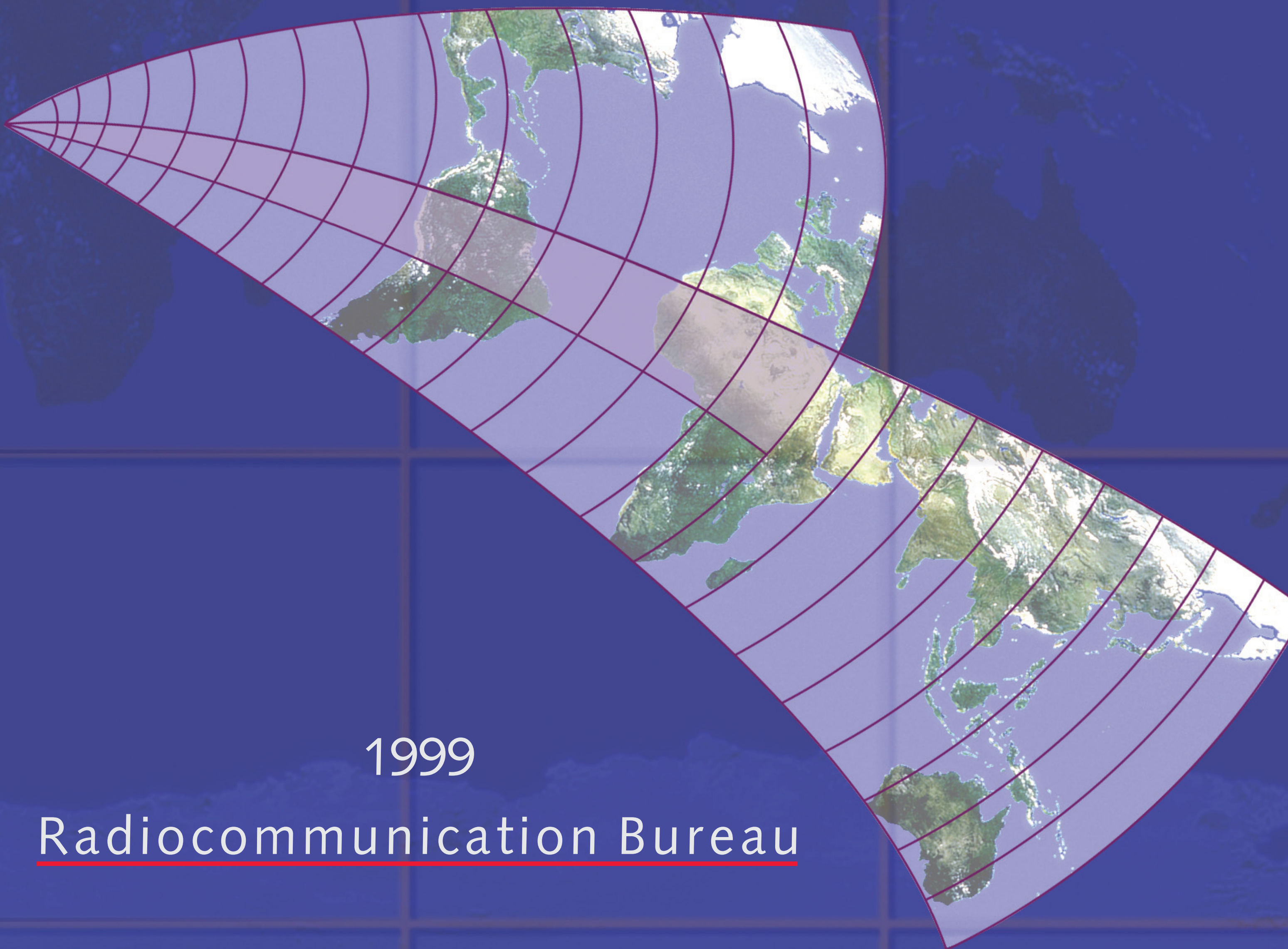
INTERNATIONAL TELECOMMUNICATION UNION

HANDBOOK

HF broadcasting system design



1999

Radiocommunication Bureau

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CHAPTER 1

INTRODUCTION

1 Introduction

Short-wave broadcasting, also known as “HF broadcasting”, has been in existence for many years and has been subject to considerable changes. The HF transmission medium has provided a means of disseminating information on a very wide variety of topics to audiences of the order of hundreds of millions of people, throughout the world.

Valuable scientific, engineering and practical experience has been accumulated over decades in the complex aspects of HF broadcasting station planning and design as well as in the number of particular components needed to be properly considered if a Handbook is to provide a comprehensive overview and guidance of paramount importance. Specific attention is also to be focused on the management aspects of HF Broadcasting station planning and design as well as its operation and maintenance.

The objective of the Handbook is to provide practical and illustrative guidance even to radio engineers not having been previously exposed to the particular task of HF broadcasting station planning. Considerable effort has been made to meet the expectations of HF broadcasting station planners from the developing world where, generally, such experience is very limited, if it exists at all.

Based on proposals and comments made particularly by the Telecommunication Development Bureau (BDT), the Special Rapporteurs Group 10A-5 of the Radiocommunication Bureau has kindly accepted to carry out fundamental changes to the Handbook structure in order to incorporate this “development” perspective.

In accordance with the wish expressed by the BDT, this Handbook has been prepared in a concise and practical manner and does not attempt to cover the theory and design of HF broadcasting antennae. The use of mathematical formulae has been avoided as far as possible and graphs and tables have been used instead.

It must be recognized that the choice of frequency, type and the ultimate design and construction of directional antennae, feeder and switching systems for a given HF broadcasting service requires expert knowledge and practical experience and perhaps the soundest and most useful advice that can be given to the developing countries is that they should endeavour to obtain the necessary supplementary expert assistance and consultation.

It is well known that HF propagation is variable:

– with time of day;

– from day to day;

– from month to month;

– from year to year,

these variations being governed by the impact of solar activity on the earth's ionosphere. Such variations create reception difficulties for listeners. Broadcasters must therefore choose their transmitting equipment, their transmitting sites, their frequencies and even their hours of transmission to minimize, as far as possible, any difficulties which could prevent listeners from receiving the intended messages.

With the Tropical Zone there are special problems to be faced. Natural noise levels are high because of the large number of thunderstorms and this creates special reception problems. There is an extra usage of the HF bands because of noise problems at medium-wave frequencies (MF) and, regrettably, the relative lack of development of VHF/FM broadcasting services in a number of countries. Some of these problems may be resolved at a later date by increasing use of Digital Audio Broadcasting (DAB) satellite transmissions but, in the meantime, the HF bands must continue to be used.

In addition to the natural problems just described, there is also the fact that most of the HF spectrum available for broadcasting is congested, that is, there are too many transmissions to permit good reception quality to be achieved in all reception areas at all times.

Faced with these problems, it is essential that broadcasters have available the best guidance possible, not only for the selection of a suitable combination of transmitting antenna and frequency, but also for maintaining and operating their station equipment and infrastructure under optimum conditions.

1.1 How to use this handbook

As a guidance through this handbook the flowchart in Figure 1.1 is intended to help the reader to:

1) provide a guideline to the order of relevant items to be covered

2) serve as a quick index to lead to the appropriate chapter

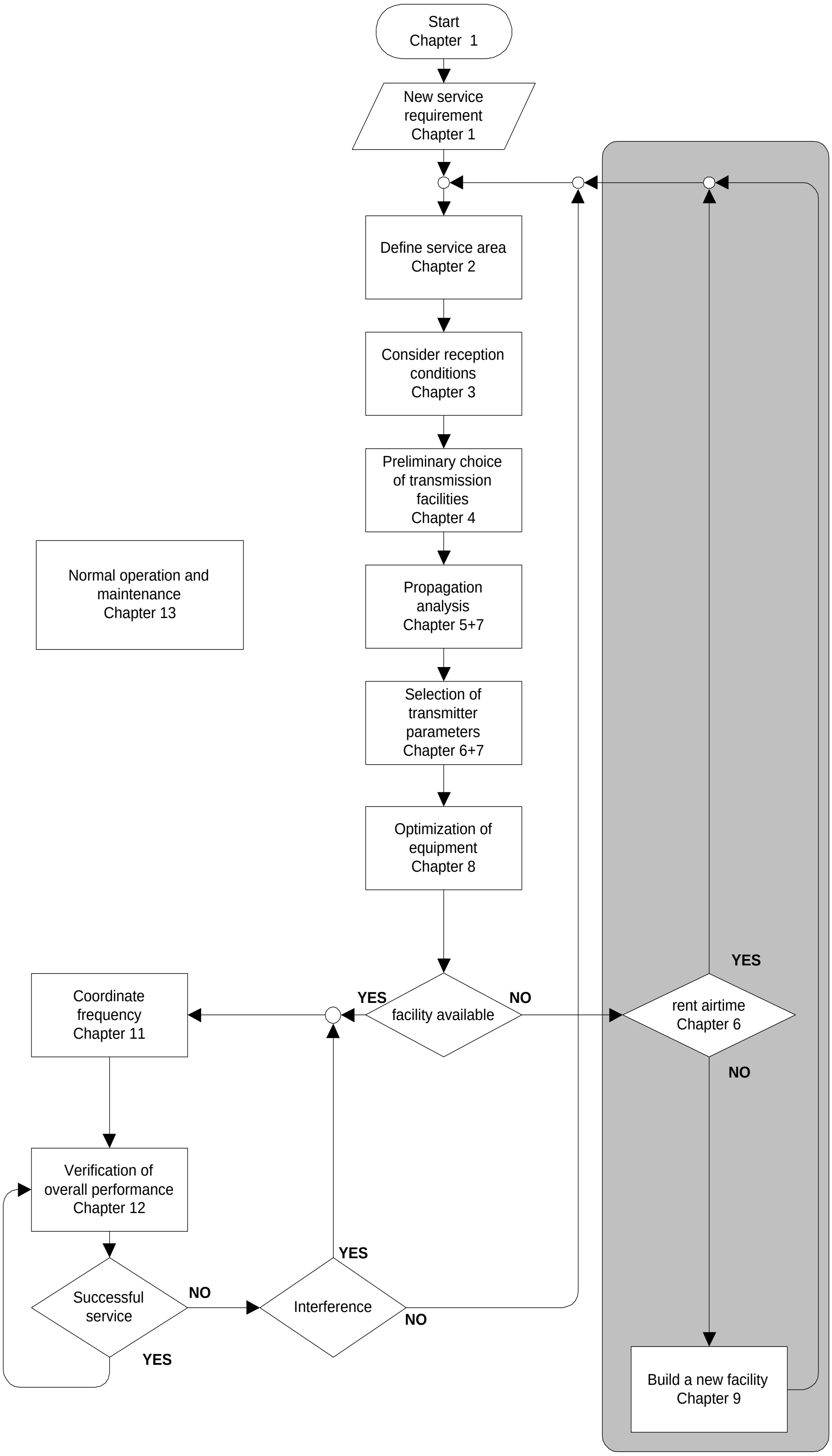

FIGURE 1.1

Flowchart for consultation of the Handbook

CHAPTER 2

DEFINITION OF SERVICE REQUIRED

Service requirements will normally lead to the defininition of the following radio programme parameters:

– specific hours of operation;

– specific days ;

– a specific transmitting site;

– geographic area to be served.

2.1 Geographic area intended to be served

The geographic area intended to be served by an HF transmission is normally associated with the programme being carried. For example, a programme in a particular language would normally be intended for a geographic area in which that language is mainly spoken.

However, in general terms, the geographic area is defined as the area where the programme is intended by the broadcaster to be received.

2.1.1 Area of primary interest

In any defined service area for a particular transmission, there is likely to be a smaller area that is particularly important for reception of the transmission. This could be the capital city of a country or the area where there is a high concentration of the population speaking a particular language.

2.1.2 Minimum area which could be considered

The attraction of HF broadcasting is that it can provide good reception over very large areas. However, the transmitting facilities available may not be capable of providing good quality reception over the entire required service area. If this is the case, the minimum area where good quality reception is needed must be defined. Usually, this is the area of primary interest described above.

2.1.3 Method of defining the area

The wanted service area can be defined in a number of ways:

– a single point such as a town, a city, an arbitrary location or a collection of such points;

– a circle of specific radius centered on the transmitter location or a service sector where the area is described by two azimuths in degrees clockwise from true north and the minimum and maximum distance ranges from the transmitter;

– the name of a country or a number of countries;

– a geographic area defined by the latitude and longitude of the boundary;

– a geographic region such as SE Europe;

– a single or a number of CIRAF zones and quadrants. These zones were defined at a *World Administrative Radio Conference* held in Mexico in 1948. The quadrants were defined as a consequence of the *HFBC WARCs* held in 1984 and 1987 and are shown in Figure 2.1; this figure also shows the additional zones agreed at those WARCs.

– an area defined in the ITU Radio Regulations e.g. the European Broadcasting Area.

Although each of these methods has its own merits, the method that is commonly used and which does not lead to ambiguity is as a set CIRAF zones and quadrants. These have the advantage that they are defined, are non-political and can describe a majority of service area requirements.

2.2 Hours and days of operation

The hours of operation are expressed in Universal Co-ordinated Time (UTC). The start time and stop time of the transmission are the actual times of the programme rounded to a multiple of 5 minutes so as to encompass the total period of the transmission. For example an actual programme time of 0558-0632 UTC would be recorded as 0555-0635 UTC.

There are occasions when a service is only required on certain days of the week rather than on a daily basis. If the transmission is only required on certain days of the week, the actual days required are indicated by using the following code:

Sunday	=	1
Monday	=	2
Tuesday	=	3
Wednesday	=	4
Thursday	=	5
Friday	=	6
Saturday	=	7

This numbering scheme takes account of the fact that the first day of a given HF broadcasting schedule is always a Sunday.

2.3 Permanent or short-term requirement

Some transmissions are only required for a certain period of time. These can be indicated by giving the start date and the end date of the period within which the transmission is required.

2.4 Required quality

The term "quality required" expresses the degree of satisfaction which may be expected by the listeners of a HF broadcast, living in the geographic area intended to be served.

a) Since the ionospheric propagation includes many disturbing elements. In order to achieve the required quality, it is necessary to consider the percentage of time for which quality required is achieved:

  – within hours of operation on any day;

  – on a day-to-day basis.

b) Noise is a physiological and psychological factor which may influence the degree of satisfaction. Provision of the required quality also includes consideration of:

- Signal-to-noise (S/N) ratio to be achieved in audio frequency (AF);
- Signal-to-noise ratio RF to be achieved in radio frequency (RF);

c) Since the spectrum allocated to HF broadcasting is not wide enough to accommodate all requirements. As a result, interference may influence the degree of satisfaction. So, provision of required quality also leads to consideration of:

- Signal-to-interference (S/I) ratio to be achieved.

In summary, the required quality must take into account the following parameters:

- short-term fading allowance on the wanted signal;
- long-term fading allowance on the wanted signal;
- S/N ratio to be achieved in AF;
- S/N ratio to be achieved in RF;
- S/I ratio to be achieved;
- percentage of the geographic area intended to be served which must benefit from the required quality.

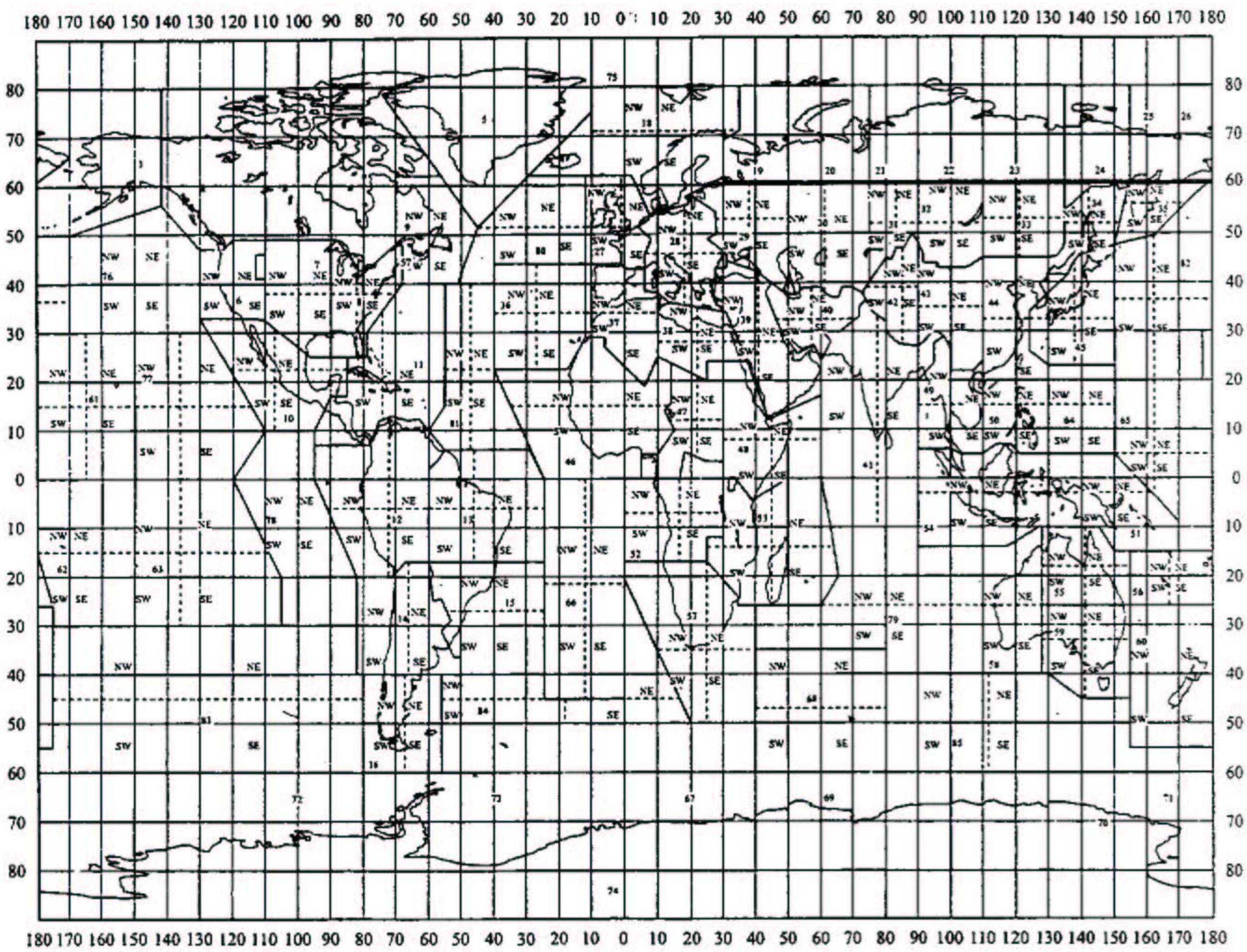

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FIGURE 2.1

Geographical zones for high frequency broadcasting (CIRAF zones)

CHAPTER 3

RECEPTION CONDITIONS

3.1 Reception environment

An accurate knowledge of reception conditions in the intended service area is essential while designing an HF broadcasting system. Factors such as radio noise along with geographical and local conditions which broadly constitute the reception environment in the service area therefore require detailed study and investigation.

