feasibility study

– Business plan

– System planning and design

– Development of specifications for the system.

A3.1 Concept for a radio monitoring system

As described in Chapter 1 of this Handbook, spectrum management is described as the overall process which regulates and administers the use of the radio-frequency spectrum. The goal of spectrum management is to maximize spectrum efficiency and minimize interference. Rules and regulations, based on relevant legislation, form a regulatory and legal basis for the spectrum management process. Information databases, including details of all authorized users of the spectrum, provide the administrative and technical basis for the process. Analysis of the information in these databases facilitates the spectrum management process resulting in decisions for spectrum allocation, frequency assignment, and licensing. Amongst others, spectrum monitoring provides the necessary means to maintain the integrity of the spectrum management process and can be defined as a process of observing the radio-frequency spectrum and reporting on its use.

In defining the operational concept, the following elements need to be addressed:

– Automation of data management and spectrum monitoring process, with appropriate computer software. The computer software and equipment for spectrum monitoring activities are specialized. Consequently, provision of adequate materials would be essential for these activities.

– Development of automated spectrum monitoring, radio noise surveys, and direction finding facilities, both in the fixed and mobile modes (capabilities up to 3 GHz).

– Specialized monitoring facilities for microwave and other higher frequency bands and for specialized services (up to 50 GHz and above).

– Development of satellite monitoring facilities for geostationary (GSO) and non-geostationary (non-GSO) satellite systems.

– Structure of the organization (staff) and its interaction with other organizations, particularly through spectrum management.

– Existing and required infrastructure.

– Training of personnel for institutional competence and capacity building, etc.

These elements are addressed in the following sections.

Once the operational concept has been defined, a cost/benefit analysis should be conducted to assess whether the requirements of the administration would be met in a cost-effective way. This is always necessary, no matter whether a new system or the modernization/modification of an existing system is planned.

A3.2 Feasibility study

A3.2.1 The goal of a feasibility study

The feasibility study is a fundamental basis when starting a tender process. The study is needed in order to analyse alternatives, study the impact of developments on the future measurement possibilities and find the best solution, including what would be the impact on spectrum management responsibilities in case one decides not to procure new equipment.

The study should also answer the question on what the achievable advantages of the technical development are for the Authority, the information society and the spectrum users?

During the development of technical planning of monitoring measuring devices or systems, one should take into consideration the technical capability, the lifetime and deterioration of the available devices or systems.

In the course of the planning and development of measurement devices or systems, the following items should be specified and taken into consideration:

- Coverage areas of monitoring based on the:
  - responsibilities of the Regulatory Body,
  - size of the country,
  - density of the spectrum usage in the country,
  - need for other functional elements of the spectrum management process, such as frequency planning, licensing and enforcement departments,
  - responsibility of the monitoring service,
  - future planned use of radiocommunications in the country.
- Measurement tasks derived from the regulatory environment.
- Technical specification(s) of the equipment related to the tasks.
- Need for a comprehensive measuring system or for a specially designed measuring system for performing a special types of measurement.
- Number and location of (remote) fixed stations.
- The functions of mobile monitoring units.
- Number and type of mobile units.
- Purchase of a turnkey system or build-up of a system from individual components.
- Integration into an existing system or purchase of a stand-alone system.
- Necessity of remote access to the measurement and/or frequency management databases.
- Degree of dependence on a single supplier.
- Price and follow-up cost.

The depth of feasibility studies and the cost for external contributors should be proportional to the value of the investment.

A3.2.2 Content and structure of the feasibility study

For attainment of the goal of the study, the intended technical purpose, the structure, the implementation procedure, the necessary resources (financial and human), the possible alternatives and the expected completion date of the task must be exactly specified in the study.

The study should report on the topics below in detail:

- Definition of the subject of the study.
- Legal and regulatory environment and analisys of the communications market.
- Definition of the reason and goal of the study:
  - Background and justification for the new monitoring system
  - Structure of monitoring system to be implemented
  - (New) tasks for the monitoring service, including frequencie ranges to be covered, etc.
  - Existing equipment is outdated and doesn’t fullfill the required measurements
  - Usability and integration of the existing measuring equipment
  - To provide the monitoring service with technical state-of-the-art system(s)
  - To improve effective and efficient way of working by the monitoring staff
  - Number of staff needed to operate a new system

  - Required staff technical competence
  - Informatics system and data management
  - Economic calculations.
- Alternatives for the implementation of project.
- Expected further developments.
- Time schedule for the study.
- Resource planning:
  - Human resources (for the preparatory, implementation and operation stages)
  - Financial resources (for the preparatory, implementation and operation stages).
- Risk management:
  - Identification of risk factors
  - Classification of risks
  - Analysis of the effects of risks
  - On the bases of analyses, elaboration of appropriate risk management policy.

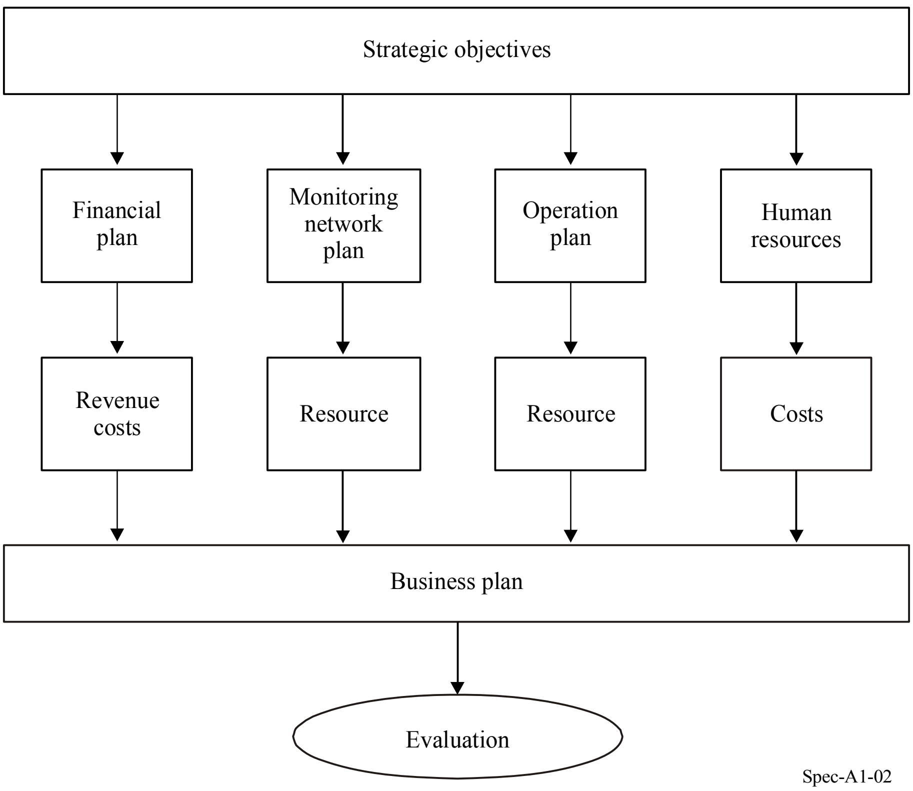
A3.3 Business plan

A system requirements study is prepared either by the administration or/and by consultants.

A tender may also be necessary in the case of replacement of equipment and in the case that some parts of the process (see Fig. A1-2) have to be modified.

FIGURE A1-2

National management of monitoring business plan



A3.4 System planning and design

This section proposes a technical approach and a methodology in order to establish a schedule of conditions for the establishment of a national system of spectrum management and monitoring which takes into account the objectives described in the preceding Chapters. In the same way, the principles described make it possible to establish a spectrum management structure built around basic functions so as to achieve what is described in the ITU-R Handbook on National Spectrum Management.