3.1.1 Impact of topography on reception

Reception in HF broadcasting also depends upon the location of a radio receiver. Though a HF broadcasting system is always designed for a reception area instead of for a particular point or location of a single receiver, it is desirable to briefly discuss the dependence of radio reception on the surroundings of a radio receiver.

3.1.1.1 Geographical considerations

In general, HF reception depends upon the conductivity of the intervening ground up to several wavelengths from the receiving location in the direction of the transmitter. HF reception will be better in a green field than in a sandy desert. Similarly, the reception in open flat land will be much better than at a location surrounded by hills or built-up areas.

3.1.1.2 Local factors

In the case of a radio receiver with an attached or in-built antenna, HF reception also depends upon the location of the receiver. HF reception will be poorer inside an apartment built from steel and concrete than in a house built with bricks or wood.

3.1.2 Noise considerations

Radio noise, natural or man-made, often determines the practical limit of performance of HF broadcasting systems. It should be understood that the quality of reception is partially determined by the ratio of signal-to-noise intensity. It is, therefore, essential to know precisely the characteristics and level of radio noise present in the reception area, although in many cases, the real limits are set by interference and not by noise.

There are a number of types of radio noise that must be considered. In broad categories, the noise can be divided into two types - noise internal to the receiving system and noise external to the receiving antenna.

The internal noise is due to losses in antenna, transmission line and matching circuit, and is generated in the receiver itself and has the characteristics of thermal noise (i.e. white Gaussian noise).

External noise can be divided into several types. The most usual types are of atmospheric, galactic, and man-made origin. Unlike the internal noise, the external noise is generally highly non-Gaussian in character, usually being impulsive in nature.

The noise power present at the input of the receiver is the sum of internal and external noise. The internal noise is that which is produced by the receiver itself. The external noise could be either from natural sources or man-made sources. Under the natural type, there are atmospheric noise, cosmic noise and thermal noise due to the atmosphere and the Earth's surface. Man-made noise could have its origin in electrical installations and is more relevant in industrialized urban areas.

In the HF band, it is the atmospheric radio noise and/or man-made radio noise which predominates in most of the environmental conditions. Galactic radio noise is significant only above 10 MHz.

3.1.2.1 Atmospheric radio noise

Atmospheric radio noise is caused by naturally occurring electrical discharges accompanying lightning flashes in the Earth's atmosphere. Since the thunderstorm activity is higher in the tropics, atmospheric radio noise intensities are also generally much higher in tropical areas compared to temperate zones.

The internal noise of a receiver, which is expressed by field strength for short length whip antenna, is approximately constant entire the frequency band. On the other hand, field strength of the atmospheric noise is generally lower at higher parts of HF band at lower parts it increases of the order of 20 dB in the night. It is, therefore, most troublesome in lower parts of HF bands.

The thunderstorm activity generally commences around local noon and continues until the following sunrise. There is usually no activity between 0800 and 1200 hours local time in tropical areas. Consequently, the noise intensity is generally higher in the evenings as compared to mornings. Similarly, winters which may be generally free from thunderstorm activity are associated with much lower atmospheric noise intensities as compared to summer and equinoctial months. Measurements of atmospheric radio noise intensities have been made in different parts of the world mainly within the framework of URSI and ITU-R. Based on these measurements and additional data contributed by various administrations during the course of time, the ITU has brought out its Recommendation ITU-R PI.372 on “Radio noise”

With Recommendation ITU-R PI.372, F_{am} (median of the hourly values of effective antenna noise figure within a time block, dB above $k\, T_0\, b$) for atmospheric radio noise is obtained for four seasons of the year and six four-hour time blocks of the day in each season. (These are for a lossless short vertical antenna over a perfectly conducting ground plane).

The noise field strength (vertical r.m.s.) corresponds to F_{am} is obtained by:

$$E_{nm} = F_{am} - 95.5 + 20 \log f_{\mathrm{MHz}} + 10 \log b \quad \mathrm{dB(\mu V/m)} \tag{3-1}$$

where:

E_{nm} = median of the hourly value of noise field strength (dB(μV/m)) within a time block for b H2 bandwidth;

f_{MHz} = radio frequency (MHz);

b = receiver noise bandwidth (Hz).

In Recommendation ITU-R PI.372, the following another kinds of external noise powers are also given in terms of F_{am}, besides atmospheric radio noise.

– median values of man-made noise at a quiet rural area carefully selected (curve D in Figure 10 of Recommendation ITU-R PI.372);

– median values of galactic radio noise which are significant above about 10 MHz.

Figure in Annex 1 shows the noise field strength E_{nm} at N 36°/E 140° (near Tokyo), N 40°/W75° (near New York), N 48°/E10° (near Zurich) and S23°/W44° (near Rio de Janeiro) for reference, calculated by eq. 11) based on F_{am} obtained from the Recommendation ITU-R PI.372).

3.1.2.1.1 Information about atmospheric noise (Recommendation ITU-R PI.372)

Recommendation ITU-R PI.372 contains a series of maps/graphs showing diurnal, seasonal and geographical distribution of atmospheric radio noise. Since the atmospheric radio noise varies with season and time of the day, the data have been grouped into four seasons of the year and six four-hour periods of the day in each season.

The main parameter presented in Recommendation ITU-R PI.372 is the median hourly value of the average noise power in a time block.

The noise power received from sources external to the antenna has been expressed in terms of an effective antenna noise factor, F_a, which is defined by the following equation:

$$F_a = p_n/k\ T_0\ b = T_a/T_0 \tag{3-2}$$

where:

p_n = Noise power available from an equivalent loss free antenna (W);

k = Boltzman's constant;

T_0 = Reference temperature = 288°k;

b = Effective receiver noise width (Hz);

T_a = Effective antenna temperature in the presence of external noise.

The antenna noise factor, F_a, in dB is related to the r.m.s. noise intensity, E_n by the following equation:

$$E_n = F_a - 65.5 + 20 \log f \tag{3-3}$$

where:

E_n = r.m.s. noise intensity for a 1 kHz bandwidth expressed as dB(µV/m)

F_a = Antenna noise factor for the frequency, f

f = Frequency in MHz.

The noise field intensity for any other bandwidth, b, can be obtained by adding ($10 \log b - 30$) to E_n. Where bandwidth, b, is expressed in Hz.

The value F_a for a given hour of the day varies from day to day. The median of the hourly value within a time block is termed as F_{am}, variation of hourly values, F_a during the time block is represented by the values exceeded for 10% (upper decile) and 90% (lower decile) of hours which have been expressed as deviations D_u and D_1 from the time block median.

Recommendation ITU-R PI.372 provides an estimate of average background atmospheric radio noise. Thus, the impulsive noise due to local thunderstorm activity has been excluded from the predictions. Since the impulsive noise could be significant for substantial periods of time in tropical areas, the data from Recommendation ITU-R PI.372 should be used with caution.

3.1.2.2 Man-made noise

3.1.2.2.1 Information about man-made noise (Recommendation ITU-R PI.372)

Recommendation ITU-R PI.372 provides data on man-made radio noise. In this Report, median values of man-made noise power for various frequencies have been provided for the following environmental categories (Figure 3.1):

– Curve A: Business.

– Curve B: Residential.

– Curve C: Rural.

– Curve D: Quiet rural.

– Curve E corresponding to cosmic noise has also been included in Figure 3.1.

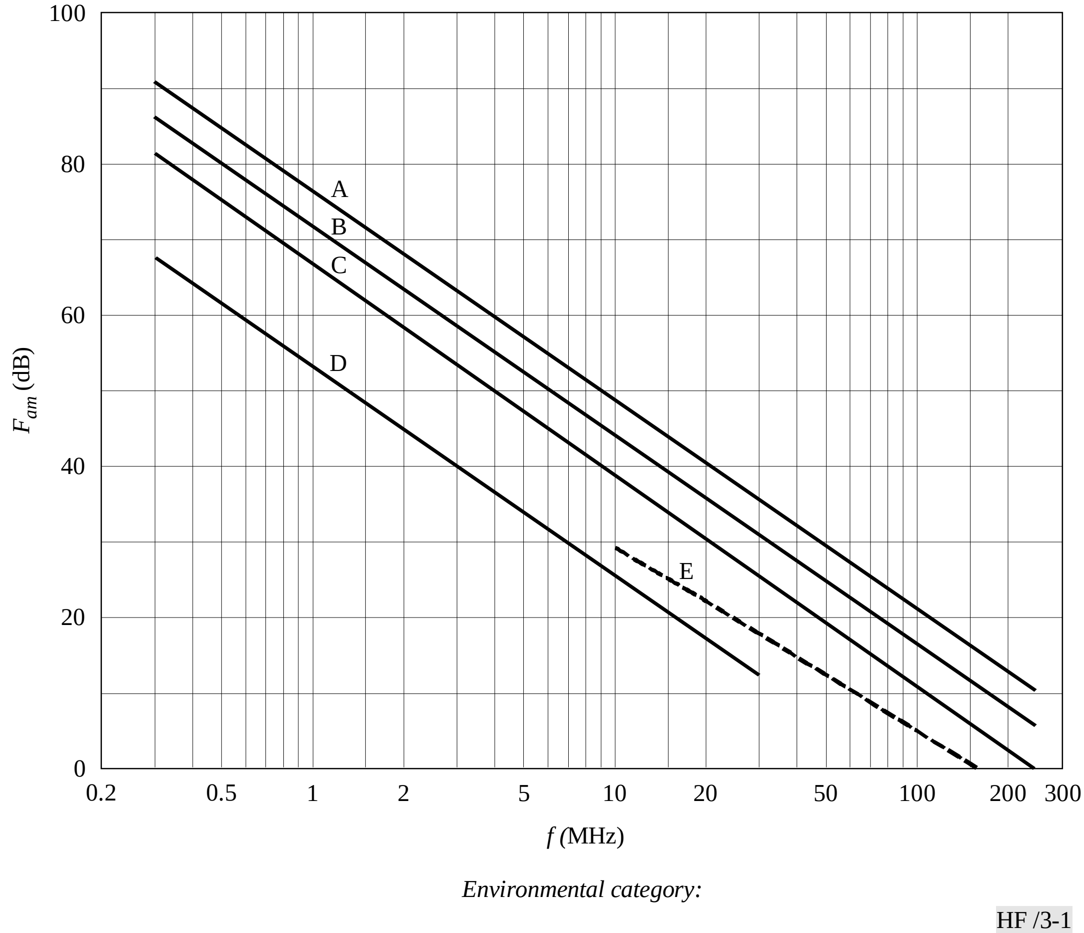


FIGURE 3.1

Median values of man-made noise power for a short vertical lossless grounded monopole antenna

Business areas are defined as the areas where the predominant usage is for any type of business (for example, offices, industrial areas, large shopping centres, main streets or highways). Residential areas are defined as the areas used predominantly for single or multiple family dwelling with a density of at least five single family units per hectare, without large or busy highways. Rural areas are defined as areas where dwellings are not more than one every two hectares. In these classifications, highly localized and intense noise sources have been excluded. Curve D corresponding to quiet rural areas relates to the values of man-made noise at carefully selected receiving sites. All the curves given in Figure 3.1 are primarily based on measurements made in the United States of America.

In Recommendation ITU-R PI.372, the median value of the man-made noise power has been expressed in terms of F_a (dB).

The curves indicated in Figure 3.1 could also be expressed by the following equation:

$$F_{am} = c - d \log f \tag{3-4}$$

where f is the frequency expressed in MHz.

F_{am} could be derived using the values of c and d given in Table 3.1.

TABLE 3-1

Values of the constants *c* and *d*

Environmental category	c	d
Business (curve A)	76.8	27.7
Residential (curve B)	72.5	27.7
Rural (curve C)	67.2	27.7
Quiet rural (curve D)	53.6	28.6
Galactic noise (curve E)	52.0	23.0

Variations measured within an hour about the hourly median value of noise power at a specified location have been provided in Table 3-2. Upper decile (D_u) and lower decile (D_1) values have been provided for various frequencies and for three types of environmental category.

The variation in the man-made noise power encountered from location to location for various environmental categories is also given in Table 3-2. Estimation of the location variability of F_{am} for these environmental categories for a particular frequency may be obtained from the standard deviation σ_{NL} given in Table 3-2.

3.2 Field strength related values

The determination of radio communication system performance and the resulting field strength level required for satisfactory reception is a matter of both the desired signal and the noise processes.

3.2.1 Signal-to-noise ratio

The required RF *S/N* ratio at the receiver input depends, apart from other factors, on the AF *S/N* ratio for a defined grade of performance. Since the majority of the physiological and psychological factors (excluding the effects of interference) are ultimately influenced only by the AF *S/N* ratio, a series of subjective listening tests were carried out to assess the minimum acceptable value of this ratio, from which the equivalent RF *S/N* ratio at the input of the receiver may also be derived.

TABLE 3-2

Representative values of selected measured noise parameters for business, residential and rural environmental categories

Frequency (MHz)	Environmental category											
	Business				Residential				rural			
	F_{am} (dB(kT_0))	D_U (dB)	D_l (dB)	σ_{NL} (dB)	F_{am} (dB(kT_0))	D_U (dB)	D_l (dB)	σ_{NL} (dB)	F_{am} (DB(kT_0))	D_U (dB)	D_l (dB)	σ_{NL} (dB)
0.25	93.5	8.1	6.1	6.1	89.2	9.3	5.0	3.5	83.9	10.6	2.8	3.9
0.50	85.1	12.6	8.0	8.2	80.8	12.3	4.9	4.3	75.5	12.5	4.0	4.4
1.00	76.8	9.8	4.0	2.3	72.5	10.0	4.4	2.5	67.2	9.2	6.6	7.1
2.50	65.8	11.9	9.5	9.1	61.5	10.1	6.2	8.1	56.2	10.1	5.1	8.0
5.00	57.4	11.0	6.2	6.1	53.1	10.0	5.7	5.5	47.8	5.9	7.5	7.7
10.00	49.1	10.9	4.2	4.2	44.8	8.4	5.0	2.9	39.5	9.0	4.0	4.0
20.00	40.8	10.5	7.6	4.9	36.5	10.6	6.5	4.7	31.2	7.8	5.5	4.5
48.00	30.2	13.1	8.1	7.1	25.9	12.3	7.1	4.0	20.6	5.3	1.8	3.2
102.00	21.2	11.9	5.7	8.8	16.9	12.5	4.8	2.7	11.6	10.5	3.1	3.8
250.00	10.4	6.7	3.2	3.8	6.1	6.9	1.8	2.9	0.8	3.5	0.8	2.3

F_{am}: median value

D_u D_l: upper, lower decile, deviations from median value within an hour at a given location

σ_{NL}: standard deviation of location variability

3.2.1.1 Audio-frequency (AF) signal-to-noise ratio

Results of listening tests carried out in India are provided in Recommendation ITU-R BS.560. In these tests, a variety of pre-recorded programme samples were mixed with white noise obtained from a random noise generator. The programme material and noise were filtered to represent the characteristics of an average HF receiver in India.

Minimum acceptable AF *S*/*N* ratios are shown in Table 3-3 for different types of programme. AF *S*/*N* ratio values of 16, 17 and 19 dB were accepted by 50, 70 and 90% of the listeners respectively, for instrumental and western music programmes. For the spoken word and vocal classical music programmes, values of 17, 19 and 21 dB were found acceptable by 50, 70 and 90% of the listeners, respectively. These values of AF *S*/*N* ratio apply for the case of a 3 kHz audio bandwidth and stable listening conditions.

Thus an AF *S*/*N* ratio of 21 dB was determined as the minimum requirement under the worst conditions.

Several series of controlled listening tests have been carried out in the USSR in accordance with the method described in Recommendation ITU-R BS.562 (subjective assessment of sound quality) for programmes of various types and for various AF *S*/*N* ratios.

The results are presented in Figure 3.2, which portrays the relation between the grade of noise impairment judged on the ITU-R scale and the AF *S*/*N* ratio. The graph is based on the selected opinions of 80% of the listeners, for speech programmes. It is known that noise is more perceptible for speech programmes, and less obtrusive for music, particularly dance music.

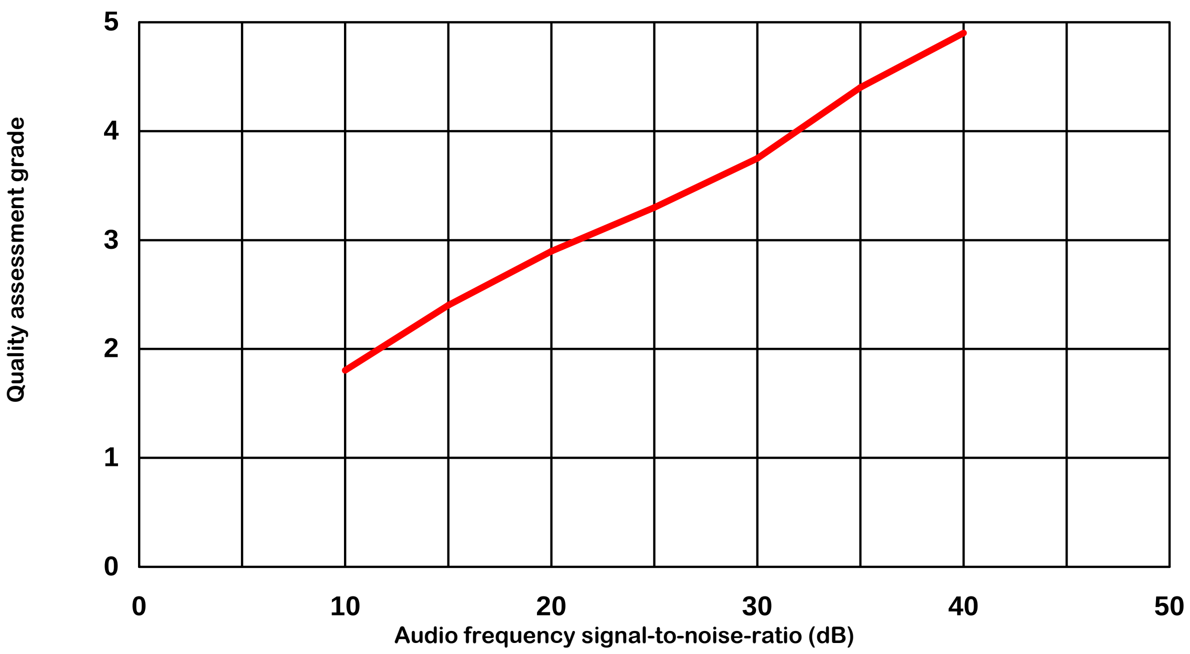


FIGURE 3.2

Received sound quality versus audio frequency signal-to-noise ratio

The graph in Table 3-3 shows that perceptible, but not annoying, noise, corresponding to grade 4 on the ITU-R scale, occurs with an AF *S*/*N* ratio of approximately 31 dB. For a ratio of approximately 21 dB, 80% of the listeners evaluated the noise as slightly annoying, i.e. corresponding to grade 3 on the ITU-R scale.

For planning purposes, the value of the AF *S*/*N* ratio adopted by WARC HFBC-87 was 24 dB.