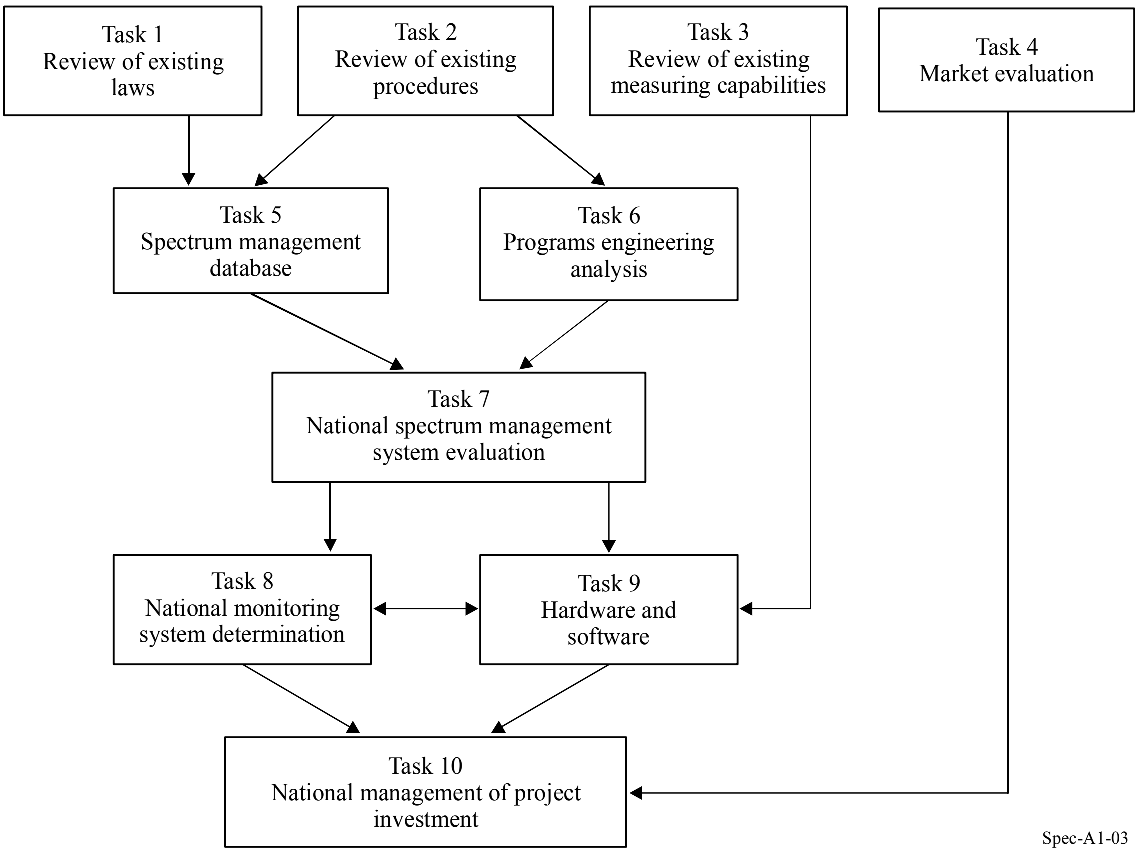
Some of its functions are grouped or on the contrary subdivided according to the traditions and resources of the country considered, thus affecting the size of the organization.

The methodology described in Fig. A1-3 is based on 10 different tasks, taking into account all legal and technical aspects generated by spectrum management in a worldwide environment.

This tender model assumes that land, building construction and utility (water, sewage, telephone, electricity, fuel, etc.) connection costs are borne by the agency issuing the tender.

FIGURE A1-3

National spectrum management and monitoring plan



A3.4.1 Review of existing laws (and legal aspects)

Task 1 will make it possible for the administration to be familiarized with the new and existing laws, at the regional and world level, which regulate the use of the spectrum. From these studies, associated with the knowledge of the national law of the country, an adequate national legal framework could be established.

A3.4.2 Review of existing procedures (and methodologies)

This task (Task 2) must be taken into account by the persons in charge of spectrum management and control. It must review and evaluate the planned organization of the regulating as well as the management operations. A framework will have to be devised that suitably harmonizes requests for licences, the attribution and granting of frequencies as well as the payments related thereto. This information will be used in order to develop a general data-processing system corresponding to the spectrum management and control needs.

A3.4.3 Review of existing measuring capabilities

During the development planning phase, the capability and suitability of the existing measuring devices must be reviewed. It must be decided what specific measurement abilities are sufficient to maintain at the present required level and what are those that must be improved by the project to satisfy future measurement demands.

The possible integration of newly purchased equipment into the existing system(s) must also be reviewed.

Additionally, the future manpower needs must be reviewed bearing in mind the new measurement tasks.

A3.4.4 Market evaluation

The use and usability of radio spectrum are essential conditions for the good functioning of the communications market. Considering that radio spectrum is a limited natural resource, it is only possible to satisfy the increasing demands of the communications market by establishing new modulation technologies (e.g. digital changeover) and opening new frequency bands. When planning the development of a spectrum monitoring system, the developers must be fully aware of the long-term spectrum demands of the communications market, the characteristics of new modulation technologies and the new frequency bands waiting to be opened. Considering the quick development of measuring systems, an effort should be made to avoid the obsolescence of a new system, even shortly after its first operation.

A3.4.5 Database of spectrum management

The spectrum management database will allow the analysis of the data elements in quantity and quality. This is necessary for effective management of the spectrum in the country. This implies analysis of the data (existing hard copy or electronic media) and their integration in the new information processing system, which will rationalize the information flow and will ensure its storage (see Recommendation ITU-R SM.1413 – Radiocommunication Data Dictionary, for notification and coordination purposes).

A3.4.6 Programs engineering analysis

The necessary engineering functionalities and modules of application should be determined and should include/explain mainly the following:

– Frequency assignments.

– Engineering systems analysis.

– Interference and electromagnetic compatibility.

– Calculation of the royalty billing.

– Inspection.

– Ratification – approval.

– Reports/ratios.

These application software modules must be directly interconnected with the administrative management database. Chapter 7 of the ITU-R Handbook – National Spectrum Management contains a list of the basic and optional modules required.

A3.4.7 National spectrum management system evaluation and monitoring system determination

In these tasks, the frequency monitoring capabilities and the requirements for an efficient nationwide monitoring system are determined. The need for a regulatory system ideally requires the establishment of both national and regional administrative offices and various types of monitoring stations. In some instances the administrative offices and monitoring stations may be accommodated in the same buildings, but not all monitoring stations will have identical facilities. Some monitoring stations will be required to monitor only VHF/UHF spectrum whilst others will monitor frequencies below VHF and/or above UHF. The location of unknown transmitters and sources of interference will be a major activity requiring suitable direction-finding capability which includes mobile stations.

Major objectives of the radio monitoring system are to support the primary activities required for national spectrum management, as well as checking for compliance with ITU regional and worldwide frequency allocations and with those allocated through bilateral agreement. To be effective, the radio monitoring system must cover all the major population centres throughout the country on a continuous basis. The tasks and activities that must be conducted by radio monitoring systems, as well as the necessary equipment, are described in this Handbook. The establishment of the technical specifications for and operation of a national regulatory monitoring system will be documented. These tasks must also consider the existing and/or development of the frequency management databases and associated planning software packages that will be required to administer policy.

A3.4.8 Hardware and software evaluation

According to the data processing needs (hardware and software) as well as the equipment of inspection vehicles expressed in the conclusions of Tasks 5, 7 and 8, the experts dedicated to this task must optimize and/or direct the solutions found based on the criteria of cost of maintenance/training.