TABLE 3-3

Minimum audio frequency signal-to-noise ratio (dB) accepted by various percentages of listeners

	50%	70%	90%
Instrumental (music Sarod)	16	17	19
Western music (pop song)	16	17	19
Spoken word	17	19	21
Vocal music (classical)	17	19	21

3.2.1.2 Radio-frequency (RF) signal-to-noise ratio (DSB receiver)

Studies have shown that the required RF (input) S/N ratio is approximately 10 dB greater than the required AF (output) S/N ratio for a reference receiver with an IF bandwidth of 4 kHz and 30% modulation of the received signal under stable propagation conditions.

This corresponds with experiments carried out by the Administration of India to determine the S/N ratio at the input of a receiver whose characteristics were representative of the average characteristics of HF receivers available in India. A steady RF signal modulated to 30% with 1 kHz tone was fed to the receiver. For an S/N ratio of 15 dB to 22 dB, a corresponding S/N ratio of 24 dB to 31 dB was observed. The differences between the AF and the RF S/N ratios was thus found to be 9 dB.

WARC HFBC-87 decided to use as a basic value for planning purposes an RF S/N ratio of 34 dB.

3.2.2 Intrinsic receiver noise and noise limited sensitivity

Noise internal to the receiving system can also be expressed by an antenna noise figure F_a (dB above $k\ T_0\ b$) or by equivalent field strength in the same way as the external noise, and these are called “intrinsic receiver noise”.

F_a for the intrinsic noise is given by:

$$F_a = L_a + F_r \qquad \text{(dB)} \qquad (3\text{-}5)$$

where:

L_a: = losses in antenna, antenna matching circuit and transmission line (dB);

F_r: = noise figure of the receiver (dB).

The equivalent field strength of intrinsic receiver noise which corresponds to F_a is obtained by the (Equation 3-5). A small value of F_r (less than 3 dB for example) is easily obtained in the current model of the receiver.

When an antenna of suitable length combined with a short length feeder and an associated matching circuit is used the value of L_a is not prominent (less than 5 dB for example), therefore, a small value of F_a (less than 8 dB for example) can be easily obtained.

The noise-limited sensitivity of a receiver is defined in Recommendation ITU-R BS.703 and is summarized for the HF bands as follows:

– for planning purposes, “sensitivity” is understood to mean “noise-limited sensitivity”, given in terms of field strength, required to achieve a specified signal-to-noise ratio at the audio output;

– for the HF bands, telescopic rod antennas are frequently used. Therefore, receivers using these types of antennas should be used as a reference, even though a variety of external antennas may occasionally be used to improve reception;

– for the HF bands, 40 dB(μV/m) is suggested for the minimum sensitivity of an average (DSB) receiver based upon an AF signal-to-unweighted noise (r.m.s.) ratio of 26 dB related to a modulation of 30% (–10.5 dB) measured according to IEC Publication 315-3.

The deterioration mentioned above results from the noise figure of the receiver RF front-end itself and matching loss between the rod antenna and the receiver front-end. However, since the former is a small value of the order of 1 to 3 dB in the current model of the receiver, the deterioration, an extensive value of the order of 30 dB in 10 MHz for example, mainly results from the latter, matching loss. And this extensive matching loss is caused by high Q impedance of the short rod antenna, series impedance of a low radiation resistance of the order of less than 1 Ω and small capacitance of the order of 2 pF (8 kΩ at 10 MHz). Because of this small series capacitance, the receiver presents almost flat noise limited sensitivity performance over the entire frequency band the frequencies cancelling the frequency response of $E(k\ T_0\ b)$ which increases in proportion to the frequency.

In accordance with this definition, tests were carried out in Japan for several models of HF receiver using the built-in telescopic rod antenna to obtain the intrinsic noise of a typical HF DSB receivers currently available in the market.

The theoretical value of the available received power of a short vertical rod antenna over a ground plane, (P_{av}), is given by:

$$P_{av} = E - 20\log_{10} f\,(\text{MHz}) - 78.5 \qquad (\text{dBm}) \tag{3-6}$$

where:

E: = field strength (dB(μV/m))

It should be noted that P_{av}, or antenna gain, of a short rod antenna is independent of the antenna height and only 3.5 dB smaller than that of a half wavelength dipole.

3.2.3 Minimum usable field strength

The minimum field strength value is that value of the field strength necessary to permit the desired reception quality, in specified receiving conditions, in the presence of natural and man-made noise, but in the absence of interference from other transmitters.

The receiving conditions include:

– the frequency band;

– the receiving equipment characteristics;

– the receiver operating conditions, particularly the geographical zone, the time and the season.

The noise floor to calculate the minimum field strength value is determined as the greatest one among the values of atmospheric noise, man-made noise and intrinsic receiver noise. A comparison of the corresponding minimum field strength values is given in Figure 3.3 for the reference receiver.

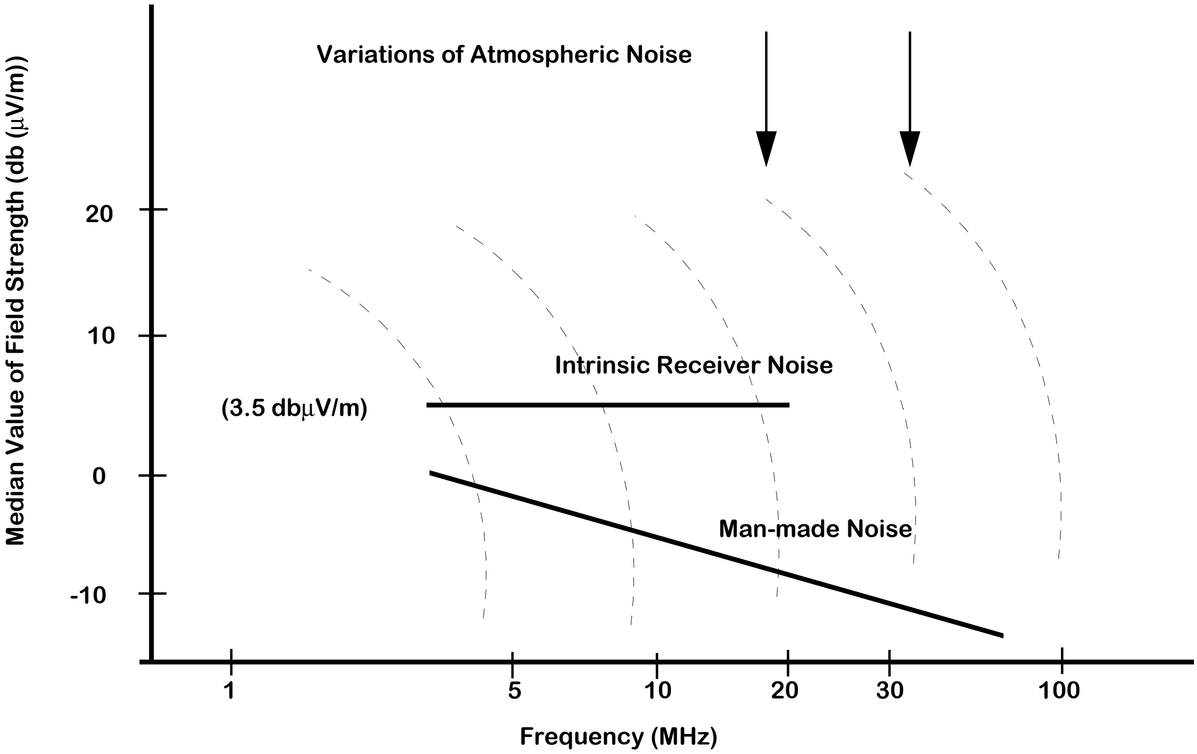


FIGURE 3.3

Median value of field strength vs. frequency

The minimum usable field strength E_{min} is determined as the level which is higher by 34 dB than the noise floor. In the cases, the intrinsic receiver noise is significantly higher than 37.5 dB (values up to 50 dB(μV/m) may be found).

3.3 Characteristics of receivers

Receivers that are used in the HF broadcasting service fall into two general categories; those produced primarily for the professional user and those produced for the recreational or casual user. This section will concentrate primarily on the technical requirements of the equipment to be provided to the latter group since they are the ones who form the bulk of the broadcaster's audience.

HF receivers must be affordable and their performance must be competitive and in agreement with the standards of the industry. To this end, Recommendation ITU-R BS.415 (Minimum performance specifications for low-cost sound broadcasting receivers) was prepared so that all manufacturers would have a common standard. This section highlights several of the most relevant topics from this and other ITU documents.

3.3.1 Tuning aspects

The HF broadcasting receiver must be designed in a manner that will allow it to be used by listeners who do not have technical skills. The controls must be comfortable to use and be effective in their purpose. Their number should be minimized. Where possible they should be identified with universally accepted symbols rather than with text.

As a minimum, the receiver should be equipped with a means to control the following basic functions.

3.3.2 Technical characteristics

There are ITU-R Recommendations and Reports in addition to Recommendation ITU-R BS.415-2. that are applicable to the design of receivers. Some of the most relevant are referenced in the following paragraphs. If the manufacturer adheres to these guidelines he will be assured of having a product that delivers an acceptable level of performance and one that is competitive in the market-place.

3.3.2.1 Tuning accuracy and stability

The nominal channel spacing in the HF broadcasting service is 10 kHz. However, interleaved channels are also used with a separation of 5 kHz. The AM broadcast service (MF) in the Americas (Region 2) has a channel spacing of 10 kHz, while AM broadcasting (both LF and MF) in the rest of the world (Regions 1 and 3) has a channel spacing of 9 kHz.

Accordingly, for the HF bands, the receiver must be able to tune in increments of 5 kHz. For AM broadcast bands, it is highly desirable to tune both 9 and 10 kHz increments, but this could be a marketing option for the appropriate region.

Recommendation ITU-R BS.597 (Channel Spacing for Sound Broadcasting in Band 7 (HF)) provides the basic guidelines for determining the channel spacing to be used in receivers.

The tuning criteria for non-synthesized receivers include accuracy, resolution, and "setability". The figures shown below are typical requirements for a receiver.

Accuracy When receiving a DSB signal, the receiver should be tunable to within 500 Hz of the desired channel. In the case of SSB, the receiver should be tunable to within 10 Hz of the desired channel.

Resolution The tuning mechanism in the receiver should allow it to be adjusted in increments of 100 Hz or less, or to be continuously tuned.

Setability The receiver should be "setable" to within 100 Hz of the desired frequency in the case of AM. When listening to SSB transmissions the receiver should be setable to within 10 Hz of the desired frequency.

Vernier, or fine tuning, features may be necessary when the receiver is used for SSB transmissions since the quality of the received signal is dependent upon the accuracy of the tuning system. They may also be used to offset the effects of long and short-term frequency drift.

3.3.2.2 Bandwidth and selectivity

A receiver must accept only the information being transmitted on the desired frequency. "Selectivity" describes the receiver's ability to do this and it is determined by the bandwidth of the filters and other tuned circuits in the IF amplifiers. If the filters are too wide then interference from the adjacent channels will degrade the quality of the received signal. If the filters are too narrow the tonal quality of the wanted signal will be affected.

Recommendation ITU-R SM.328 defines the spectral limits, or necessary bandwidth, required for various forms of emission. In the case of DSB it is equal to twice the highest modulation frequency. With SSB the necessary bandwidth is equal to the highest modulation frequency. Recommendation ITU-R BS.639 discusses the technical implications of the necessary bandwidth with respect to the receiver characteristics.

The use of SSB in the HF broadcast bands imposes a special requirement on the circuits within the receiver that determine its selectivity. Since the necessary bandwidth of SSB is one-half that required by AM the receiver should automatically adjust to this value when the receiver is adjusted to receive SSB emissions, or provision for a user selectable "narrow" or "wide" selectivity must be provided. If not, extraneous noise will degrade the quality of a received SSB signal.

3.3.2.3 Sensitivity

The sensitivity of a receiver is, perhaps, most effectively defined as the IF input signal level, and modulation level if appropriate, which will deliver an output signal of defined quality. When threshold sensitivity measurements are needed, the output signal quality is typically expressed as a SINAD (Signal plus Noise and Distortion) ratio. SINAD is a ratio of the total energy present in the demodulated signal when modulation is present to the energy present when the modulation is absent. Thus, it includes a measure of all harmonics and extraneous noise in addition to the desired signal.

Sensitivity can also be described in terms of a specific RF input and modulation level that will produce a given audio output level from the receiver. This method, however, is actually more of a "Gain" measurement than a "Sensitivity" measurement.

In the case of transistorized receivers, Recommendation ITU-R BS.415 suggests a sensitivity that produces 50 mW of audio with a S/N ratio of 26 dB when the RF input level is not greater than 150 μV and modulated to 30% by a 400 Hz test tone.

When the receiver is used for SSB reception the sensitivity measurement must be modified to consider the type of detection and the differences, if any, in the selectivity characteristics of the receiver. These specific characteristics will govern the changes that must be made to the standard measurement.

3.3.2.4 RF signal handling capability

The highest signal levels that can be accommodated by the receiver must also be addressed. If the input level is too high the receiver will overload causing the audio output to become distorted. In the worst case, the receiver will block causing the audio output to be reduced perhaps to zero and certainly to be grossly distorted.

Receiver designers frequently use Automatic Gain Control, or AGC, circuits to reduce the receiver's susceptibility to overload by high-level signals. These circuits actually reduce the gain of the receiver so that the output level is held relatively constant as the input level varies.

In addition to AGC circuit, some designers use variable or stepped attenuators at the front-end of the receiver to decrease the signal level that is applied to the active circuits within the receiver. Attenuators are also effective in reducing the detrimental effects of high-level signals on frequencies adjacent to the one to which the receiver is tuned.

Recommendation ITU-R BS.415 suggests an AGC slope such that the audio output level changes 10 dB or less when the RF input level changes 30 dB with respect to 0.1 volt at the receiver input.

3.3.2.5 Audio fidelity

The quality of the signal that is heard by the listener is primarily determined by the capability of the audio stages in the receiver. If these circuits are deficient, nothing else really matters. Conversely, ideal audio may only enhance other deficiencies if they exist. For this reason, the designer must carefully address the characteristics of the audio portions of the receiver.

The audio frequency response of the receiver should be equal to the necessary bandwidth of the emission being received. If the response of the audio stages is greater than this, the quality of the signal will be degraded as extraneous noises will also be reproduced. Harmonic distortion should be minimized since this will detract from the quality of the received signal. The receiver should have as large a speaker as the designer can accommodate within the confines of the radio. The audio level from the speaker should allow comfortable listening at moderate distances. In the case of battery power radios, it may be advantageous to include provisions for earphones as they do not require high audio power levels and this will reduce the energy consumed by the radio.

3.3.2.6 Special considerations

On-going developments in integrated circuit technology present the receiver manufacturer with opportunities to improve performance and add features while reducing the energy consumption of the receiver. At the same time, the manufacturer can produce a receiver at a lower cost which will ultimately benefit both him and the consumer.

The proposed use of single sideband in the short-wave broadcast band also presents the manufacturer with special design problems. Whenever possible the manufacturer should use synchronous detectors since they perform well when receiving both normal AM and SSB transmissions. The manufacturer should also employ frequency synthesizers as local oscillators since they can be designed to be very stable even when their power source is varying such as would occur with battery power. In addition, the synthesizers can be used very effectively with synchronous detectors which simplifies the design of the receiver.

3.4 Radio frequency protection ratios

The amount of interference heard due to a transmission in the adjacent frequency channel depends not only on the ratio of field strengths but also on channel spacing, the selectivity characteristic of the receiver, the psophometric weighting curve, which takes into account the frequency dependent sensitivity of the ear, and on the spectra of the emissions involved, which are influenced by the modulation bandwidths of the transmitters and the amount of compression of the programme signals.

In ITU-R it has been found convenient to introduce for planning the concept of relative protection ratio. This is generally used when discussing the protection ratio for adjacent-channel interference that is required by receivers. It is equal to the adjacent-channel protection ratio minus the co-channel protection ratio, in decibels. In the context of receiver requirements it can also be regarded as the difference between the dB levels of co- and adjacent-channel signals which give the same degree of audio disturbance. A negative value means that the adjacent-channel signal can be stronger.

3.4.1 RF-protection ratios for DSB

WARC HFBC-87 adopted Recommendation 510 (HFBC-87), in which § 1.3 gives values of relative RF protection ratios, A_{rel}, for DSB emissions, and which are accepted for planning purposes. The relative RF protection ratios, A_{rel}, for carrier frequency separations, Δf, with reference to the co-channel protection ratio are given in Table 3-4:

TABLE 3-4

Δf	A_{rel}
0 kHz	0 dB
±5 kHz	–3 dB
±10 kHz	–35 dB
±15 kHz	–49 dB
±20 kHz	–54 dB

These values apply when a high degree of modulation compression is applied to the two emissions by means of an automatic device, when the bandwidth of the audio-frequency modulating signal is of the order of 4.5 kHz and when the receiver selectivity curve corresponds to that shown in Figure 3.4 below.

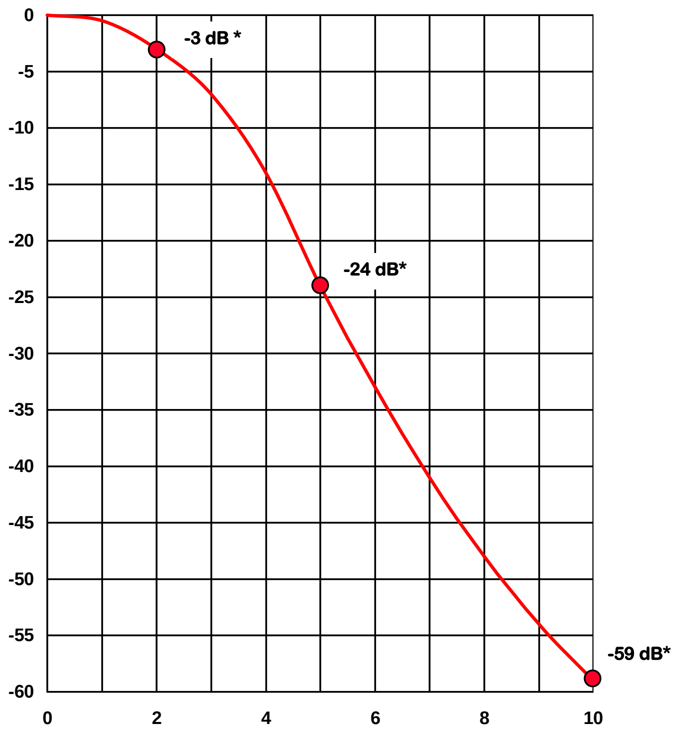


FIGURE 3.4

Receiver selectivity curve
(European Broadcasting Union (EBU) MBF receiver)
overall response, AF bandwidth (–3dB) = 2 kHz

* values taken from Recommendation ITU-R BS.560

3.4.2 Relative RF-protection ratios for SSB

Most of the characteristics of the future SSB-system in HFBC were specified and accepted at WARC HFBC-87 and therefore are contained in Appendix S11 to the Radio Regulations. The values of A_{rel} to be applied for all relevant combinations of wanted and unwanted DSB and SSB emissions, however, were not included in this Appendix, due to their provisional nature. They are contained in the Annex to Recommendation 517 (HFBC-87).

Table 3.5 shows these provisional values which were calculated using the numerical method described in Recommendation ITU-R BS.560, using the receiver characteristics given in Recommendation ITU-R BS.703 DSB and Appendix S11 for SSB. This method allows the determination of A_{rel} values in good agreement with measurements, when the relevant receiver selectivity characteristic and the power density spectra of the wanted and the unwanted emission are given.

It is desirable that the values in this table should be verified by measurements. These measurements, however, are not yet available.

TABLE 3-5

Relative SSB RF protection ratios

	Wanted signal	Unwanted signal	Carrier frequency separation f unwanted - f wanted, Δf (kHz)								
			–20	–15	–10	–5	0	+5	+10	+15	+20
1	DSB	SSB (6 dB carrier reduction relative to p.e.p.)	–51	–46	–32	+1	3	–2	–32	–46	–51
2	SSB (6 dB carrier reduction relative to p.e.p.)	DSB	–54	–49	–35	–3	0	–3	–35	–49	–54
3	SSB (6 dB carrier reduction relative to p.e.p.)	SSB (6 dB carrier reduction relative to p.e.p)	–51	–46	–32	+1	0	–2	–32	–46	–51
4	SSB (12 dB carrier reduction relative to p.e.p.)	SSB (12 dB carrier reduction relative to p.e.p.)	–57	–57	–57	–45	0	–20	–47	–52	–57

Relative RF protection ratio values with reference to the co-channel RF protection ratio for DSB wanted and unwanted (dB)[1] for use in the HF bands allocated exclusively to the broadcasting service.

[1] Frequency separations Δf exceeding 20 kHz need not be considered.

3.4.3 Signal to interference ratio

3.5 Receiving antenna considerations

3.5.1 Antenna types

Theoretically, all types of transmitting antennas can be used for receiving purposes. Practically, due to cost considerations, the HF receiving antennas currently connected to HF receivers are less sophisticated than transmitting antennas.

3.5.2 Receiving antennas for broadcast listeners

3.5.2.1 Outdoor installation types

– Broadband dipole.
– Multi-frequency half-wave centre-fed dipoles.
– Half-wave folded dipole.
– Full-wave cage dipole.
– Sloping vee.
– Long wire.

3.5.2.2 Indoor installation or built-in types

– Loop.
– Whip monopole.
– Active whip monopole.

CHAPTER 4

TRANSMISSION FACILITIES

4.1 General

The choice of a transmitter site is highly dependent on the area to be served. To see if the wanted area will be served, it is essential to study beforehand the propagation path between transmitter and reception area.

4.1.1 Available facilities

At the moment, about 550 sites all over the world are known for short-wave broadcasting stations for short distances up to about 800 km and long distances from about 800 km. In the Table 15-1 Table of stations, a list of these sites is given with, for every site, the country code, station name and geographical co-ordinates

4.1.2 New facilities

If there is no possibility to make use of one of the already available sites, it will be necessary to set up a new one. For short- and long-distance operation, the following matters have to be studied, after the decision that the location is suitable from the propagation point of view:

Primary matters:

– antenna type;
– frequency band(s);
– power;
– required reliability.

Secondary matters:

– existing infrastructure;
– obstacles;
– soil conductivity;
– EMC problems.

Concerning obstacles, (e.g. buildings, mountains, etc.), it is important to investigate the possible negative influence due to reflections. Also the minimum take-off angle in relation to the elevation angle is of importance.

The soil conductivity is especially important for antenna systems designed for short distance operation where a main lobe with an elevation angle near 90° is needed. Also in the case of vertical polarization a good ground conductivity will be necessary. In Recommendation ITU-R BS.139, further details are given for such cases in the Tropical Zone.

When a new transmitter site has been set up at least the following parameters are necessary for further treatment in the whole process:

– country;
– station name;
– geographical co-ordinates;
– antenna type;
– transmitter power.

4.2 Transmitters

4.2.1 Transmitter technology

New HF transmitter concepts, while demanding higher powers, improved efficiency and greater component reliability, also seek to lower capital, operating and spare-parts costs. In HF transmitters, the RF final stage tetrode and the modulator contribute largely to the achievement of these objectives.

For many years, Class B high-level anode modulation has been the standard modulation system for broadcasting. Because of its popularity, it has set a standard for judging other systems. Nowadays, the alternative to the Class B modulator is the switching mode modulator, offering a higher overall efficiency.

All modern high-power transmitters, ranging between 50 and 500 kW, consist, amongst other things, of a low power broadband solid state amplifier, a driver and a power final stage. For carrier powers above 50 to 100 kW, the RF final stage of broadcast transmitters is still tube equipped. Tube technology sets the maximum in available RF output power, being 500 kW nowadays.

4.2.2 Amplitude-modulation double sideband (AM-DSB) operation

Broadcasting started in the twenties using amplitude-modulation double sideband operation exclusively. AM-DSB survived because of its simplicity and is still very popular in broadcasting. Classical Class B anode modulation uses a high-power push-pull Class B audio amplifier coupled to a balanced modulator transformer. The system has a good all-round performance and is simple and reliable (see Figure 4.1).

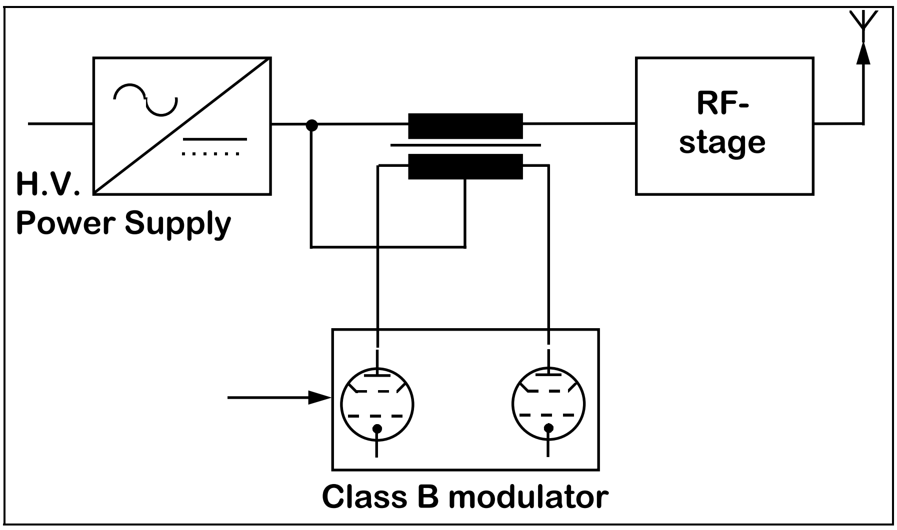


FIGURE 4.1

Class B anode modulation

The disadvantage of the Class B modulator is inherent in its operation in a linear mode. This limits its efficiency with full modulation. At average levels of modulation (modulation index 0.3 to 0.4), its efficiency is quite low. A further drawback of the system is the need for a costly modulator transformer.

One way of overcoming this problem is to replace the high voltage rectifier and Class B modulator by a switching amplifier operating either as a Pulse Duration Modulator (PDM) - also designated Pulse Width Modulator (PWM) - or Pulse Step Modulator (PSM). In contrast to the Class B modulator, this switching amplifier delivers both the carrier and sideband power for the final stage (see Figure 4.2).

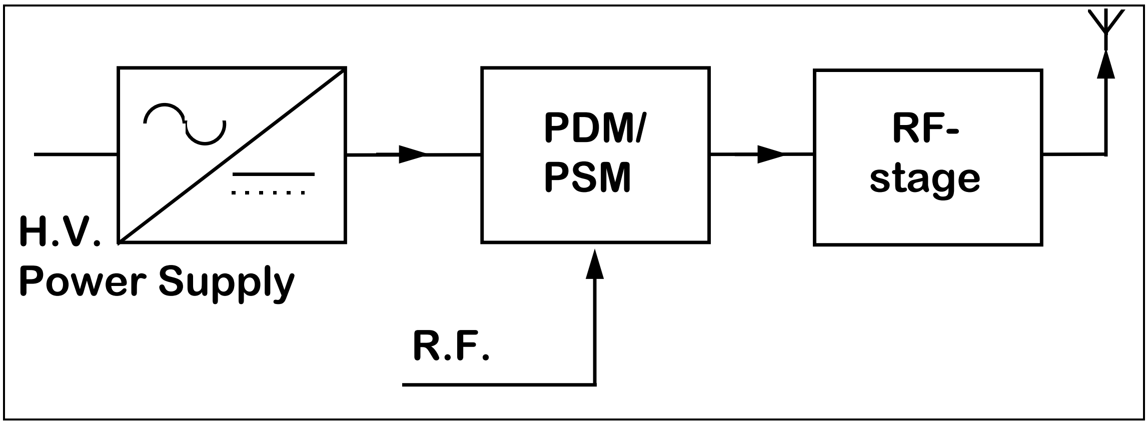


FIGURE 4.2

Switching mode modulation

PDM is accomplished by using either a switching tube or a solid state switching device. The modulator operates in a manner similar to a switch. It has two conditions: on and off. Audio information is contained in the duration of the "on" pulse. There is no need for modulator transformers or reactors. PSM uses a switching module consisting of several solid state switching amplifiers which deliver the AF modulated anode voltage to the RF final stage of the transmitter.

The output voltages of each solid state switching amplifier are added in a summing network. The number of amplifiers switched on depends on the output voltage required. For a modulation degree of 100%, all amplifiers are switched on.

In general, all digital techniques offer high average modulation levels and a high overall transmitter efficiency at all modulation levels. Often, variable carrier power (see 4.2.2.2) and reduced RF power levels are programmable.

4.2.2.1 AM-DSB emission characteristics

– Audio frequency bandwidth.

  AM transmitter frequency response characteristics, referred to a reference frequency of either 400 or 1 000 Hz, are typically well within ±1 dB from 50 to 5 000 Hz (measured without audio band limiting filter).

The upper limit of the audio-frequency band (at −3 dB) of the transmitter (with audio band limiting filter) shall not exceed 4.5 kHz and the lower limit shall be 150 Hz, with lower frequencies attenuated at a slope of 6 dB per octave.

– Audio harmonic and intermodulation distortion.

Current short-wave broadcast transmitters typically produce less than 3% Total Harmonic Distortion (THD) up to 90% modulation at any frequency of modulation between 50 and 5 000 Hz. Full modulation of the series PDM system can produce considerably higher audio distortion levels, particularly near the trough where 100% modulation requires zero pulse widths. Although harmonic distortion is important, intermodulation distortion (IMD) is recognized to be more disturbing for listeners. The ITU-R method of IMD measurement is the preferred method for short-wave broadcast transmitters.

With this method, two equal audio tones, separated by 170 Hz are input to the transmitter and the peak modulation level adjusted to between 85 and 95% modulation. The level of odd and even order products are measured using an audio-wave analyser or spectrum analyser connected to the test output terminals of a high quality modulation monitor. High quality broadcast transmitters should produce IM distortion products more than 30 dB below the level of either of the two modulating tones.

– Characteristics of modulation processing.

The audio-frequency signal shall be processed so that the modulating signal retains a dynamic range of not less than 20 dB. Excessive amplitude compression, together with improper peak limitation, leads to excessive out-of-band radiation and thus to adjacent-channel interference, and is therefore to be avoided.

– Necessary bandwidth.

The necessary bandwidth shall not exceed 9 kHz.

4.2.2.2 Carrier power control

4.2.2.2.1 Dynamic amplitude modulation DAM

In the amplitude modulation process (A3E modulation), the bigger part of the produced RF power is contained in the carrier. Even at 100% modulation both sidebands combined contain only 50% of the carrier power. A process in which the carrier power is controlled in relation with the modulation degree improves the efficiency.

With the advent of switched modulators easy control over the carrier power becomes possible. In some transmitter designs controlled carrier modulation is characterized by a residual carrier of 60% for low levels of modulation rising to 100% at full modulation, called Dynamic Amplitude Modulation (see Figure 4.3).

4.2.2.2.2 Dynamic carrier control DCC

In "AM Companding" system, the carrier power is 100% at zero modulation in order to improve signal/noise ratio and is reduced when modulation increases. In other systems such as Dynamic Carrier Control (DCC), carrier power is at its minimum at average modulation level (30-40%) and is increased at low and high modulation levels thus offering a better signal/noise level (see Figure 4.4).

Transmitter operation using VCP offers a potential for substantial savings in electric power consumption. In practice, savings on energy up to 50% as compared with regular AM modulation on PDM transmitters are feasible.

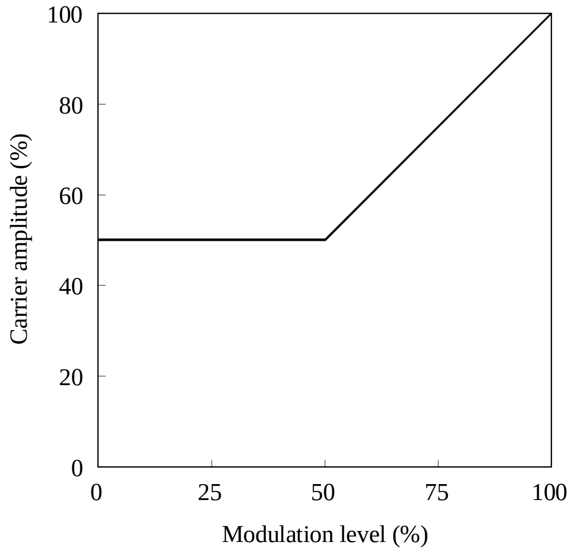


FIGURE 4.3

DAM control curve

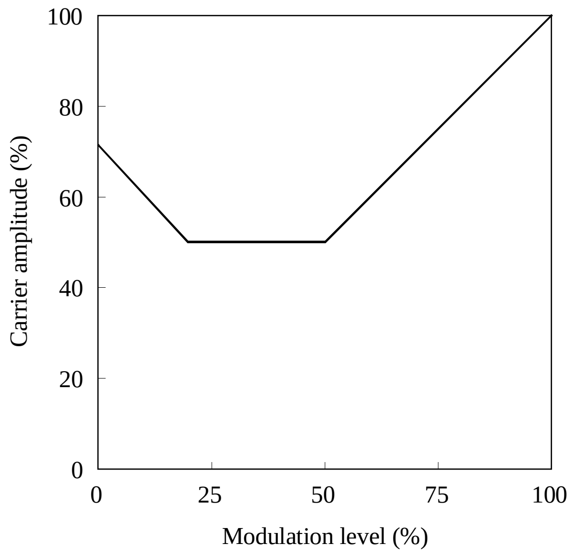


FIGURE 4.4

DCC control curve

4.2.3 Single sideband (SSB) operation

The WARC HFBC-87 Conference adopted Recommendation 515 (HFBC-87) recommending that new transmitters which are installed after 31 December 1990 should, as far as possible, be capable of working, either:

– in double sideband (DSB) mode, or

– SSB mode, with the possibility of both a 6 dB and a 12 dB carrier reduction relative to peak envelope power.

Most modern transmitters comply with this Recommendation although there are considerable differences in overall efficiency when operating on SSB. In the development of new transmitters, special effort is directed at making them suitable for conversion to SSB operation without losing any of the efficiency modern transmitters exhibit for DSB use.

4.2.3.1 SSB emission characteristics

– Audio-frequency bandwidth.

  The upper limit of the audio-frequency bandwidth (–3 dB) of the transmitter shall not exceed 4.5 kHz with a further slope of attenuation of 35 dB/kHz and the lower limit shall be 150 Hz with lower frequencies attenuated at a slope of 6 dB per octave.

– Necessary bandwidth.

  The necessary bandwidth shall not exceed 4.5 kHz.

– Characteristics of modulation processing

  The audio-frequency signal shall be processed so that the modulating signal retains a dynamic range of not less than 20 dB. Excessive amplitude compression, together with improper peak limitation, leads to excessive out-of-band radiation and thus to adjacent-channel interference, and is therefore to be avoided.

– Sideband to be emitted.

  The upper sideband shall be used.

– Suppression of the unwanted sideband.

  The degree of suppression of the unwanted (lower) sideband and of intermodulation products in that part of the transmitter spectrum shall be at least 35 dB and, whenever possible, exceed 40 dB, relative to the wanted sideband signal level.

– Degree of carrier reduction.

  The carrier reduction relative to peak-envelope power shall be 12 dB (6 dB until the end of the transition period).

4.2.3.2 Types of SSB modulations

4.2.3.2.1 Low level SSB generation followed by linear amplifier

The first method yields a total transmitter efficiency around 40% with full peak power P_p, i.e. 100% modulation, by using additional energy saving circuitry. With 100% modulation, the second method reaches 65-75% efficiency which is similar to the DSB value. With a 40% average modulation level and –12 dB carrier reduction the total efficiency for the EER method decreases by 10%, resulting in a 55-65% efficiency. This reduction in efficiency results from the fact that the mean RF output power is reduced while the input power requirements of the transmitter (cooling, heaters, etc.) remain the same.

The maximum P_p, achievable for SSB is less than the maximum P_p of DSB for transmitters operable for both DSB and SSB modes. For the method of linear amplification the P_p reaches 0.25 times the DSB value. The P_p generated using the EER-Kahn method reaches 0.5-0.75 times the DSB value. Keeping P_p constant, the change from –6 dB to –12 dB in carrier level can be utilized for the increase of wanted sideband power up to 3.5 dB.

4.2.3.2.2 Kahn method

Low level SSB generation followed by separation of the amplitude information and the phase information. The amplitude information is amplitude modulated by an anode modulator. The frequency source for the transmitter is phase modulated by the derived phase information. The composite signal, available at the transmitter output, resembles the SSB signal. This method is known as Envelope Elimination and Restoration (EER) method or Kahn method (Figure 4.5).

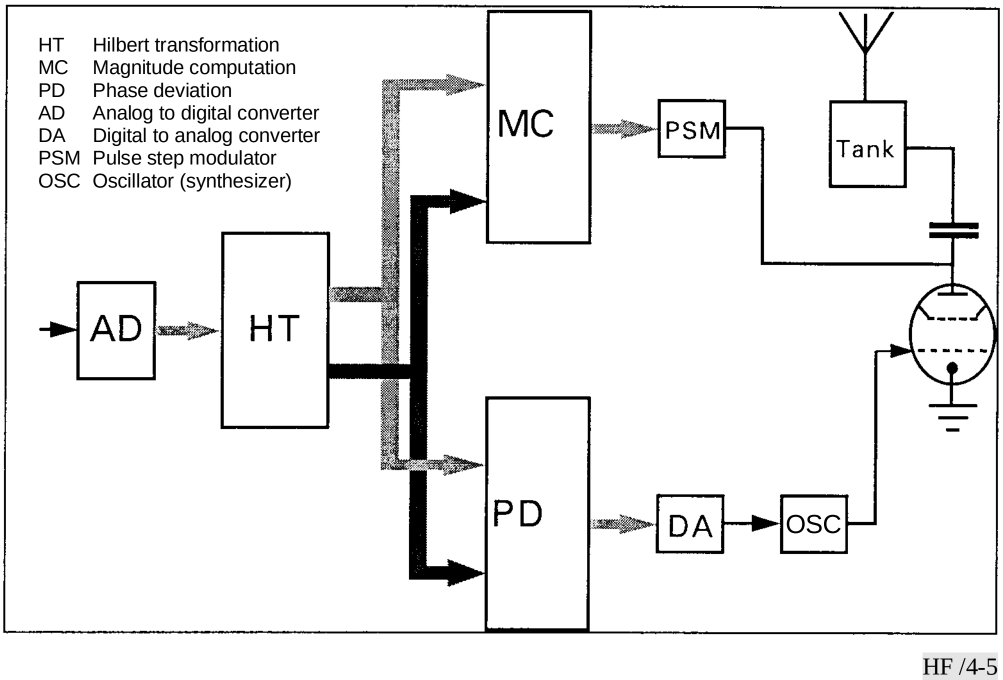


FIGURE 4.5

Envelope elimination and restoration process for SSB modulation

4.2.3.3 Possibilities for conversion of existing DSB transmitters to SSB

The majority of existing DSB transmitters still apply anode modulation using a modulation transformer and a modulation choke. The anode modulator is AC-coupled to the final radio-frequency stage and therefore only the linear amplification type of SSB generation is possible. The accompanying modifications are significant. Resulting SSB P_p cannot exceed original DSB carrier power.