A3.4.9 National management of project

At the completion of the network design, the project manager, data engineer and the financial analyst will develop the capital costs and investment requirements for the spectrum monitoring network. It is assumed that part of the national network can be provided using existing facilities or enhancing existing infrastructures. It will also be necessary to assess the budgetary limitations that the country may impose upon the spectrum programme project, so that a system concept and specifications that are within these constraints may be developed. In the case of a limited budget, the committee could make recommendations on the time phase programme that would meet the budget requirements and meet the immediate spectrum monitoring requirements. In line with this study (project investment brief), the committee prepares a project report including tender documents for submission to the national authorities.

A3.5 Development of specifications for the system

A3.5.1 National and regional centres, monitoring stations

Administrations in smaller countries tend to have a national monitoring centre and an appropriate number of fixed and/or mobile monitoring stations, which are controlled directly by the national monitoring centre. Administrations in larger countries may find it desirable to have regional monitoring centres in addition to the national centre. In either case, the national monitoring centre may also include a national spectrum management centre to provide integrated automated management and monitoring of the radio spectrum.

The mobile monitoring stations supplement the network of fixed stations. In practice they have the same measuring capabilities as for fixed stations, but can easily be installed almost anywhere in the country, to be able to monitor different areas.

In compliance with their functions, certain mobile monitoring stations (vans for interference investigation, coverage measurement, measurement of microwave networks) possess specialized measurement capabilities. When specifying their types and necessary number, an effort should be made to achieve the most optimal building-up and measurement capacity during the planning stage. In the case of mobile stations, the required frequency of the measurement tasks should be taken as the first criteria when specifying their necessary number.

During the planning of the system's measurement capacity, the necessary number of fixed stations depends on the size and the terrain conditions of the area, as well as the frequency range that must be monitored.

When designing a mobile monitoring station, a compromise must be found between full-scale equipment, budget and limitations on weight and space of the vehicle. Therefore, it must be decided whether a general-purpose vehicle or a specialized vehicle, for the task at hand, should be procured.

The available service network and spare parts supplies in the country for the selected vehicles are also important criteria.

A3.5.1.1 Monitoring station organization, number of operator positions and equipment

The following points will have to be defined:

Control centre/monitoring station	Organization/tasks/means/interactions
Hierarchical position	National/regional/local/other
Allocation of responsibility	Frequency range (e.g. VLF up to HF and/or VHF/UHF and/or SHF) Services to be monitored, services areas List of monitoring stations to be directly controlled and list of mobile stations List of dependant lower level control centres
Organization of the work	Existing computer or network architecture(s), software for automation For the number of operator positions, specify: – Operating hours/number of shifts – Hierarchy and responsibility sharing between operators – Tasks/reports/document follow-up procedures (specify) Archiving methods and resources (data, audio, interval…) Reporting resources Security concerns and procedures
Work position description	Controls all or some of the remote station functions Programme or scheduled automated tasks to run off-line in remote stations Perform location computation and display results Access to database to consult technical frequency management files (interactivity) Display of geographical information Issue automated reports Expected response time (specify for each task) Maximum number of simultaneous connections with remote stations and type of connections (data, voice-grade or broadcast-sound grade audio, etc.) Maximum number of simultaneous recordings (if done at control centre) Man-machine interface: language(s), operation system and database
Interaction with the frequency management system	Is a computerized frequency management system available? If yes, which one? Is interaction with the frequency management system required? Availability of a local frequency management database?
Geographical information system (GIS)	Which geographical information system is available with which integration format? 2-D (road map, administrative map, topographic map), vector and/or raster 3-D (digital terrain model) Coordinates to be used (UTM, geographical, etc.), scales and resolutions, areas required
Communications	a) Resources for operators:

Control centre/monitoring station	Organization/tasks/means/interactions
	– Fax/telephone/Internet (individual or shared) – E-mail (with work positions, control centre(s), station(s), frequency management department, etc.) – Radiocommunication resources (public, private, HF, VHF/UHF, SHF) b) Resources for remote stations or other control centres: – Private networks – Private point-to-multipoint (radio/microwave/PSTN/ISDN/analogue or digital leased lines/X25/VSATs, Internet, etc.) – Speed and bandwidth

A3.5.1.2 Measurement tasks

It should be noted that it is the responsibility of each country to decide on the measurement tasks and the related frequency ranges to be covered.

To define the essential measurement equipment characteristics for each operator position, the following points should be specified:

Frequency measurement

– Frequency range
– Required accuracy (is a central frequency standard available?)
– Classes of emission (measurement method).

Field strength, level and power-flux density measurement

– Quantity and methods of measurement at fixed stations and at mobile stations
– Required accuracy
– Frequency range
– Special measurements:
  – Coverage measurements (measurements along a route), measurement of antenna patterns (e.g. by helicopter).

Spectrum occupancy including channel occupancy measurement

– HF, VHF/UHF emissions
– Technical specifications of channels: bandwidth, spacing, type of modulation
– Duration of occupancy recording: continuous, time from … to …, special days, distribution of scans
– Required scanning speed (software)
– Additional information to be recorded (e.g. call sign, automated identification/decoding).

Occupied bandwidth measurement

– β/2 and/or x-dB methods of measurement using a spectrum analyser or software
– Others methods.

Modulation measurement

– Modulation depth
– Frequency deviation

– Bit error rate (BER)
– Other quality parameters
– Constellation diagram.

Direction finding and location measurement

– System concept
– Type of station: fixed, mobile, transportable, portable and required accuracy
– Frequency range
– Location (by triangulation or SSL), digital terrain mapping required
– Response time
– Needed space for DF antenna
– Display of bearings on digital maps.

Identification measurement

– Classes of emission
– Identification (e.g. decoding) of the various transmissions
– "Fingerprinting"/individual transmitter envelope characteristics.

Monitoring of spacecraft emissions

– Frequency, bandwidth, power-flux density measurements
– Determination of orbital positions
– Occupancy of frequency bands at orbital positions.

Multimedia broadcast

– Type terrestrial or satellite
– Quality of received signal (special equipment needs)/decoding.

Cellular networks to be monitored:

– System parameters to identify network type
– Field strength
– Quality parameters (e.g., RxQual/CIR/BER)
– Additional information (e.g., handover for cellular radio)
– Number of channels
– Maximum allowable distance between measurement points
– Maximum distance between measurement points of the same frequency/channel (valid for all allowed velocities)
– Is a special data evaluation tool needed and is it intended to combine this system with the mobile monitoring (mapping) system?

Microwave links including satellite links

Receiving and measuring equipment in the 1 to 50 GHz range and for which services?

A3.5.2 General equipment specifications

With regard to the elected measurements: to select the equipment allowing for these measurements for each monitoring centre, fixed (remote) and/or mobile monitoring station.

a) System concept and architecture centre, station, means of communications, software

The performance of a monitoring station is directly related to the quality of antennas, receivers or field meters and radio direction-finders.

b) Antennas

To determine the type and number of antennas for each station with regard to the elected measurements, the following information has to be known:

- Basic information:
  - Polarization (diversity) and frequency range (sub-ranges)
  - Approximate distances from the region to be monitored (radius)
  - Geographic pointing of the antennas (degrees)
  - Distance between antennas and signal distribution system.
- Signal distribution system:
  - Frequency range
  - Number of receiver connections per antenna
  - Number of antennas if antenna diversity is required
  - Operation of the signal distribution system: manual, semi-automatic or automatic.
- Omnidirectional and dipole antennas:
  - Active receiving antennas
  - Transmitting/receiving antennas
  - Air traffic control antennas.
- Directional antennas
  - Linearly polarized log-periodic antennas
  - Dual-polarized log-periodic antennas
  - Dish and feed antennas.

For all antennas: frequency range (from 10 kHz to 50 GHz or higher); identification of the antenna types in cooperation with the system supplier.

c) Receivers, direction-finders

- Frequency bands
- Reception channel number
- Analogue or digital type
- Manual or automatic control (computers, software).

d) Additional equipment

Certain additional equipment will permit more effective operation of a monitoring station. One example is the reporting equipment: reproduction machines, oscilloscopes, audio-video recorders, printers, etc., or:

- Frequency (10 MHz) and time standard (rubidium, GPS or GLONAS)
- Air conditioner.

For mobile monitoring:

– Navigation and positioning system (dead-reckoning system, GPS, GLONAS (or other), or a complex navigation system)

– Compass for azimuth determination.

A3.5.3 Monitoring vehicles and devices

The VHF/UHF bands mobile monitoring stations shall be designed and fixed in a vehicle, and shall be completely equipped with all necessary monitoring equipment, monitoring antennas, modem(s) communication antenna(s), GPS and GPS antenna, interconnecting cables, power supplies, cabinets, racks, mounting hardware, interface devices and terminal blocks to form a complete and working stand-alone system, as well as a reliable component that is an integral part of the national spectrum monitoring system. The vehicle can be also equipped with portable measuring instruments for doing spot monitoring or exact interference source locating.

When purchasing a vehicle, the following options must be considered:

– Type of vehicle (van, jeep, passenger car)

– Engine type (petrol, diesel)

– Four-wheel or two-wheel drive

– Size and weight.

A3.5.4 Software

The management system and monitoring system shall contain a significant amount of software to automate data collection, processing, evaluation, and interference analysis tasks. Using software to save spectrum monitoring results in relational databases and correlating this information with the central database of authorized users will save considerable research time while increasing accuracy.

The monitoring system application system and control software shall be developed in accordance with ITU-R Recommendations, in particular Recommendation ITU-R SM.1537, the Handbook – National Spectrum Management (2005) and the relevant recommendations of the Handbook on Spectrum Monitoring.

Monitoring application software items:

– Digital mapping software.

– Direction-finding software (integrated with the mapping software).

– Database management software.

– Intelligent archive system software.

– Interface software between licensing database and monitoring measurement results.

– Measurement result evaluation software (data filters, post processing and graphical displays of data, automatic reference values and licence database compliance investigation).

The monitoring application program shall be of a user-friendly design, and shall be described in detail in the relevant manuals and guidelines.

A3.5.5 General requirements for the units of monitoring systems

In the Technical Annex concerning the invitation for tender document, the measurement tasks, the required equipment and the expected minimal technical requirements are specified and published.

The optimal number of fixed, mobile, portable or hand-operated measuring systems and the division of the measuring tasks among them must be decided on during the implementation planning of the project. For detailed information on the technical requirements for the monitoring systems' units, see Chapter 3 of this Handbook.

A3.5.6 Specifications for services

A3.5.6.1 Site survey

The location of a fixed radio monitoring system has a very important effect on its efficiency and on the costs that are involved. Siting is governed by geographic, topographic and climatic conditions, including local noise, and sites must be selected very carefully because this will guarantee the required performance of the overall system.

Generally, the user is responsible for site investigations. Documents, results of measurements, topographical maps, etc., must then be made available.

When developing the systems' operational concept, the number of individual stations and their tasks will be decided on, and the selection of sites can then be made according to ITU-R Recommendations. In the HF range, sites can be selected by evaluating computerized radio-propagation forecasts, but supplementary measurements should still be carried out on-site.

A3.5.6.2 Telecommunication links and network

– Are telecommunication links between the individual stations listed? If so, of what kind (physical lines, radio links, microwave)? Will the administration provide them? Are telecommunication lines available?
– What is to be transmitted (voice, music, data)?
– Details of lines: type (public dialling network, dedicated network, dedicated telecom line with interfaces in line with ITU-T Recommendations (e.g. V.24)), quality (transmission rate in bauds, bits/s), length, system (two-wire, four-wire).
– Details of radio or microwave links: frequency, mode, channel bandwidth and transmit/receive systems. If available, computers are to be integrated into the system, it is then necessary to have details of the type, memory capacity, interface conditions, peripherals and software. A transmitter (or transmitters) shall normally be operated remotely to avoid interference to the monitoring station.
– Details of structure: point-to-point, point-to-multipoint, ring, star.
– Is masking or encryption called for?

A3.6 Training

In order to make effective use of the monitoring facilities, it is essential that a comprehensive training programme be acquired, along with the monitoring facilities. The Bidder shall provide suitable training for the staff in the form of classroom training and on-the-job training, either in the country or abroad. There are two components to this training programme, as listed below:

Factory training is to be provided at the supplier's factory on equipment that is identical to that being purchased by the Administration. The classroom training must include a course on the fundamentals of spectrum monitoring (and spectrum management) by suitably qualified instructors with first-hand experience.

Site training is to be provided at the administration's monitoring facilities once the equipment has been installed. Most of the remaining time shall be used by the administration to learn on-the-job the increasingly sophisticated monitoring tasks. A final information course shall be provided to show how monitoring information is to be used to validate national spectrum monitoring.

The number and qualifications of the persons taking part in the training, the location and duration of the training must be discussed. This calls for separate training courses at different levels.

A3.7 Maintenance and repair

The concept for maintenance and repair should in all circumstances be worked out (e.g., what is to be repaired locally, what centrally and what by the manufacturer(s)?)

Stocking of spares, the considerations to be taken into account are as follows:

a) Single component.

b) Sub-assemblies (e.g. circuit boards).

c) Whole rack-mounts or plug-ins.

d) Critical equipment (not forgetting the mean time between failures (MTBF)).

It is also necessary to check the time interval for which the stocking is intended (not forgetting the differing mean time to repair (MTTR)).

A3.8 Documentation

Equipment/system documentation should be provided in the necessary language(s).

Detailed documentation must be available as part of the project.

A4 Implementation stage: Tender processes

A4.1 Specimen of invitation for monitoring tenders

Depending on the type of tender procedure, the invitation for monitoring tender is an advertisement, which invites bidders to implement a project. Usually, the national legislation prescribes its form, the required contents and the applicable rules of the tender procedure. The invitation for tender gives a brief description of the project's background, the scope of work and the duties of bidders and customer. This may also contain information on site inspections and any deadline for clarifications of the bidding documents. The technical requirements of the monitoring system are detailed in the enclosure of invitation for tender.

The tender procedures, including publications, are dependent on the national law.

A4.1.1 Invitation for monitoring tender document should include the following:

A4.1.1.1 Guidance part

This section of the bidding documents provides the information necessary for bidders to prepare and submit constructive bids that meet the purchaser's requirements. The guidance part describes the critical steps of a bid submission, opening and evaluation, and the award-of-contract stipulations.

– Availability of data from the purchaser administration who issued the invitation for tender to supply and install the new system.

– Summary (of the project).

– Availability (and sometimes the price) of the technical enclosure of the invitation document.

– Instructions for the required format and content of the tender document.

  (Filling out the registration form clearly and legibly is very important as it can ensure that registered applicants receive information on any possible modification, amendment or clarification regarding the contents of the tender document.)

– Stipulations, of participation and mandatory prequalification (of bidders), that they have the financial, technical, and production capability necessary to perform the contract and meet the specified qualification criteria:

  – Certified references (experience in handling similar contracts with names of former clients)
  – Competence with respect to personnel, equipment, and construction or manufacturing facilities
  – Financial and economic stability
  – Quality assurance system.

– Manufacturer's authorizations (if manufacturer is other than supplier).

– Queries:

  Bidders requiring any clarification about the invitation to tender shall submit their queries by fax or e-mail:

  – Name(s), address and telecommunication facilities
  – Deadline for bidders to submit queries in writing (before the pre-bid meeting)
  – Deadline for relevant replies from administrations is communicated to all registered bidders.