4.2.4 Frequency tolerance and stability

In the Radio Regulations (Appendix S2), transmitter frequency tolerances are given. The tolerance applicable to short-wave transmitters is 10 Hz with the following notes: for double sideband (A3E) emissions with carrier power of 10 kW or less the tolerance is 20 parts in 10^6, 15 parts in 10^6 and 10 parts in 10^6 in the bands 1 606.5 (1 605 Region 2) - 4 000 kHz, 4-5.95 MHz and 5.95-29.7 MHz, respectively.

It is suggested however that administrations avoid carrier frequency differences exceeding 0.1 Hz, which cause degradations similar to periodic fading. This is avoided if the frequency tolerance is 0.1 Hz, a tolerance which would also be suitable for single sideband emissions. Modern transmitters enable tolerances of 0.1 Hz on both A3E and SSB modulation. A typical value for frequency stability is $\pm 2\ 10^{-7}$ per month.

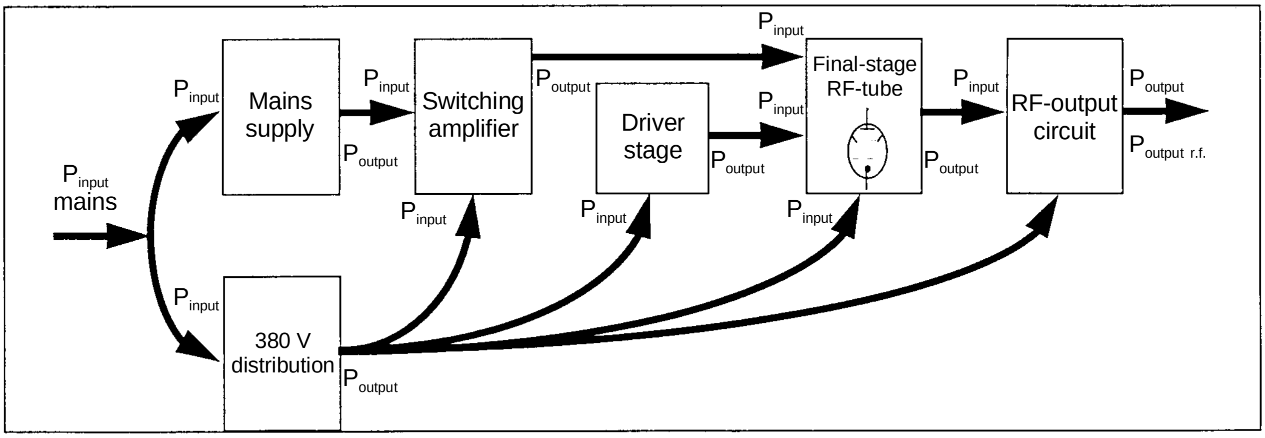
4.2.5 Spurious radiation level

The ITU Radio Regulations (Appendix S3) state that, for all new transmitters below 30 MHz, the mean power of any spurious output must be 40 dB below the mean power of the fundamental without exceeding 50 mW. For a 500 kW transmitter, the 50 mW level requires spurious emission to be 70 dB down on fundamental.

In the United States, the Federal Communications Commission (FCC) has specified that, at HF, spurious emissions should be 80 dB below fundamental. In the ever-increasing congestion of the HF bands, it is clearly an advantage for transmitters to achieve the lowest possible spurious output.

4.2.6 Overall transmitter efficiency

The overall transmitter efficiency is defined as the ratio of RF power output consumed by a dummy load to the mains power input to the transmitter and its auxiliary subsystems of coolant pumps, heat exchangers and air handling equipment (see Figure 4.6) Modern Class B transmitters have typical overall efficiency values of 62-70% at low modulation levels, falling to 54-60% at high modulation levels. Modern transmitters equipped with switched modulators show values that are higher and far less dependent on the modulation level.



HF /4-6

FIGURE 4.6

Power distribution in transmitter

$$\text{Efficiency} = \frac{P_{\text{output}}}{P_{\text{input}}} = \eta \qquad \text{Overall efficiency} = \frac{P_{\text{output r.f.}}}{P_{\text{input mains}}} = \eta_0 \tag{4-1}$$

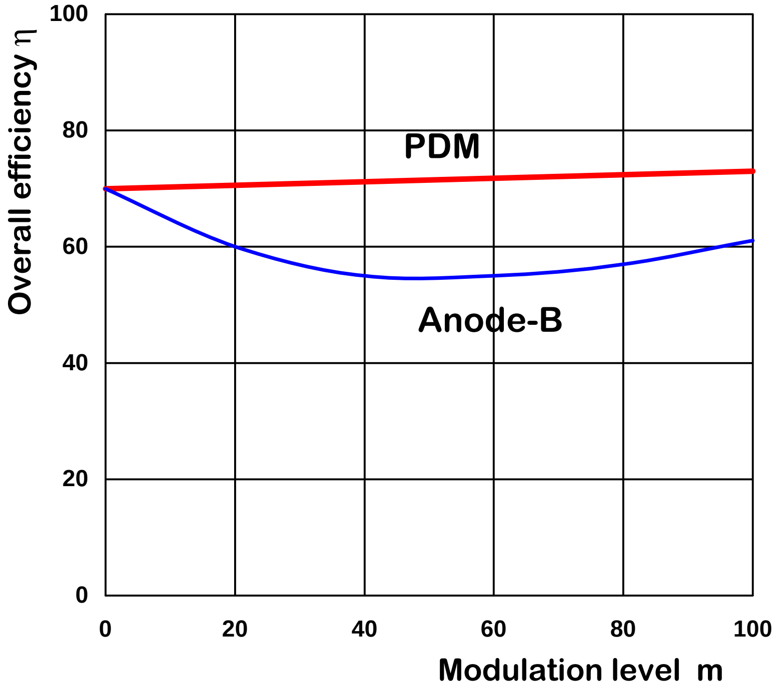


FIGURE 4.7

Overall efficiency Class B modulated transmitter vs. PDM transmitter

Typical overall efficiency values are 65% to 85% over a tuning range between 4 and 26 MHz without any measurable degradation in audio response or fidelity as compared to Class B modulators (see Figure 4.7). In general, any modern transmitter has an overall efficiency over 60% in its tuning range between 4 and 26 MHz. This efficiency remains good when power levels in a 500 kW transmitter are reduced from 500 kW to 250 kW or even 125 kW.

4.3 Transmitting antennas

4.3.1 Introduction

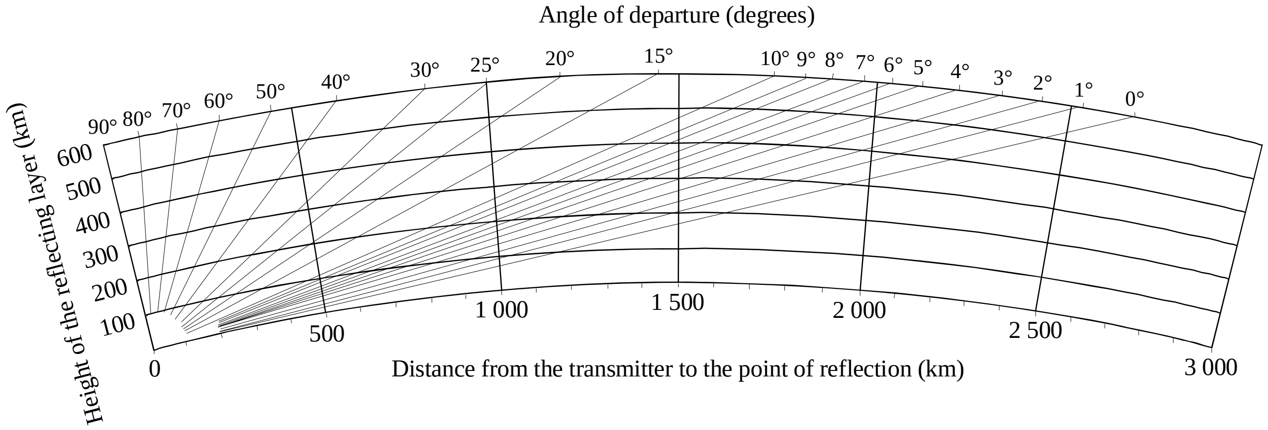
The transmitting antenna is one of the key elements in a HF broadcasting system. The antenna has two tasks:

– concentration of the RF energy of an emission on the wanted coverage area, and

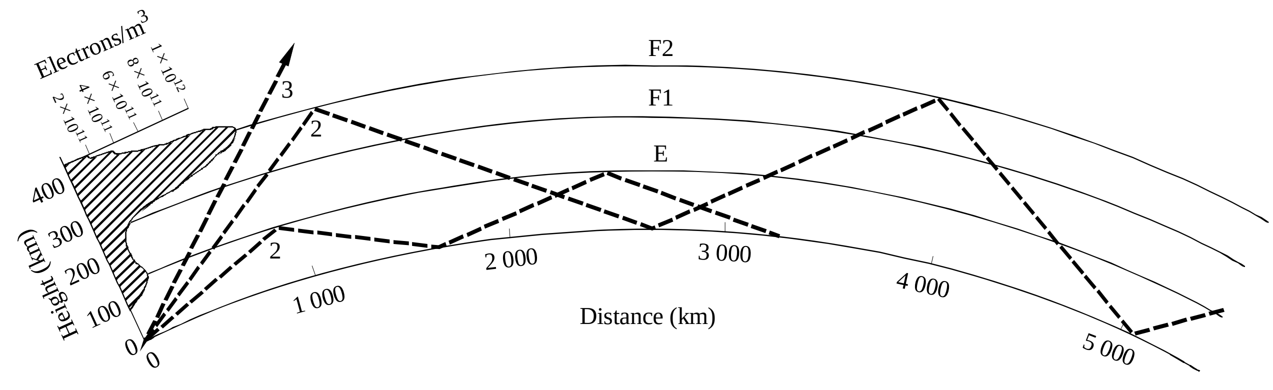
– to avoid radiation into coverage areas of other emissions.

Short-wave broadcasting is based on propagation by reflection of the radiated waves at different layers of the ionosphere. The main reflecting layers, E, F1 and F2, have (in average) heights above the Earth of about 260 km and 370 km, respectively. Figure 4.8 illustrates the interrelation between height of the layer, angle of elevation of the maximum radiation and distance of the reflection point. Ionospheric propagation is possible with one or more reflections (hops) at the layers and the surface of the Earth. The distance that can be reached with an emission will largely depend on the height of the layer, the angle of elevation at which the antenna has its maximum radiation and on the number of hops.

a) Interrelation between angle of elevation and distance (parameter, height of layers)



b) Sky-wave propagation and ray paths



HF /4-8

FIGURE 4.8

Representative distribution of electron density and ray paths

Figure 4.9 shows the necessary angle of elevation if a given area with a distance of *d* km is to be covered.

If this area is far remote from the transmitting station a highly **directional antenna** with rather low angle of elevation of its maximum radiation is needed. In cases where the transmitting station is located in the centre of the area to be covered an **omnidirectional antenna** with maximum radiation at much higher angles of elevation will be necessary.

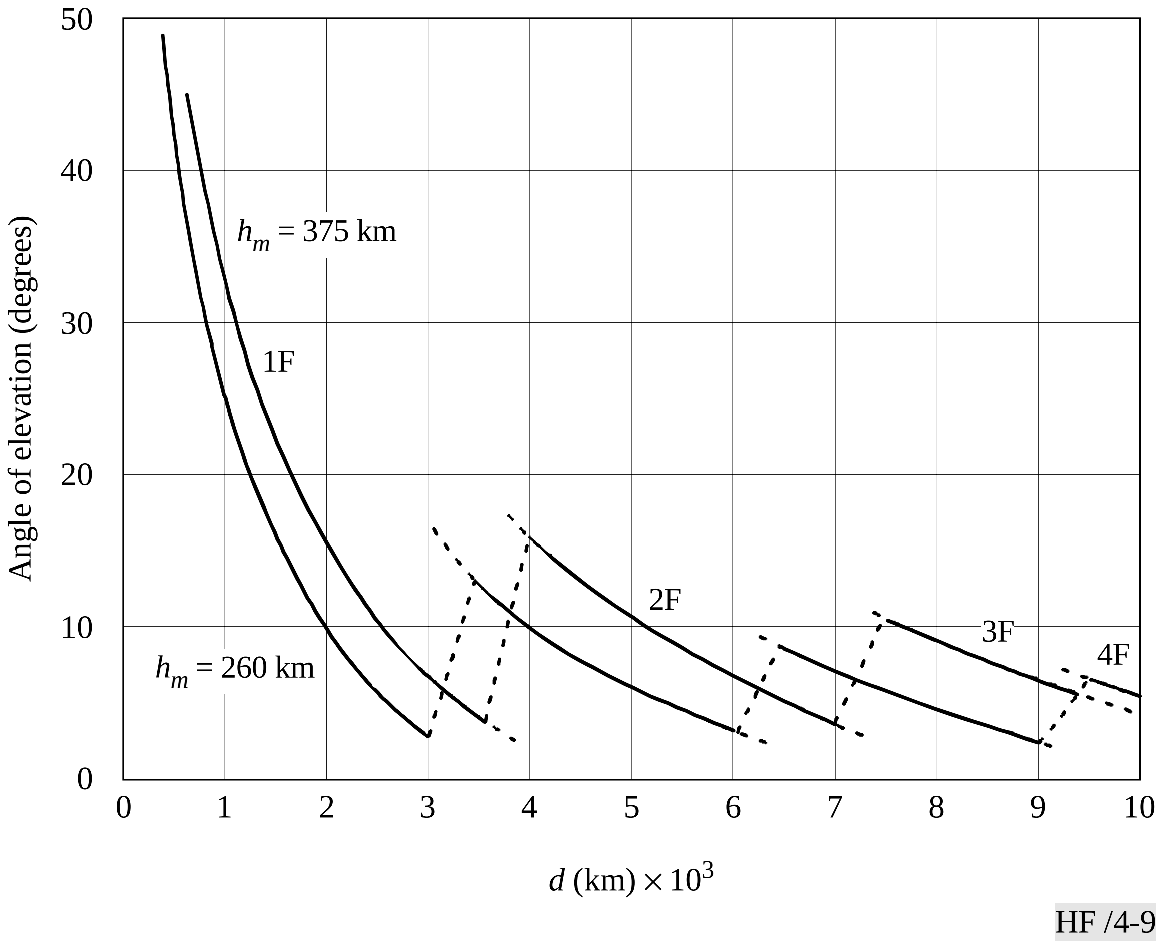


FIGURE 4.9

Variation of elevation angle with distance for representative ionospheric F-layer heights h_m

4.3.2 Radiation patterns

The radiation properties of transmitting antennas in short-wave broadcasting with respect to their wanted effect (coverage of a certain area) and the unwanted effect (interference in other coverage areas) are described by the **horizontal and vertical radiation patterns**. Figure 4.10 depicts examples of typical radiation patterns of a directional and an omnidirectional antenna together with the patterns of the **isotropic radiator** which serves as reference for the gain of directional antennas.

In short-wave broadcasting, the gain of antennas is mostly defined relative to the isotropic radiator in dBi. If it is defined relative to a half-wave dipole in dBd, the value will be 2.2 dB lower because of the gain of the dipole.

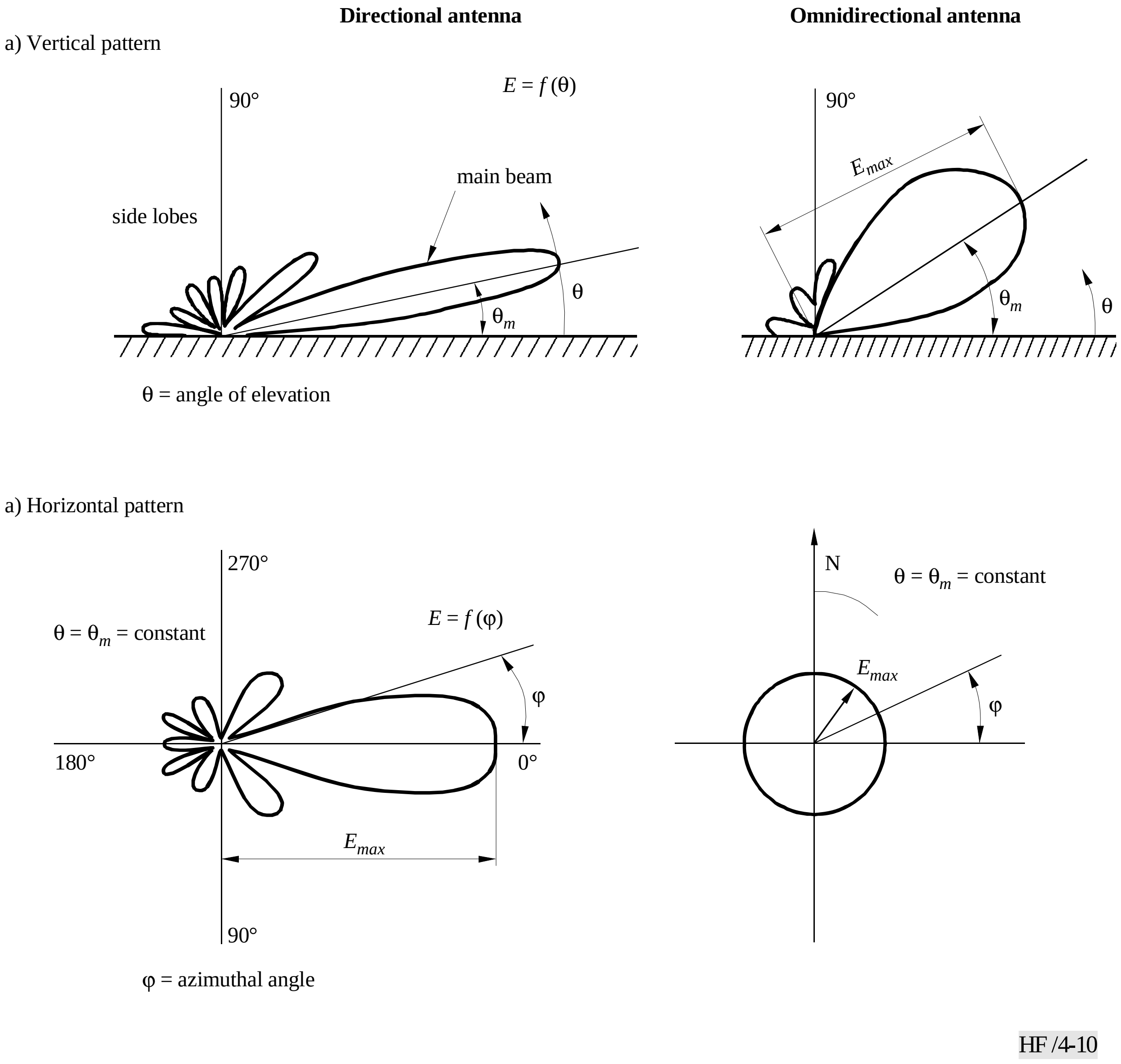


FIGURE 4.10

Directional and omnidirectional antenna characteristics

The coverage area achieved by a given transmitting antenna is determined primarily by the main lobe of radiation while the sidelobes can cause interference outside the wanted coverage area. The best quality of service is achieved when the optimum antenna is used for the required service area.