– Pre-bid meeting (date, time and place of clarification meeting, generally not less than three weeks prior to the deadline for submission of bids).

The bidder shall bear all costs associated with the preparation and submission of his bid, and the purchaser will in no case be responsible or liable for those costs

– Technical visit to installation sites:

  Two options:

  Option 1: Bidders that so desire may conduct a site survey in order to make sure that the equipment it intends to propose matches actual tender requirements. The cost of visiting the site or sites shall be at the bidder's own expense.

  Option 2: For many tenders, the purchasing administration requires from the bidders a visit to the sites. For each visited site, the administration delivers an official site report signed by both parts. These documents should be supplied with the offer. Failure by a bidder to make a site visit is a cause for disqualification.

– Instructions to bidders:

  The bidding documents shall furnish all information necessary for a prospective bidder to prepare a bid for the equipment and work to be provided. Bidders are expected to examine all instructions, forms, terms, specifications and other information in the bidding documents. Failure to furnish all information or to submit a bid not substantially responsive to the bidding documents in every respect will be at the bidder's risk and may result in the rejection of his bid.

  – Submission of proposals:
    – Address (for submission of bid)
    – Number of the original and copy tender documents
    – Legalize the bid (signed by a person or persons duly authorized to sign on behalf of the bidder)
    – Sealing and marking of bids
    – Deadline for submission of the bid (any bid received by the purchaser after the bid submission deadline will be rejected and returned unopened to the bidder)
    – Bid language issues (working language, technical documentation comprising the bid, instruction manuals, software interface, etc.).
  – Bid forms
  – Price and currency proposal
  – Conformity to international standards meeting the requirements of the latest ITU Recommendations on the subject
  – Up-to-date design and the use of modern techniques (high standard of performance and reliability)
  – Delivery

- Guarantees
- Specific information to be provided in the proposal.

With regard to national laws and the principles applied by administrations: "Proposals shall contain, but not necessarily be limited to, the following information":

For example:

- Proposed organization of the work (organizational chart(s), work plan, etc.)
- Detailed description of the work plan and final delivery of products
- Name and Curriculum Vitae of all staff assigned to each particular task
- Statement of compliance/non-compliance
- Deviations from specifications, in particular if the bidder can prove that the alternative offered will be in all respects as satisfactory and as fully capable of meeting the administration's needs, fully conforming to the Technical Specifications. The alternative offer must be fully explained.
- On-the-job training. The proposal must clearly indicate: Curriculum Vitae of the training staff, objectives, target group, desired entrance qualification and number of trainees.
- Tender Bond (Tender Guarantee, or Bid-Bond)

  This document contains the Bidder's bank guarantees: in the case that the client withdraws from the conditions proposed in his bid within the validity period, the bank pays the amount of the guarantee (generally 2% to 5% of the bidder's proposed price) to the Purchaser Authority.
- Performance Bond (will be required only from the winning bidder)
- Validity of the proposals (must be valid for an established time period after the deadline date for bid submission prescribed by the purchaser)
- The original of the technical and commercial proposals shall be signed by an official legally authorized to enter into contract on behalf of the bidder; generally, each page of the original shall be witnessed.

– Evaluation of proposals:

- Date, time and place for opening the sealed proposals
- Detailed specification of the viewpoints and method for evaluation of the bids.

– Disqualification conditions:

- The offer is rejected if it is incomplete (e.g. Bid Bonds, validity of the offer).

Bids may be rejected:

- After the technical evaluation shows that one or more of the recommended technical parameters is less than the minimal requirement in the call for tender document.

Bidders shall be notified of the decision taken, within the indicated date in the tender or the legal date (by fax, followed by a letter).

A4.1.1.2 Main articles of the contract

- Subject of contract
- Obligations of the customer
- Obligations of the bidder
- Payment conditions (timing and method of payment)
- Guarantee conditions
- Procedure in case of violation of contract
- Procedure in case of *force majeure*

- Procedure for disputed cases
- Management of confidential information
- Modification of contract
- Other instructions.

A4.1.1.3 Technical requirements

- Subject of the tender
- System description
- Inclusions (what the project will include, like software, infrastructure, services)
- Others inclusions (like warrantee, spare parts, software support and update)
- Minimum technical requirements for each parameter of the system and each measuring instruments.

A4.2 Bidder proposals specimen

A4.2.1 Introduction

- Introduction of bidder and their expertise
- Advantages of the proposed system
- How to adjust the proposed system to future needs
- Ability to integrate into the customer's existing system
- Inclination to take part in further developments
- List of proposed sub-contractors
- Period of validity of bids.

A4.2.2 General technical characteristics

- Performable measurement tasks (e.g. according to the relevant standards)
- Operating frequency range
- Accuracy of measured data.

A4.2.3 System functions

- Characteristics of the system

  Information on how they match up to the technical demands of the tender.

A4.2.4 Method of system implementation

- Designation of local sub-contractors, installation and starting up.

A4.2.5 Technical guarantees

- Period of guarantees (system, software)
- Provision period for spare parts after guarantee has elapsed.

A4.2.6 Detailed description of:

- Undertaken tasks
- Presentation of delivered products
- General system characteristics
- Technical specifications of each measuring instrument of the system

– Setting-up in accordance with requirements
– Remote and local control
– Data storage and transfer
– Possibilities of further developments
– Characteristics of software and integration with spectrum management
– Power supply solutions
– Types and characteristics of antennas
– Type(s) and technical data of vehicle(s)
– Health and safety solutions
– Calibration and selftesting
– Implementation schedule and delivery deadlines
– Expected tasks from customer
– Training
– Resolving controversial matters
– Etc. (e.g. bid for system and software maintenance contracts).

A4.2.7 Presentation of references

– Financial and economic stability
– Certified references
– Quality control system
– Copy of the company's registry court document
– Manufacturers' authorizations
– List of approved sub-contractors.

A4.2.8 Block diagrams of the system

A4.2.9 Price

– Individual prices and total price
– Terms and conditions of payment.

A4.3 Specimen contract format

The contract is a legally binding exchange of agreements between parties that the law will enforce. Breach of contract is recognized by the law and remedies can be provided.

The contract documents must clearly define the scope of work to be performed, the goods to be supplied, the rights and obligations of the purchaser and of the supplier or contractor.

Introductory provisions

– Designation and addresses of the contracting parties
– Preliminaries to the contract
– Scope, character and purpose of the contract
– Terms used in the contract
– Working language.

Legal status of the parties, their rights and obligations

- Rights and obligations of the supplier concerning:
  - Sub-contracting
  - Shipping and installation of system and system elements
  - Guarantees
  - Repairing and maintenance of system
  - Repairing, maintenance and development of software
  - Related services
  - Training related instructions.
- Rights and obligations of the customer:
  - General instructions
  - Customer's right to supervision
  - Obligatory cooperation
  - Obligatory payment
  - Training related obligation.
- Applicable law and forum for settlement of disputes.

Subject of the contract

- Subject of the contract
- Software and related rights
- Provisions related to the completion of the contract
- Compliance with statutes, laws, regulations, etc.
  - Installation place and date of completion
  - Method of fulfilment
  - Date of completion of the contract
- Procedure of acceptance:
  - Factory acceptance prior to the acceptance procedure
  - General rules for the acceptance procedure of the system
  - Place of the acceptance procedure
  - Minutes to be drawn up during the acceptance procedure
  - Acceptance procedure of fixed and mobile stations
  - Acceptance of the software and the completed system
- Packing, shipping and insurance
- Product upgrades
- Additional services:
  - Training
  - Services to be provided under warranty.