In any planning system, the impact of any one transmission on the reception of other transmissions needs to be assessed. This requires the calculation of antenna performance over all angles of elevation and azimuth, not just in the main lobe.

4.3.3 Types of transmitting antennas for HF broadcasting

For short-wave broadcast the most frequently used types of directional and omnidirectional antennas are: horizontal dipole arrays, log periodic antennas, rhombic antennas, quadrant antennas, tropical antennas and vertical monopoles.

These antennas are described in the following.

4.3.3.1 Arrays of horizontal dipoles

The half wavelength dipole is one of the radiating elements most commonly used at HF. Horizontal dipoles can be used on their own, or more often as arrays of dipoles arranged co-linearly and/or stacked in parallel to obtain increased gain, improved directivity and/or slewing of the main beam.

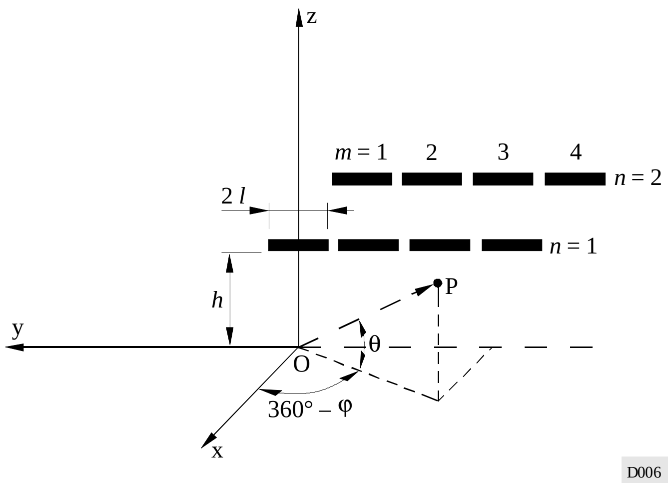


FIGURE 11

Tropical antenna

Unidirectional patterns are generally obtained by the use of a passive reflector. This reflector can be comprised of either:

– an identical array of dipoles tuned to provide an optimum front-to-back ratio over a limited range of operating frequencies (this type of reflector is known as a "tuned dipole" or "parasitic reflector");

– a screen consisting of horizontal wires which act as an untuned reflector over a wide frequency range (this type of reflector is known as an "aperiodic" or "screen" reflector).

Non-directional short distance services at HF generally require the use of omnidirectional or nearly omnidirectional antennas.

4.3.3.2 Arrays of horizontal dipoles in a vertical plane - curtain antennas

Arrays of horizontal half wavelength dipoles arranged vertically (curtain antennas) are realized by aligning and/or stacking dipoles vertically, one above the other.)

Two different basic feeding arrangements for the dipoles are used:

– centre-fed, where each dipole element has its own feeding point; (Figure 4.12).

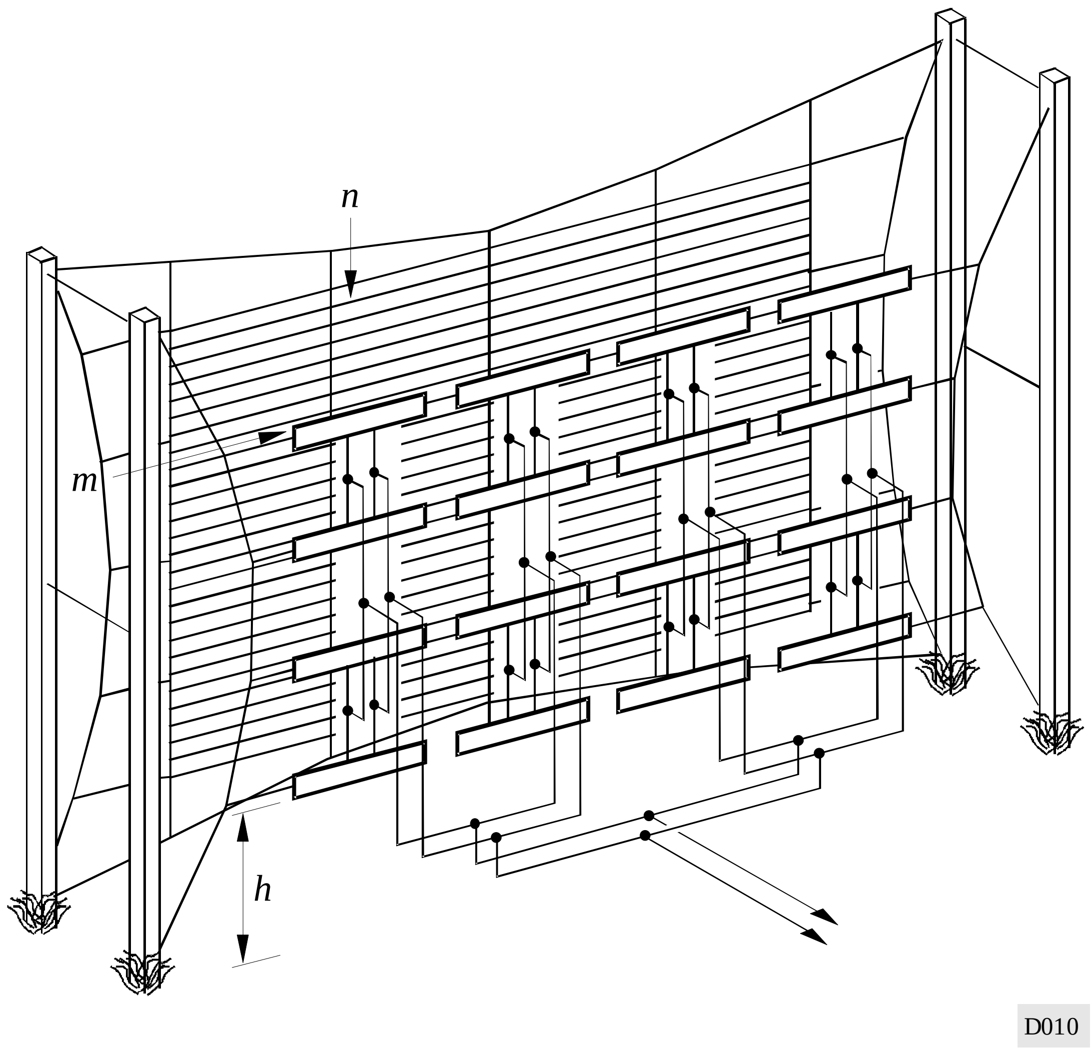


FIGURE 4.12

Centre-fed dipole array with aperiodic reflector

– end-fed, where two adjacent dipoles have a common feeding connected to a single transmission line. (Figure 4.13).

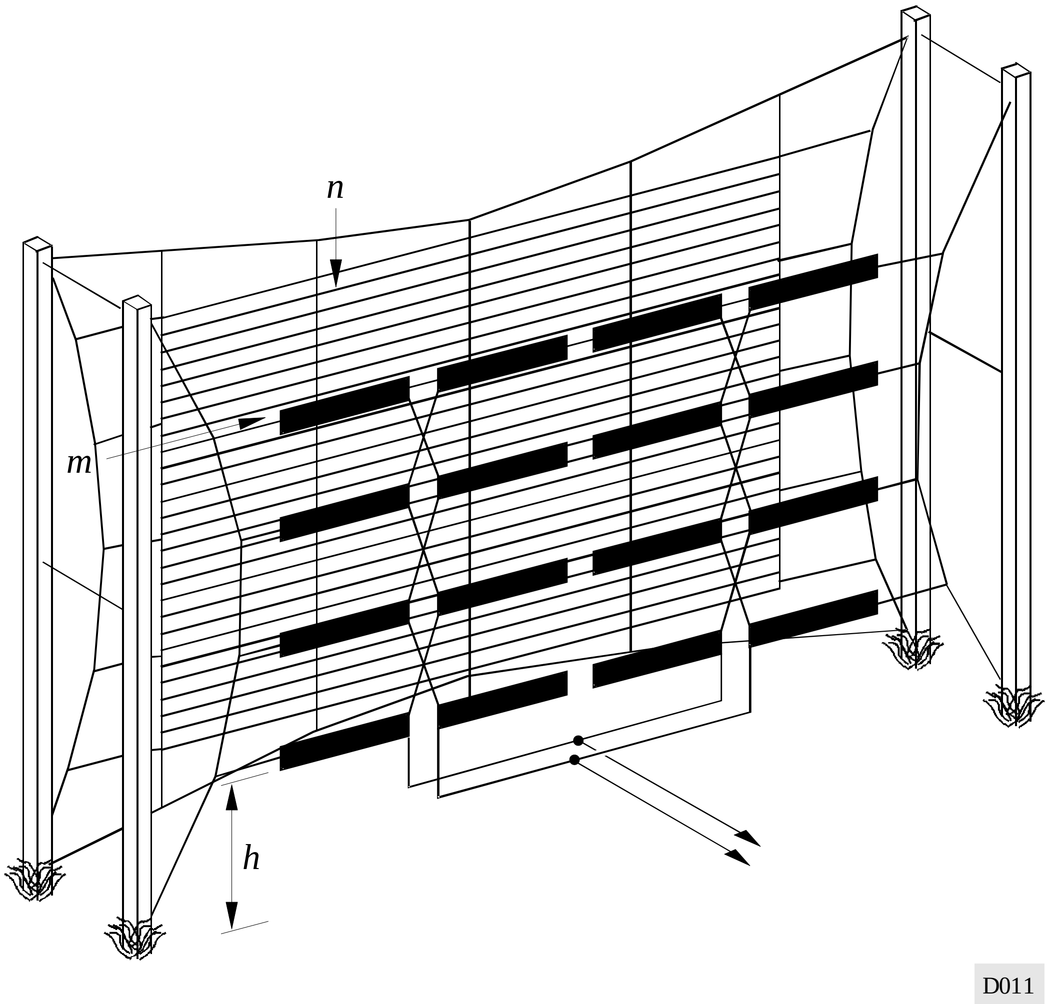


FIGURE 4.13

End-fed dipole array with aperiodic reflector

Antennas with more than one feeding point in a row may be slewed electrically in the azimuthal plane.

Curtain antennas using centre-fed elements are of more modern design and, at the cost of a more complex feeding arrangement, offer greater slewing capabilities when compared to the corresponding end-fed type.

For example, an HRS 4/n/h centre-fed dipole array with four feed points can be slewed up to ±30° and still maintain acceptable side-lobe levels.

A corresponding HRS 4/n/h end-fed dipole array with only two feed points spaced about one wavelength apart can be slewed up to ±15° before sidelobe levels become unacceptable.

The main features of a horizontally slewed antenna are that:

– the main beam is not in the direction normal to the plane of the dipoles, nor is it symmetrical about the axis of the direction of the slewed maximum,

– the sidelobes of the forward horizontal radiation pattern are not symmetrical with respect to the direction normal of the plane of the dipoles, nor with respect to the main beam of the antenna,

– the backward radiation pattern is no longer symmetrical with respect to the direction normal to the plane of the dipoles. Slewing the forward radiation of an antenna in one direction (e.g. clockwise) will cause the back radiation to slew in the opposite direction (i.e. anti-clockwise). (Figure 4.14).

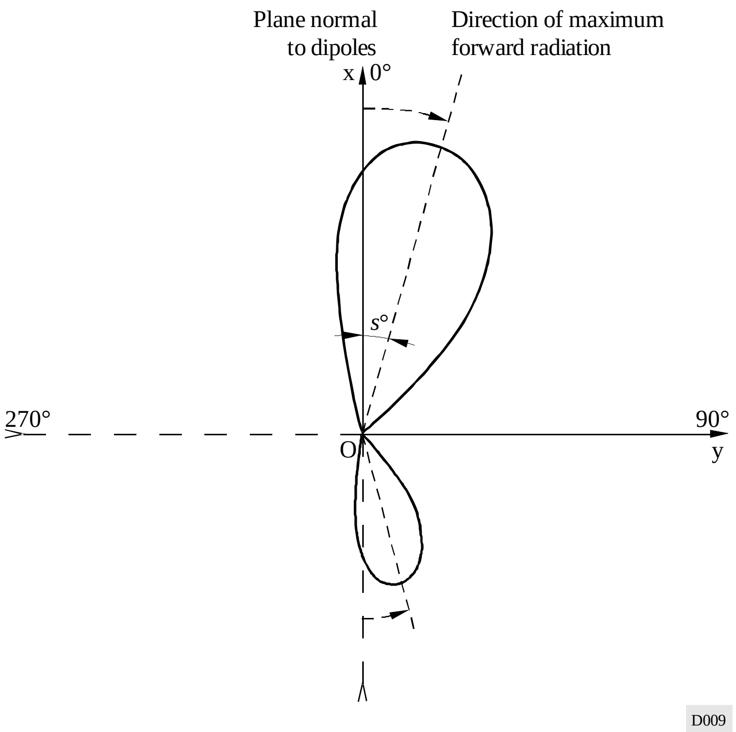


FIGURE 4.14

Azimuthal pattern of a horizontally slewed antenna

With a suitable construction, antennas may be slewed mechanically. This retains the radiation pattern of the unschemed antenna but introduces mechanical complexity.

4.3.3.3 Arrays of horizontal dipoles arranged in a horizontal plane - tropical antennas

Radiation mainly concentrated at high elevation angles (up to 90°), in many cases associated with a nearly circular azimuthal radiation pattern, is achieved by using arrays of horizontal dipoles in a plane parallel to and at a specified height above the ground.

These antennas, also called tropical antennas, are often used for short distance broadcasting in the Tropical Zone and consist of one or more rows of half-wave horizontal dipoles at a height above ground usually less than 0.5 wavelengths. (Figure 4.15).

Slewing of an otherwise symmetrical beam can be achieved by varying the phases of the feed currents in the elements of the same row. The resulting pattern shows a more or less pronounced main beam tilt and thus provides a directional effect useful for specific coverage situations.

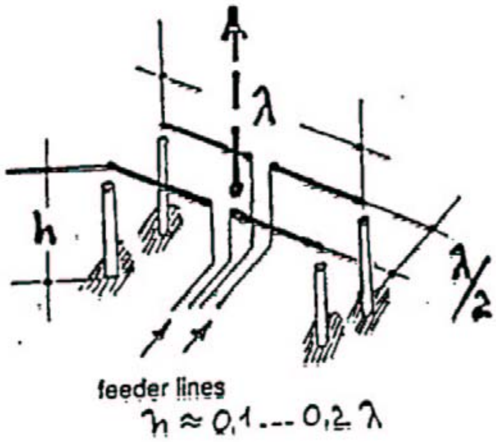


FIGURE 4.15

Tropical antenna

4.3.3.4 Omnidirectional arrays of horizontal dipoles

– Quadrant antennas (Figure 4.16).

The simplest form of quadrant antenna is represented by an arrangement of two horizontal end-fed half-wave dipoles placed at right angles. Another form of quadrant antenna, sometimes encountered in practice, consists of four dipole elements in the form of a square and fed at opposite corners.

Quadrant antennas may also be stacked to achieve a more directive vertical radiation pattern and thus a higher directivity gain.

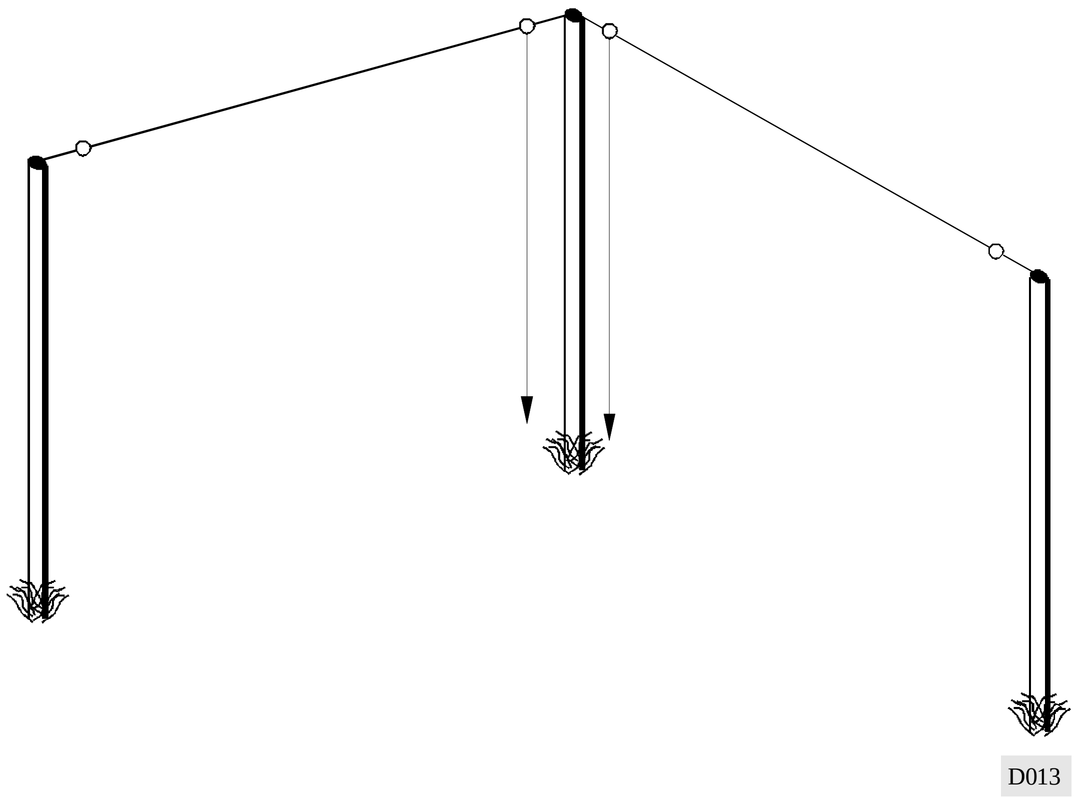


FIGURE 4.16

2-leg quadrant antenna

– Crossed dipole antennas (Figure 4.17).

A crossed dipole antenna consists of two horizontal centre-fed half-wave dipoles placed at right angles to form a cross.

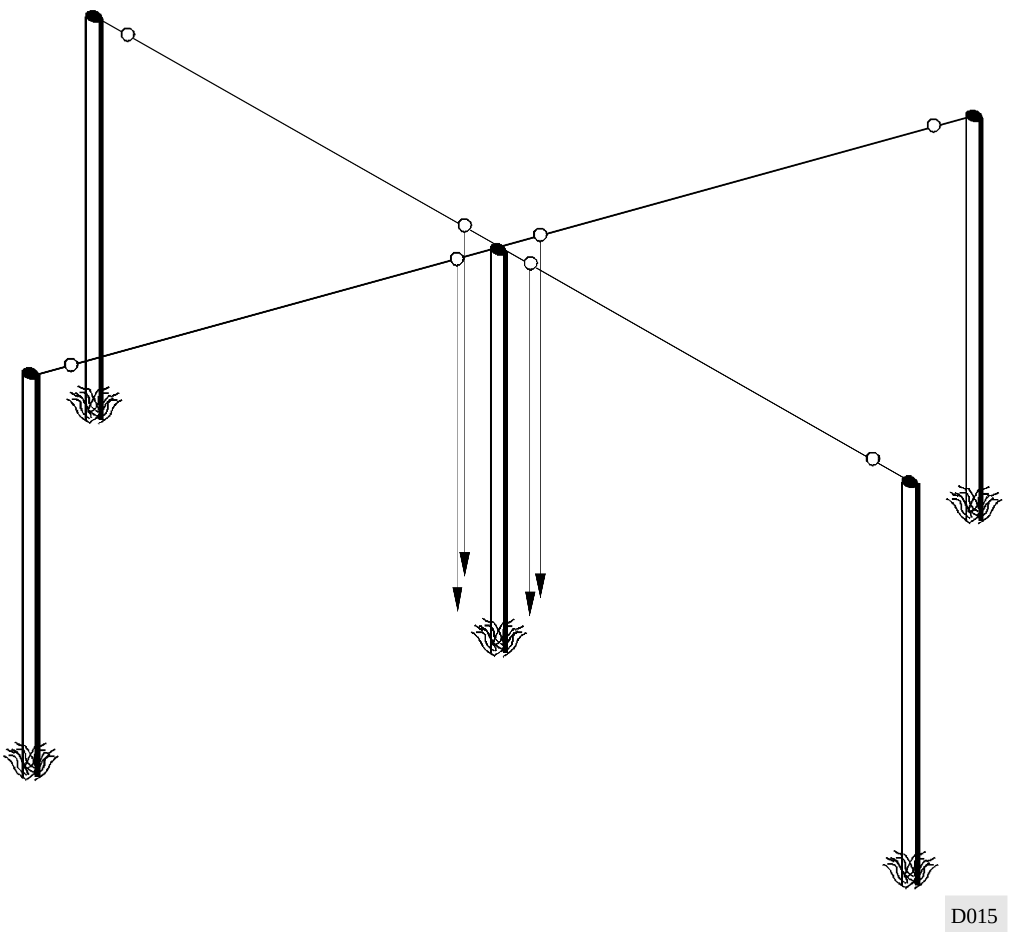


FIGURE 4.17

Crossed-dipole antenna

4.3.3.5 Log-periodic antennas

Log-periodic dipole arrays are tapered linear arrays, consisting of centre-fed dipole elements of different lengths, which operate over a wide frequency range. The spacing between the elements is proportional to their length. The array elements are fed using a transmission line along the axis of the antenna. Wideband operation is achieved since at different frequencies different groups of elements are radiating effectively. As the frequency varies, the elements which are at or near resonance couple energy from the transmission line. The resulting radiation pattern is directional and has a broadly constant directional pattern over the full operating frequency range.

The antenna in general is usable at frequencies between the resonant frequencies of the smallest and largest dipole elements. (Figure 4.18).

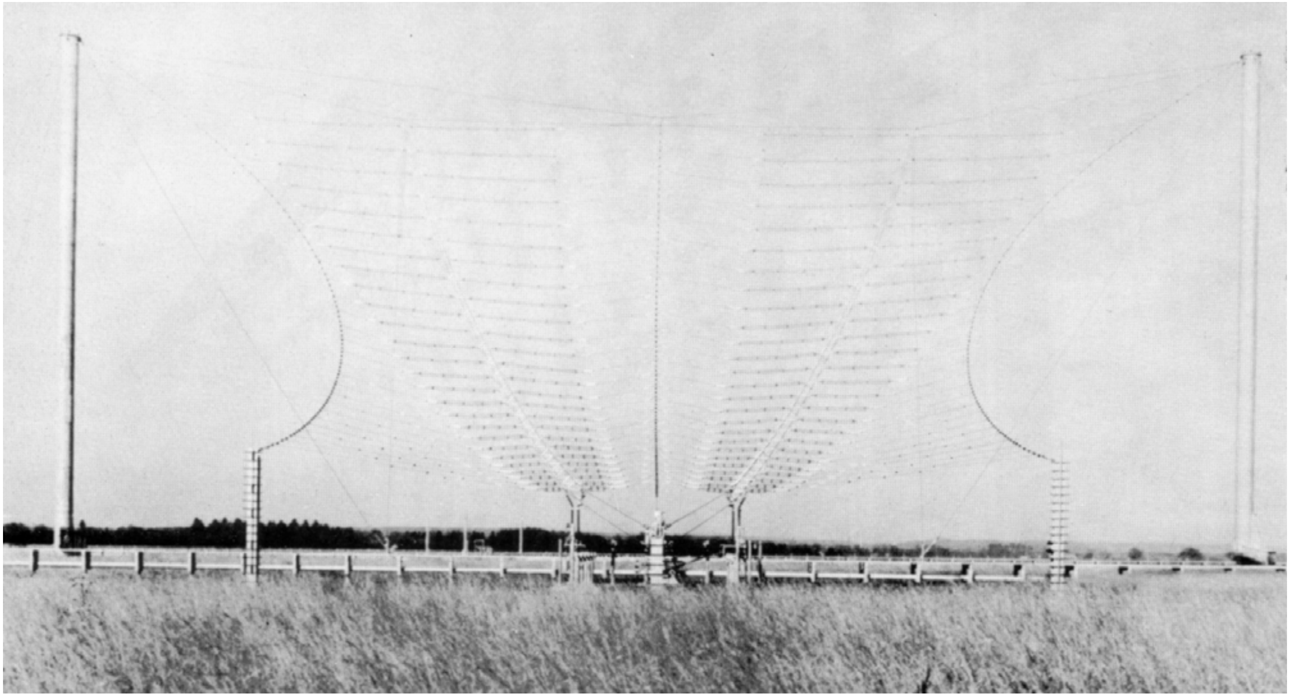


FIGURE 4.18

Log-periodic antenna

4.3.3.6 Rhombic antennas

A rhombic antenna consists of four horizontal straight wires of the same length arranged in the form of a rhombus. A rhombic antenna typically has side lengths of several wavelengths and a height of between 0.5 and 1.0 wavelengths at the middle of the operating frequency range. The currents in the conductors of the antenna can be considered as travelling waves originating from the feed point and propagating along the wires towards a terminating resistance. (Figure 4.19).

The rhombic antenna has been extensively used for HF broadcasting but is no longer recommended for this purpose as:

– the main lobe is narrow in both horizontal and vertical planes and this could result in the required service area not being reliably covered;

– there are a large number of strong sidelobes which can cause interference to other broadcasts;

– a significant proportion of the transmitter power is wasted in the terminating impedance and in the sidelobes.

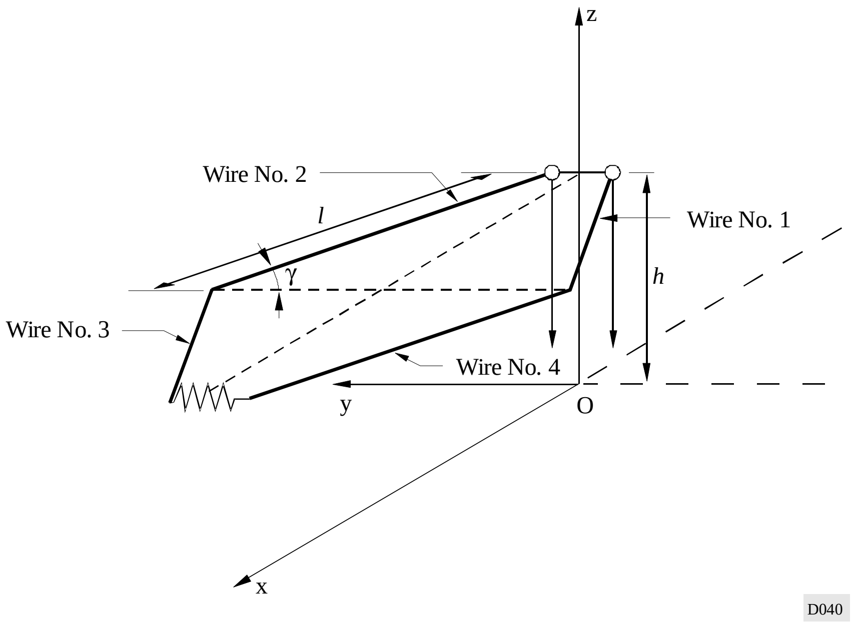


FIGURE 4.19

Horizontal rhombic antenna

4.3.3.7 Vertical monopoles

Vertical monopoles are seldom used as transmitting antennas in HF broadcasting due to their low gain and non-directional properties. When these vertical antennas are used, there are large currents in the ground local to the antenna resulting in significant losses of power particularly for ground of poor conductivity. These losses can be reduced by the use of an earth system normally consisting of a number of radial wires.

The main application of vertical monopoles should be confined to short-range omnidirectional broadcasting where economic and/or site constraints prevent the installation of more efficient radiating structures. (Figure 4.20).

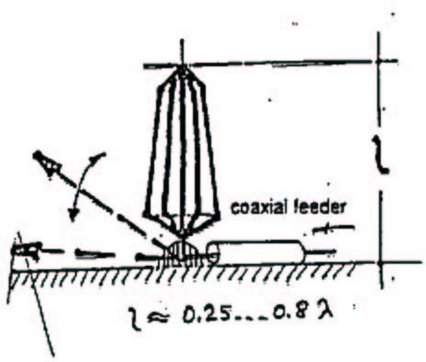


FIGURE 4.20

Vertical antenna

4.3.4 Selection of optimum antenna

The antenna selection chart in Figure 6.4 gives some general guidelines for the choice of a suitable antenna or a given type of service according to the required distance range. Two different categories are considered: short-distance and medium-/long-distance services.

A short-distance service is understood here to have a range of up to about 2 000 km. The required service area can be covered with either a non-directional or a directional antenna whose beam width can be selected according to the angular width of the sector to be served. In the case of a directional antenna, either a horizontal dipole curtain or a log periodic antenna can be employed.

Medium- and long-distance services are considered here to have a range beyond about 2 000 km. Such services require the use of antennas whose main lobe elevation angle is typically less than 13°. The horizontal beam width, depending on the width of the area to be covered as seen from the transmitter, is either wide, between 65° and 95°, or narrow, less than 45°.

4.3.5 Designation of types of antenna

Complete information on antenna designation is given in Recommendation ITU-R BS.705.

4.3.6 Calculation of antenna pattern

4.3.6.1 General

For horizontal dipole arrays designed or one band, the geometrical dimensions needed for the pattern calculation are contained in the antenna designator. Further parameters are necessary to describe multiband operation and slewing:

– the lowest and the highest operating frequency band of a multiband antenna;

– the design frequency if it is not the arithmetic mean of the lowest and highest operating frequencies;

– slew angle relative to the plane normal to the dipoles;

– type of reflector: tuned dipole or aperiodic screen;

– kind of feeding: centre-fed or end-fed.

Similar information will be needed for other antenna types. Details are given in Recommendation ITU-R BS.705.

4.3.6.2 Recommendation ITU-R BS.705

The performance of the transmitting is one of the key elements to be considered when planning an HF broadcasting system. It obviously has a major impact on the extent to which the coverage achieved matches the coverage required. However, there is also a major effect of the extent to which one transmission can interact with or cause interference to another transmission.

The coverage of the wanted area is determined primarily by the main lobe of the transmitting antenna, rather than by the side lobes, although these can play some role. Interference can be caused either by radiation from the main lobe which reaches other parts of the world than those intended and also by radiation from the side lobes.

In traditional planning, it is customary to consider only the wanted coverage area and not to consider interference aspects as being of major importance. With the increasing congestion evident in the HF bands, it is becoming ever more important to consider both wanted coverage and interference during the planning process. In order to do this, it is necessary to have a method of calculating antenna performance which is both accurate and fast.

This is the aim of Recommendation ITU-R BS.705.

4.3.6.3 Minimum radiation level

It is necessary to set a lower limit, or floor value, to the calculated antenna gain. This floor value is the lowest value to be used when calculating the radiation pattern of an antenna (see Figure 4.21). Whenever the calculated gain in any direction is above this floor value, this gain is to be taken into consideration for field strength calculation.

To avoid specifying:

– high gain antennas which have greater than 0 dBi gain in all directions,

– low gain antennas which have no directivity,

– it is necessary to express the floor value as a function of the maximum gain of the antenna.

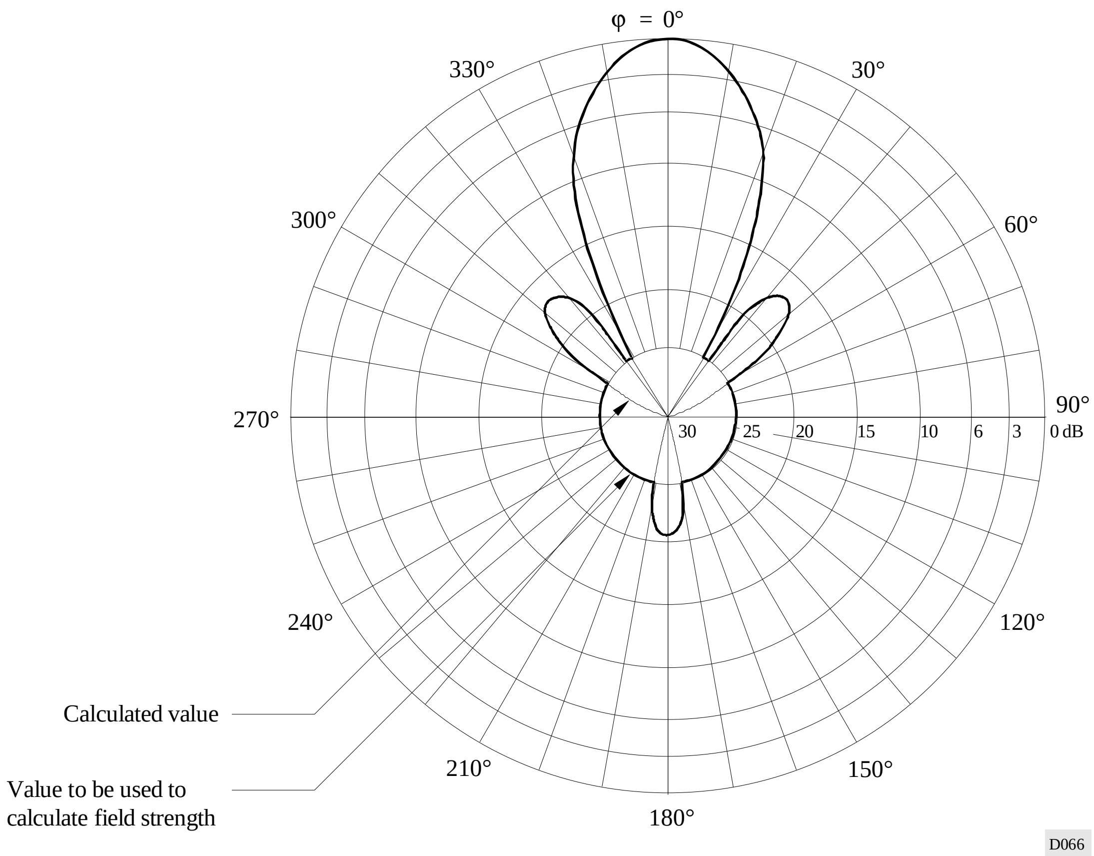


FIGURE 4.21

Example of floor value in the horizontal antenna pattern

The floor value is given as follows:

– if the maximum gain of the antenna is greater than or equal to 25 dBi, then the floor value is 0 dBi;

– if the maximum gain is less than 25 dBi, then the floor value is 25 dB below the maximum gain value.

4.3.7 Measurement of antenna pattern

The actual radiation pattern of an antenna at a specific location can only be determined by measurement.

The preferred method employed to determine the actual radiation pattern of an antenna is to use an airborne measuring equipment. The measuring equipment is mounted in a helicopter (the preferred type of aircraft for these measurements) and receives transmissions from the antenna under test. However, it is also possible to interchange the receiver and the transmitter.

It should be noted that a transmitter of adequate power is required to ensure a sufficient signal is available to exceed the background signal level particularly in pattern nulls.

Normally, a set of measured radiation patterns for an HF antenna consists of a horizontal radiation pattern (HRP) and a vertical radiation pattern (VRP) for each operating condition of the antenna. The HRP is measured at the elevation angle of the maximum radiation in the main lobe and the VRP is measured in the vertical plane through the maximum of the main lobe of radiation.

The accuracy of the results depends on the performance of the field strength measuring equipment and the system used to determine the location of the helicopter. Careful consideration has to be given to the following points:

– the characteristics of the airborne antenna and the method of mounting it;

– the accuracy of the field strength measuring equipment, including any connecting cables;

– the position determining system used to give accurate three dimensional coordinates and guidance to the pilot.

To ensure reliability, the HRP and VRP should be measured at least twice.

4.3.8 Comparison of measured and calculated pattern

Variations in the performance of practical antennas from the calculated patterns are due to differences in the actual design and construction details and the effects of the physical environment.

For example, in the case of curtain antennas, the main sources of variation resulting from the difference between the recommended design criteria and the actual constructional detail are:

– spacing of wires in reflection screen;

– diameter of wires in reflecting screen;

– spacing of reflecting screen from radiators;

– size of the reflecting screen in relation to the size of the array of dipoles;

– spacing between dipoles both horizontally and vertically;

– design frequency of antenna;

– effective thickness of dipoles.

In addition, it is known that the following features of the installation and transmitting site can modify the radiation patterns:

– physical arrangement of the supporting structures (e.g. towers, guys, catenaries);
– ground topography;
– ground conductivity;
– coupling of energy to adjacent antennas;
– any obstruction in the foreground of the antenna, e.g:
    – transmitter buildings;
    – high structures;
    – high tension towers;
    – antenna guys;
    – trees;
    – feeder lines.

Comparisons of measured and theoretical patterns for a large number of antennas demonstrate that, while the antenna performance within the main lobe of radiation can be predicted with reasonable accuracy, there can be significant differences in number, size and location of minor lobes.