Contracted responsibility for performance; rules dealing with impossibility of performance

- Responsibility of the supplier in case of improper performance:
  - Obligations of the supplier
  - Penalty obligation of the supplier
  - Obligation of the supplier to remedy failures
  - Warranty obligation of the supplier
- Client's responsibility for improper performance
- Impossibility of fulfilment.

Prices and terms of payment

All prices shall include what was required by the tender document.

Fees to be paid for the production, installation of the system as well as the related additional services:

- Total contractual price
- Payment of the contractual price
  - Additional payment obligations.

Prices shall be quoted, excluding taxes, based on national regulations.

Miscellaneous and final provisions

- Obligation of Parties to cooperate, handling of confidential information
- Settlement of disputes, enforcement of legal rules, governing law
- *Force majeure*
- Amendment(s) to the contract
- Validity and termination of the contract
- Other contracts concluded between the Parties
- Responsible contact person(s) duly authorized by the Parties
- Liquidated damages
- Compensation.

Annexes to the contract

Annexes to the contract will be based on the procedures from either ITU, the World Bank or the purchasing administration.

In all cases, the bid will always be annexed to the contract.

A4.4 Evaluation and comparison of proposals and award of contract

For the evaluation and comparison of proposals, the purchasing administration needs to follow a predefined process of evaluation such as:

- Procedures as defined by the International Telecommunication Union (ITU)
- Procedures as defined by the World Bank
- Procedures in the case that the purchasing administration is not bound to the procedures of ITU or the World Bank.

A tender evaluation committee appointed by the purchasing authority will evaluate the bids from the financial, legal and technical aspects. The evaluation methodology will be defined by the purchasing administration and should be described with all details in the evaluation report of the committee.

The proposals submitted by the bidders may be opened in the presence of the bidders' representatives at the stipulated time and place specified in the invitation to bid. Proposal may be rejected if not accompanied by a Bid-Bond.

During the evaluation, the purchasing administration may ask clarifications from the bidders as to their offers.

A4.4.1 Procedures as defined by ITU

Evaluation of proposals:

- Evaluation group established by ITU *or* by ITU and the purchasing administration
- Technical evaluation and commercial evaluation carried out separately (technical evaluation is carried out first):
  - The technical evaluation should cover the following main points:
    - Measuring receiver, antenna system, workstation, software, optional DF system, Factory Acceptance Test (FAT), delivery, training (see Appendix 1: ITU example of the technical analysis of the proposals)
  - The commercial evaluation should cover the following main points:
    - Price, payment terms and conditions and commercial conditions, legal evaluation (see Appendix 2: ITU example of the commercial and legal evaluations)
  - Appreciation of technical problems
  - Capability
  - Experience of experts
  - Total price
  - Incomplete offers shall be rejected
  - Confidentiality (no information concerning examination, clarification or evaluation shall be communicated to bidders or any other concerned person)
  - Bidders shall be notified of decisions as soon as possible (by fax followed by letter).

Rejection of proposals:

- ITU reserves the right to reject any proposal and to call for a second tender
- No obligation to accept the lowest **priced** tender.

A4.4.2 Procedures as defined by the World Bank COST or PRICE

NOTE: The terminology used is that of the World Bank.

When the World Bank (WB) (IBRD or IDA) delivers a loan agreement to one of its Members, the WB supplies the borrower with a set of GUIDELINES named "Proposals Evaluation Report". These guidelines facilitate the borrower proposals evaluation in conformity with the *Directives: Contracts signing financed by IBRD loans or IDA credits – January 1995 (January 1996, August 1996 and September 1997 revisions)*, refer to paragraph 2.53 and paragraphs 2 and 4 of Annex 1 in particular.

(See dbusiness@worldbank.org)

NOTES:

1. According the Directives in paragraph 1.6 and footnote page 9, some countries are not authorized to profit from the contracts financed by the WB,

2. The State of the borrower can exclude countries or territories from the tender if the borrower can apply the criterion given in paragraph 1.8,

3. The United Union Security Council under United Union Charter Chapter VII can forbid a WB loan close to determined countries.

The Proposals Evaluation Report (PER) describes the procedure for the borrower to evaluate the received offers. Moreover, in all cases , it is of importance to apply the evaluation and request procedures described in the Instructions section of the tender document. The PER includes a letter of advice and its annexes are sent to the WB.

The borrower must examine the evaluation tables included in the Guidelines during the project's preparation in order to determine the staff needs required for the offer's evaluation. The WB can explain in detail the procedure to be followed. The WB encourages the borrower to contract consultants with relevant experience to evaluate the offers relating to complex projects. The consultant's contribution can eventually be financed by the loan if the agreement allows for this (Directives, Annex 1, paragraph 2-C).

The PER includes:

Preamble

Forms – usage

Typical forms for evaluation of offers

LETTER OF ADVICE

a) If the project is subject to previous examination from the WB (WB agreement before project awarding decision), the borrower (ministry, organism or service) should send the PER to the WB under cover of a letter of advice. This letter should indicate the evaluation conclusions and supply all complementary information liable to facilitate the WB evaluation.

b) For projects subjected to an *a posteriori* examination procedure by the WB (WB agreement not necessary for project awarding), the evaluation report and a signed copy of the contract should be presented to the WB previous to (or simultaneously) any demand of payment (Directives – Annex 1 and loan agreement).

TABLE 1: Identification

Description of the loan agreement, in particular that of cost evaluation and WB evaluation procedure (administrative data)

TABLE 2: Evaluation procedures

Tender publications (administrative data)

TABLE 3: Proposals delivery and offers opening

In accordance with the Directives, paragraph 2.44, this Table gives the date, time, number of offers, offers' validity. If the tender procedure is in two stages (technical and economic), this Table should be supplied for each step. The opening meeting minutes should be addressed to the WB and to each supplier.

TABLE 4: Prices of offers (Public lecture)

All the modification of the prices read in public including discounts, options, variants, etc., should be described in Table 4.

TABLE 5: Preliminary examination

Conformity with the tender obligations, including technical specifications. The evaluation process should start as early as the offer opening. The preliminary examination forms the subject of identifications and rejections of offers that are incomplete, not admissible or do not correspond to the tender's essential provisions and which consequently should not be evaluated. This examination should consider the following points:

– Verification: identification of offer's deficiencies

– Origin criterion

– Offer guarantee

– Conformity with tender dispositions and technical specifications.

The evaluation principles are the following:

– The borrower should evaluate the proposals only with regard to the tender obligations and information

– During the evaluation process, the borrower can ask the suppliers to provide more information on equivocal points or incoherencies noted in their proposals. These demands are presented in writing but the suppliers cannot modify the prices and the type of supplies, work or offered services except for errors in calculation (Directives, Annex 4, paragraph 10). Any price or offer requisites cannot be modified.

TABLE 6: Unconditional corrections and discounts

For each supplier, this Table gives the offer prices, the corrections (calculation errors), the discounts and the total amount of the offers.

TABLE 7: Exchange rate

The exchange rates used for the evaluation are indicated.

TABLES 8A and 8B: Currency exchange

According to the currency chosen by the borrower and indicated in the tender, these Tables give the offer's total amount in the borrower's currency.

TABLE 9: Additions for omissions, adjustments and currency variations

Table 9 gives the offer's price totals.

– Omissions, mistakes detected in the offers should be balanced by additional prices. (Omitted elements in one offer can be met by the other offers, pricing average.) At the same time, it is possible to refer to external sources such as pricing lists, transport cost scales, etc.

– Adjustments: the tender instructions give the implementation and operation criterion.

The offers, including minor variations with respect to tender instructions, can be considered acceptable if after detailed analysis it is possible to give it a monetary value, which is added to the offer prices, as a penalty, to facilitate comparisons.

The evaluation methodology concerning these factors should be described with all details in the evaluation report and fully in compliance with tender instructions.

Sometimes, the WB authorizes the use of a point system for the supplies purchased. In this case, the adjustments are expressed in points (see Directives, paragraph 2.6.5). In order to obtain details on offers evaluation by means of a point system, the borrower can obtain the advice from the WB.

TABLES 10A and 10B: Priority rights for national supplies and works

If the tender allows a national preference, it is possible to take into account national customs and the preference margin given in the tender provisions.

TABLE 11: Final evaluation of offers and contract awarding proposal

Table 11 sums up all the data included in the above Tables (prices at the opening meeting, error corrections, discounts, adjustments) and nominates the tender winner.

Annex I: Instructions for offers evaluation

Annex II: Meeting for offers opening. Information on offers

Annex III: Non-eligible countries

Annex IV: Example of preliminary examination

Annex V: Proposals evaluation Report. Content.

A4.4.3 Procedures in case the purchasing administration is not bound to the procedures from ITU or the World Bank

Before the evaluation starts, the evaluation committee decides on which methodology is to be used to decide to which bidder the contract can be awarded. The following methodologies can be used:

– Scoring approach by use of formulas
– Weighting method
– Yes/no compliant
– Compliant combined with the offered prices

A5 Final (termination) stage: Acceptance procedure

A5.1 Factory acceptance

The provider shall (at its own expense) carry out at the place of manufacture all such tests and/or inspection of the equipment and any part of the equipment as specified in the contract according to the factory acceptance documents submitted by the provider amended or not by the administration (mutual agreement).

A5.2 Site acceptance test procedure

The provider supplies the site acceptance document(s) to the administration and shall give a reasonable advance notice of such test and/or inspection and the place and time thereof. The tests are carried out to demonstrate that all items of equipment are present; that they are correctly assembled and interconnected; that they function correctly according to the technical specifications (visual inspection and technical tests). A final test of the entire system including the communication links should be carried out taking into account the respective responsibilities of the administration and the contractor for the supplies.

Acceptance of the system is normally followed by a one-year warranty period, during which the provider may be required to maintain a warranty bond. Alternatively, for some administrations, provisional acceptance is given upon successful completion of an acceptance test, then at the end of a fixed period of time (usually the warranty period), final acceptance is given.

A5.2.1 Acceptance (or provisional acceptance in the case of provisional and final acceptance)

Acceptance shall occur with respect to the equipment or any part thereof, when:

– the acceptance test has been successfully completed and functional guarantees are met;
– the acceptance test has not been successfully completed or has not been carried out for reasons not attributable to the provider.

Acceptance shall not be withheld if minor discrepancies or problems exist. Rather, acceptance shall occur and the discrepancies and problems shall be noted and corrected during the warranty period.

The following list provides an example of the site acceptance test procedure report content concerning a HF/VHF/UHF fixed station:

a) *Subject*

The document describes the acceptance procedures of a spectrum monitoring station under the terms of the contract.

b) *Visual inspection*

Operations to be carried out to check the presence of all the items listed on the contractual configuration statement:

– Antenna systems, switching, cables, lightning protection

– Masts, towers (stays, painting, lightning)

– Inspection of building, wiring, security devices, frames, racks, computers, receivers, energy

– Software implantation

– Equipment manuals, software and system

– Marking (equipment homologation)

– Documentation will be controlled and the list of the delivered documents annexed to the acceptance report.

c) *Technical tests*

– Energy check (mains supply and UPS);

– HF/VHF/UHF direction-finding functions: fixed frequency, scanning, location;

– HF/VHF/UHF ITU measurements: fixed frequency, frequency scanning, memory scanning;

– Signal analysis;

– Manual and automatic missions: systematic control of transmitters, frequency occupation rate, search of unknown transmitters;

– Build integrated test equipment (BITE).

The result of the tests carried out during acceptance will be consigned in the acceptance test report signed by the administration and the supplier.

A5.2.2 Final acceptance

In the case of acceptance followed by a warranty period guaranteed by a warranty bond, this section does not apply. In the case of a provisional acceptance followed by a final acceptance, the provisional acceptance certificate is signed by both parties, according to the administrative terms specifying the warranty period (generally one year), and after this period the final acceptance certificate is provided.

Appendix 1

to Annex 1

ITU example of technical analysis of the proposals

TABLE A1-1

Functional parameters	Specifications	Requirements	COMPANY Y Basic	COMPANY X
Control	Monitoring and supervision of radio signals	Operational functions, for training purposes	COMPLIANT	Option 1: software only – NOT COMPLIANT Option 2: Hardware + software Only Option 2 is considered below
1 Frequency range of monitoring receiver:	Frequency range: 100 kHz – 2.5/3 GHz	The frequency range must include all radio services operated in the bands indicated	COMPLIANT	COMPLIANT with some reservations (see observation on last row)
2 Receiving antennas:	Frequency range: 100 kHz – 2.5/3 GHz	In accordance with the system's characteristics	COMPLIANT	COMPLIANT
3 Operating modes:	Manual and automatic	The system must make it possible to differentiate between manual and automatic monitoring	COMPLIANT	COMPLIANT
4 Measurement of technical signal parameters:	1) Frequency 2) Field strength and power flux-density 3) Bandwidth 4) Modulation percentage (AM) 5) Frequency offset (FM) 6) Spectrum analysis 7) Spectrum occupancy measurements	– Measurements in accordance with ITU-R Recommendations and RR. – Real-time and differentiated measurements. – Interception, demodulation, recording and analysis of signals – Free determination of the threshold for signal reception	COMPLIANT	COMPLIANT

TABLE A1-1 (*end*)

Functional parameters	Specifications	Requirements	COMPANY Y Basic	COMPANY X
5 Demodulation:	CW, AM, FM, SSB, NFM, WFM		COMPLIANT	COMPLIANT
6 Tracking functions:	1) Discrete frequency tracing 2) Frequency tracking by band 3) Discretionary selection of frequency steps	Manual and automatic frequency selection	COMPLIANT	COMPLIANT
7 Data collection:	Storage of measurement results and generation of reports	Interface for connection of peripheral equipment such as printers and PCs	COMPLIANT	COMPLIANT
8 Application software:	1) Man-machine interface: – User-friendly – Clearly identified functions – Frequency spectrum – Easy reading of results – Conversion of units – Visualization of statistical occupancy tables 2) Simulation of the radio direction-finding process 3) Potential growth of the system: – Ability to install radio direction-finding equipment easily – Easy to maintain – Automatic testing – Easy to use – Versatile		COMPLIANT	COMPLIANT

TABLE A1-2

Functional parameters	Specifications	Requirements	COMPANY Y Basic	COMPANY X
Training	1 Course on assembling an installation 2 Course on operation and maintenance 3 Guidance material for training (in printed or electronic form)	Five days for two engineers. Course No.1 will take place at the factory. Course No. 2 includes the preventive and corrective maintenance	COMPLIANT	NOT COMPLIANT
Vocabulary of terms, acronyms and abbreviations	Both in English and French	Optional: Spanish	COMPLIANT	COMPLIANT
Power supply	220V ± 5%, 50 Hz		COMPLIANT	Not indicated
Documentation	1 Installation plans 2 Operational and maintenance manuals of both the system and its components	Conceptual diagram of the system. Description of systems and equipment. Assembling and installation plans. Operational acceptance test-run of the station. Procedures to carry out detection and correction of system flaws. Operational procedures for corrective and preventive periodic maintenance. Procedures to locate system breakdowns and repair thereof	COMPLIANT	COMPLIANT
Supply of goods and services	The contractor will assume the responsibility for providing goods and services as established in the respective contracts		*	
Support and spares	Supply of pieces and spare parts (fungibles and non-fungibles) necessary for the maintenance service of the system for a two-year period after the final acceptance of the contract		*	10 years after the final acceptance

* *Note*: Compliant according to statements made by COMPANY Y in “compliance list”.

TABLE A1-2 (*end*)

Functional parameters	**Specifications**	**Requirements**	**COMPANY Y Basic**	**COMPANY X**
Factory acceptance test	Verification of technical specifications of the equipment		One ITU specialist, three working days	No indication concerning factory acceptance test
Transportation and delivery	A maximum of [180] days on site, including the responsibility of packing, transportation and installation		*	Four months after the order. Delivery in Geneva
Installation	It is the responsibility of the contractor to install the equipment and carry out all required tests to guarantee the perfect condition and functioning of the system	Installation, testing, integration and operation	*	
Running of provisional tests before acceptance	To test the reliability of the installation and functioning of the system and the equipment		*	
Running of final tests before acceptance	Protocol of acceptance		*	COMPLIANT
Guarantee	Guarantee of quality covering the smooth functioning, material and software for 12 months after the date of final acceptance		*	COMPLIANT

* *Note*: Compliant according to statements made by COMPANY Y in “compliance list”.

TABLE A.1-3

Functional parameters	**Specifications**	**Requirements**	**COMPANY Y Basic**	**COMPANY X**
The insurance responsibility	The contractor signs an insurance policy to cover any risk that can arise until the certificate of provisional acceptance has been issued (covering the period from the moment when the equipment leaves the factory until its provisional installation, where it has been delivered)			
1) Overall presentation of technical part 2) Computer workstation (item 2 of terms of reference)			1) Very good 2) OK **List of options:** ….	1 Poor presentation of the offer and difficulty to find the appropriate/relevant information 2 Workstation: minimum configuration 3 No Factory acceptance test 4 Training: proposal not compliant with the ToR

Appendix 2

to Annex 1

ITU example of the commercial and legal evaluations

1 Commercial evaluation – opening of commercial proposals

1.1 The total opening price of each of the offers as identified by the Evaluation Group is as follows:

Bidders (in alphabetical order)	**Total opening price in USD**
Company X	[999 999.00] – 1st proposal [999 999.00] – 2nd proposal
Company Y	[999 999.00] – basic proposal [999 999.00] – optional proposal

1.2 COMPANY X submitted the most comprehensive commercial proposal. COMPANY Y provided most of the required information in its offers. However, the level of detail (e.g. price breakdown) was not satisfactory and consequently required further clarifications.

1.3 The Total Evaluated Price (TEP) of each of the two offers as identified by the Commercial Evaluation Committee is as follows:

Bidder	**Basic proposal**	**Optional proposal 1**	**Optional proposal 2**
COMPANY X	USD [999 999.00]	USD [999 999.00]	USD [999 999.00]
COMPANY Y	USD [999 999.00]	USD [999 999.00]	–

1.4 No detailed price breakdown was presented by COMPANY Y. Consequently, it was necessary to require a detailed explanation of its overall price in order to complete the commercial evaluation of its proposal. COMPANY X did not provide the complete required information (a detailed price breakdown list of items for options 1 and 2).

1.5 COMPANY X and COMPANY Y are considerably different in their respective opening prices. In the case of COMPANY X, the most significant difference comes from the fact that the basic proposal contains only training. Consequently, following the recommendation of the TEC…., for more details please see TEC’s Technical Evaluation Report.

1.6 Prices quoted by … contain a 10% discount of the item total price.

1.7 Price is in USD CIP Geneva (taking into consideration that ITU did not identify the point of destination). ITU needs prices quoted DDU – in accordance with Incoterms 2000 including customary packing (point of destination to be determined). This point has to be clarified during the negotiation contract.

1.8 ***Payment terms and conditions***. Both companies have proposed payment terms. Therefore, payment terms and conditions of the future contract ***need to be negotiated*** with the selected company.

1.9 Both offers include ***commercial conditions***. In the case of contract negotiations with both companies, ITU may discuss all proposed modifications and additional payment conditions of the Contract in accordance with ITU rules and regulations (see for COMPANY X pages ii to jj of chapter N of the commercial proposal and for COMPANY Y proposal pages kk to ll of chapter M).

2 Legal evaluation – Compliance with specimen contract format (Part II of Invitation to Tender)

General Information	COMPANY X			COMPANY Y	
	1st proposal	2nd proposal	3rd proposal	1st proposal (basic)	2nd proposal
Proposal validity					
Compliance with contract	Yes (α)	Yes	Yes	Yes	Yes
Compliance with technical requirements	Yes	Yes	In addition	No	Yes
Total man/days	5	5	–	–	15
Total working time	7.5 h/day 3-5 days	7.5 h/day 3-5 days	–	9 h/day 2 days	9 h/day 6 days/4 weeks
Price per man/day	9 999.00	9 999.00	–	–	9 999.00
Total man/days	6	6		10	10
Total working time	7.5 h/day 5 days (37.5 h)	7.5 h/day 5 days (37.5 h)		6 h/day 1 day (6 h)	6 h/day 5 days/3 weeks (90 h)
Price per man/day	9 999.00	9 999.00		9 999.00	9 999.00
Elements that may increase the total firm fixed price	None, if items are restricted to items Price Schedule I to III submitted with the offer	None, if items are restricted to items Price Schedule I to III submitted with the offer		Training classroom and equipment not available	Training classroom and equipment not available
Counterpart services the bidder expects will be provided by ITU	Appropriate installation site must be provided	Appropriate installation site must be provided		Set up classroom and make sure necessary training equipment is available	Set up classroom and make sure necessary training equipment is available
Commitment to start and perform work	Effective date of contract	Effective date of contract		Effective date of contract	Effective date of contract
Time of delivery/ conditions	*N* month	*N* month		*M* weeks	*L* weeks
Total firm fixed price in USD					

2.1 α – Concerning the compliance with requirements:

COMPANY X remarks that:

– The translation of the system software into the French language is offered separately, since all our customers worldwide do accept the software in the English language;

– Translation of software into French requires a one-time charge;

– The manuals for equipment and training will be provided in French;

– Training for preventive and corrective maintenance will be provided, if trainees have engineering degrees and experience.

COMPANY Y second proposal (optional) fully complies with the requirements.

2.2 With regards to the proposed ***Specimen Contract Format***. In the case of contract negotiation with both companies, ITU may discuss all proposed modifications and additions to Specimen Contract Format and payment conditions. The most important concern the following articles:

a) **Substantive law** (compliance with statutes, laws, regulations):

COMPANY X proposes that "all disputes shall be settled in accordance with the terms of the contract and the supplementary agreements, otherwise in accordance with the substantive law in force in the country XYZ without referring to other substantive laws".

This requirement is not in accordance with ITU rules and regulations.

Note: Declare "comply" with Specimen Contract Format.

b) Arbitration:

COMPANY X proposes that "the attempt shall be regarded as being miscarried, if one of the two parties informs the other party of this fact in writing". If an attempt at settlement has failed, the disputes shall be settled under the Rules of Conciliation and Arbitration of the CCI in [CITY] by three arbitrators… (see page *k/k*, chapter *N* of the commercial part) – ***This article could be negotiated.***

c) Factory inspection acceptance and delivery:

See comments/proposal of COMPANY X, paragraph *n,* page *m* of Chapter *N* of the optional proposal.

d) Guarantees:

Both companies give detailed conditions of guarantee and request modifications. Some of the proposed modifications are not in accordance with the ITU standard contract but could be negotiated.

e) *Force majeure:*

COMPANY X suggests modifying this article. See Chapter *N*, page *i/k* "…the event of *force majeure* shall be confirmed by the Chamber of Commerce, …". Some of the proposed modifications are not in accordance with the ITU standard contract but could be negotiated.

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