CHAPTER 5

PROPAGATION

5.1 Propagation prediction

5.1.1 Recommendation ITU-R PI.533 method

Annex 1 to Recommendation ITU-R PI.533 is based on the method developed by IWP 6/12 for the HF Planning Conference (WARC HFBC-84). The second session of the Conference (WARC HFBC-87) asked the ITU-R to improve the prediction method and IWP 6/1 has introduced some modifications in order to improve the accuracy. The method was known as of former CCIR Report 894 method before it became a part of the Recommendation.

The prediction method is a combination of a simplified former CCIR Report 252-2 method for paths of 0 to 7 000 km and the FTZ method developed in the Federal Republic of Germany for paths greater than 9 000 km, with interpolation from the values obtained by the above two methods for path lengths between 7 000 and 9 000 km.

The FTZ method is semi-empirical and applies mainly to distances beyond 4 000 km. Its main intention is to extrapolate the field strength from the MUF through the usable frequency range up to operational MUF. The operational MUF, taken for a certain level of field strength, is determined by applying an empirical correction factor to the basic MUF.

Recommendation ITU-R PI.533 composite method does not take into consideration all aspects of propagation effects, but it is relatively simple and quick for computation, and may be convenient for operational use of the different HF services. A computer program has been developed for the Recommendation ITU-R PI.533 method.

5.1.2 Other methods

The above described Recommendation ITU-R PI.533 method is the only one that is recommended by the ITU-R. The old ITU-R methods such as those contained in former CCIR Report 252-2 and its supplement are not recommended any more because, although they are more complex, they do not give better results compared to measured data included in the ITU-R databanks.

There are a number of other methods such as IONCAP and MINIMUF which are available from different sources.

5.2 Fading

In any assessment of the performance of a broadcast service, the knowledge of the fading characteristics of the signals is required. Fading is referred to as "short-term" when the variation lies within the hour whereas "long-term" fading describes the variation of the hourly median values from day to day.

5.2.1 Short-term fading

Recommendation ITU-R BS.411 contains results of measurements of signal short-term fading. The fading depth depends on the time period considered and the circuit operating conditions such as path length and whether a single propagation mode or magnetoid component is involved. Thus the fading for periods up to 10 min follows a Rayleigh distribution, whereas over an hour it appears to be a log-normal distribution with decile variations close to those for the Rayleigh distribution. For HF broadcast planning, it is proposed that the upper-decile amplitude deviation from the median of a single signal be taken as 5 dB and the lower-decile deviation be taken as 8 dB.

5.2.2 Long-term fading

The long-term fading magnitude is determined by the ratio of the operating frequency to the basic MUF and is used for both the wanted signal and the interfering signal if present.

5.2.3 Combination of short- and long-term fading

To combine allowances for long-term fading of the wanted signals and the background together with the appropriate values of short-term fading, the allowance of fading for the necessary reception quality for 90% of time may be approximated by the root mean square of **SWH**, **SDD**, **BH** and **BD** in dB, where:

SWH = Wanted signal lower decile deviation from hourly median field strength arising from within-an-hour changes.

SDD = Wanted signal lower decile deviation from the monthly median field strength arising from day-to-day changes.

BH = Background upper decile deviation from the hourly median field strength arising from within-an-hour changes.

BD = Background upper decile deviation from then monthly median field strength arising from day-to-day changes.

TABLE 5.1

90% and 10% deviation from the predicted monthly median value of signal field strength in dB

Corrected geomagnetic latitude	**< 60°**		**> 60°**	
Frequency/MUF	**90%**	**10%**	**90%**	**10%**
<= 0.8	–8	6	–11	9
1.0	–12	8	–16	11
1.2	–13	12	–17	12
1.4	–10	13	–13	13
1.6	–8	12	–11	12
1.8	–8	9	–11	9
2.0	–8	9	–11	9
3.0	–7	8	–9	8
4.0	–6	7	–8	7
>=5.0	–5	7	–7	7

CHAPTER 6

SELECTION OF TRANSMISSION PARAMETERS

6.1 Basic considerations

To avoid difficulties to the HF listeners to tune in a wanted broadcasting station, frequent frequencies-changes should be avoided, as far as possible. For a specified coverage, several types of continuities may be identified:

– same frequency during the time of transmission in a given season;
– same frequency during two different parts of the day with similar propagation conditions such as morning and evening hour, in a given season;
– same frequency during the time of transmission from a season to the next season;
– same frequency during a year (four seasons);
– same frequency during the time of transmission from a season to the same next year season;
– same frequency during the time of transmission during the whole solar cycle.

Practically, due to daily, seasonal and yearly propagation variations, these continuities can not be easily achieved. On the other hand, due to spectrum congestion, frequencies-shifts must be done to avoid damageable interference.

6.2 Selection of frequency band

The frequency band may be selected according to several parameters:

– highest level of received signal in the target, with a given reliability;
– highest reliability of the received signal in the greatest number of test-points in the target;
– longer continuity in a given slot-time, in the greatest number of test-points in the target;
– availability of required transmitting equipment in the transmitting station.

6.2.1 Consideration of synchronization

In terms of spectrum efficiency synchronization can be a useful measure to keep frequency allocations low. It serves to a great extend the listeners demand of having just one or few frequencies to keep in mind in order to find a particular station. The application of synchronized frequencies however has to be treated with great care. It should only be used to cover a large area with non-overlapping beams. There will be always an area of cluttered reception, where the signals of two stations involved will have approximately the same field-strength. Within these areas a strong selective fading will occur, that can deteriorate the reception to a great extent. Due to permanent changes of propagation these areas will not remain fixed, but move across a particular region of the target area.

Synchronization can be used to:

– serve large target areas from different transmitting sites;
– serve the listeners demand for one frequency in the whole area;

Special care has to be taken when using synchronization:

– synchronization of 2 transmitters from one site with beam bearings close to each other should be avoided because diagram distortion can occur and coupling effects can interfere with transmitter operations (see Figure 6.1).

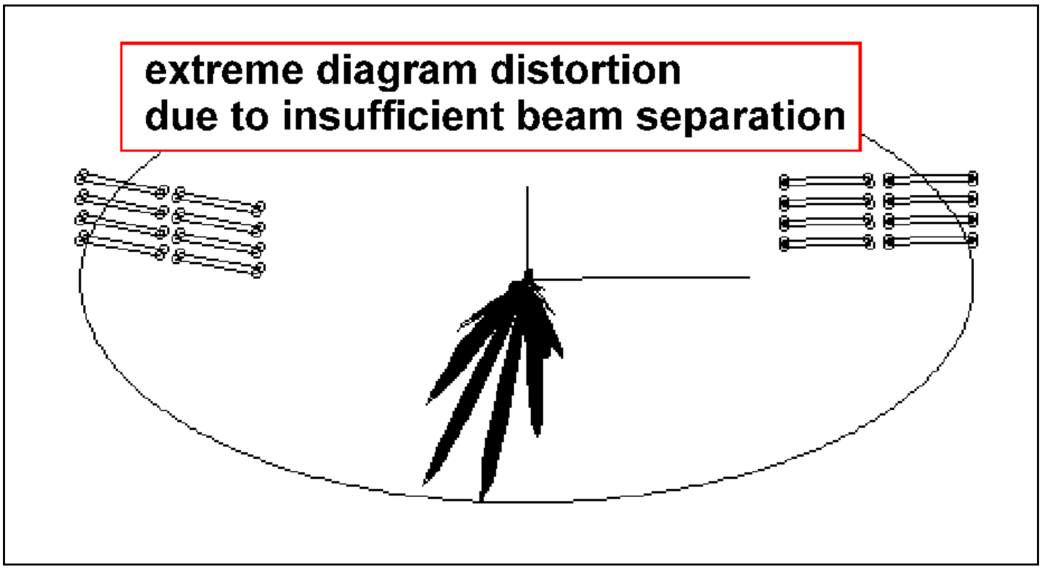


FIGURE 6.1

– the target areas of the synchronizing transmitters should merely overlap to add up to cover the intended area, otherwise there may be a cluttered area of disturbed reception (see Figure 6.2).

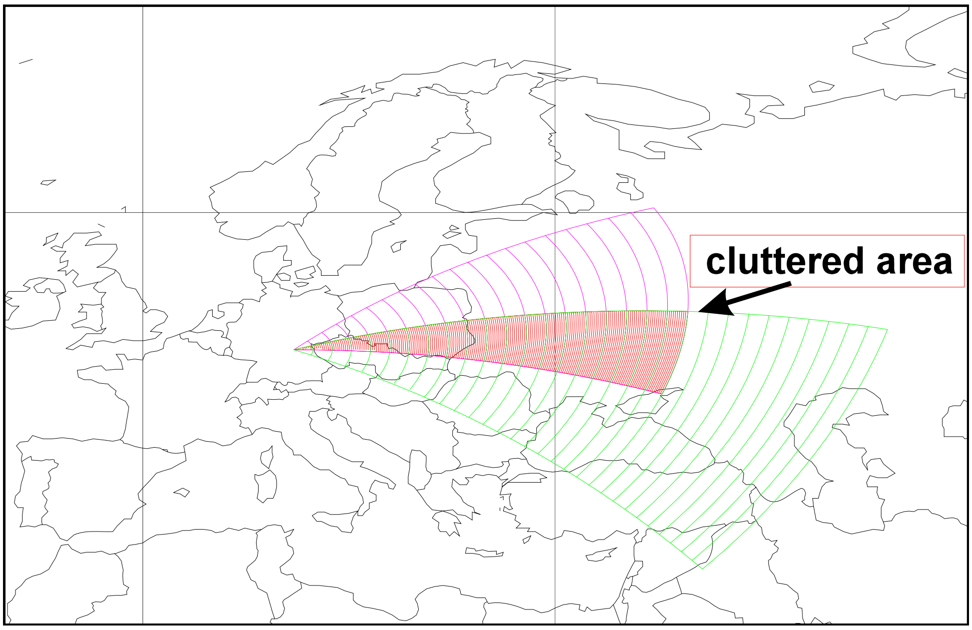


FIGURE 6.2

– when synchronizing two or more transmitting sites, the propagation delay from the stations involved to the target area should not differ more than a few milliseconds;

– the transmitters involved should be locked to the same frequency standard;

– the audio feed delay to the transmitting stations should be compensated in particular when one station is fed via satellite link and another via land line.

Synchronization should not be used when:

– the target area can be covered with one antenna beam under stable propagation conditions;

– the propagation or audio delay differs to much on the circuits involved;

– the circuits overlap to a great extent in the target area.

6.2.2 Need for multiple frequency bands

The need for the use of multiple frequency bands can arise out of several factors to be considered when planning a service for a particular area:

– size of the area to be covered;

– duration of the transmission e.g. change of propagation during the transmission;

– difficult propagation effects;

– restrictions or limitations of available transmitting sites.

Basically the aim will be to serve a target area by a transmitter from the site providing:

– the optimum propagation e.g. the best field-strength over a large service area. This, in many cases will be the station closest to the area. If the azimuth range seen from the site is greater then the antenna can cover, a second or probably third antenna bearing has to be added. If the propagation is unreliable during the transmission (e.g. MUF falls below LUF) the use of more than one frequency can provide alternatives for the listener if the reception of one transmission deteriorates.

The example in Figure 6.3 should illustrate some reasons that make it necessary to use multiple frequency bands:

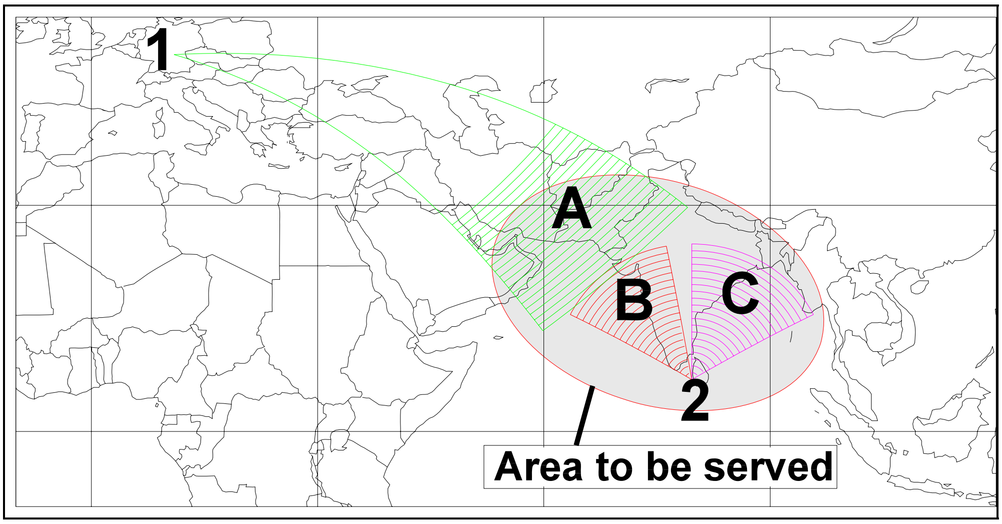


FIGURE 6.3

Given: a transmission during winter season between 0200 and 0300 UTC.

2 transmitting sites are available (1 + 2).

Site 2 can cover with 2 azimuth bearings the target area to a large extent.

Site 1 can fill the north-western gap.

As the optimum frequency for beams A, B and C are different, the area has to be served with 3 different frequency bands (e.g. beam A: 6 MHz, beam B: 9 MHz, beam C: 11 MHz).

There are a number of reasons why more than one frequency is necessary to reliably cover the required service area.

If the geographic area to be served is large, additional frequencies and/or transmitters may be required.

If the width of the required service area as seen from the transmitter is greater than the beam width of the antenna available, additional transmitting facilities will be required. Usually, the same frequency can be used for the additional transmission. This technique is known as frequency synchronisation.

If the depth of the required service area is greater than can be achieved with the vertical beam width of the antenna, additional transmissions on different frequency bands will be required.

During the transition between night to day and day to night, the ionosphere changes very rapidly. The layer height, critical frequency and absorption characteristics can change dramatically within a few minutes depending on the location of transmitting site in relation to the required service area. The result of this rapid change is that the optimum band for a 30 minute transmission may be 6 MHz at the start of the transmission but could rise to 12 MHz or greater by the end of the transmission. A further complication is that this change in optimum band will vary in time on a day-to-day basis with the normal daily change in propagation conditions. To provide a viable service a number of frequency bands will need to be scheduled to give the listener the ability the receive the whole programme by re-tuning to the band that gives best reception during the course of the transmission.

6.2.3 Synchronization and multiple frequency use per programme

It is recognized that the synchronization of transmitters is an accepted technique for improving the efficient use of the spectrum and helpful to relieve the current overloading of the HF-bands. Provision No. S12.8 of the Radio Regulations states: "... the number of frequencies used shall be the minimum necessary to provide a satisfactory quality of reception. Whenever practicable, only one frequency should be used."

It is therefore recommended that:

– wherever possible, only one frequency should be used to radiate a particular programme to a given reception area;
– over certain paths, e.g. very long paths, those passing through the auroral zone, or paths over which the propagation conditions are changing rapidly, it may be found necessary to use more than one frequency per programme;

– in certain special circumstances, namely:

1) where the depth of the required service area extending outwards from the transmitter is too great for it to be served by a single frequency;
2) when highly directional antennas are used to maintain satisfactory signal-to-noise ratios, thereby limiting the geographical area covered by such antennas;
3) where the required service area subtends an azimuth angle greater than can be served by a single directional antenna.

Synchronized transmitters:

– at the same site, driven by a common oscillator and modulated by the same programme in the correct phase;

– at separate sites, driven by separate oscillators, the frequencies of which are precisely controlled (a carrier frequency difference of 0.1 Hz or less) and modulated by the same programme;

can be considered as not introducing any appreciable deterioration in reception.

This conclusion is valid:

– for non-overlapping coverage areas;

– for overlapping coverage areas, provided that due consideration is given to:

1) the shape and size of the reception area;
2) the availability of suitable transmitting antennas;
3) the propagation conditions over the respective transmission paths.

6.3 Use of existing facilities

Clearly in the interests of economy and time scale, it is better to select the facilities required for a new service from those already available. In practice, this may lead to some compromises. In all cases, however, it is also desirable to consider the availability of transmitters and antennas owned and operated by other countries or broadcasters.

6.4 Selection of antenna type

The characteristics of the transmitting antenna selected for use should match the size and shape of the required service area. The horizontal beam width of the antenna should be approximately the same as the width of the service area as seen from the transmitting site. The vertical beam width of the antenna should also be approximately the difference in vertical angles required to serve the nearest and furthest parts of the service area from the transmitting site. The chart given in Figure 6.4 gives a guide to the selection of the appropriate antenna for use with different types of service area.

In practice, the actual antenna used should have radiation characteristics, at the broadcasting band to be used, that are as close as possible to the characteristics calculated as being necessary to provide optimum coverage for the required service area.

6.5 Selection of transmitter power

Once the appropriate antenna has been selected, the power of the transmitter can be selected to give the required reliability for the service. In general terms, the minimum power should be used, but in practice, the transmitter having the higher output power nearest to this minimum should be used.

If the highest transmitter power available is not sufficient to provide the required quality of service then consideration should be given to splitting the required service area into 2 or more smaller areas and using different transmitting facilities for each of the smaller areas.

6.6 Special considerations for broadcast in the Tropical Zone

The transmitter power is primarily decided by the minimum signals required in the service area to override the noise that is present.

In the tropics, atmospheric noise level predominates and, at certain times of the day and certain seasons of the year, can be such as would call for very large powers of transmitters. A compromise is made and practical value is chosen.

Based on this compromise and taking into account practical values attainable, Recommendation ITU-R BS.215 sets forth the following values of the upper limits of power for broadcasting transmitters in the Tropical Zone:

– for a service area limited to 400 km, the nominal power of the transmitter should not exceed 10 kW;
– for a service area limited to 800 km, the nominal power of the transmitter should not exceed 30 kW; the powers mentioned in §§ 1.1 and 1.2 of Recommendation ITU-R BS.215 are for frequencies below 5 060 kHz used in tropical broadcasting for such ranges;
– for frequencies above 5 060 kHz, where tropical broadcasting services use the same frequency bands as the high-frequency broadcasting services, the same power limit as recommended by the Mexico City Conference, 1949, shall apply.

Over the past years, the occupancy of the HF bands for broadcasting has increased dramatically. As an overall result, the amount of interference increased. Many international broadcasters in the high frequency broadcasting bands turn to high-power transmitters in order to assure reception quality in their service zones under conditions of increasing congestion in those bands. In general, the minimum usable carrier power nowadays is 50 kW. The standard power at major, modern transmitter outlets has become 500 kW. The standard power at relay stations ranges between 100 and 300 kW with 250 kW transmitters being most popular.

In regional broadcasting, low-power transmitters are still being used, with 10 kW being the minimum output power required. In both regional and international broadcasting, the tendency exists to replace obsolete transmitters by high-power transmitters offering higher efficiency and better performance in the service area.

6.7 Need for new transmitter or antenna

Given a transmitting station where all transmitters are operated during a significant part of the day, it appears clearly that any further requirement to broadcast a new program will create a demand for new transmitting equipment: transmitter and antennas.

This new equipment may be:

– added to the existing station;
– built as a new station or a relay station;
– rented to another station offering facilities and able to cover the wanted target.

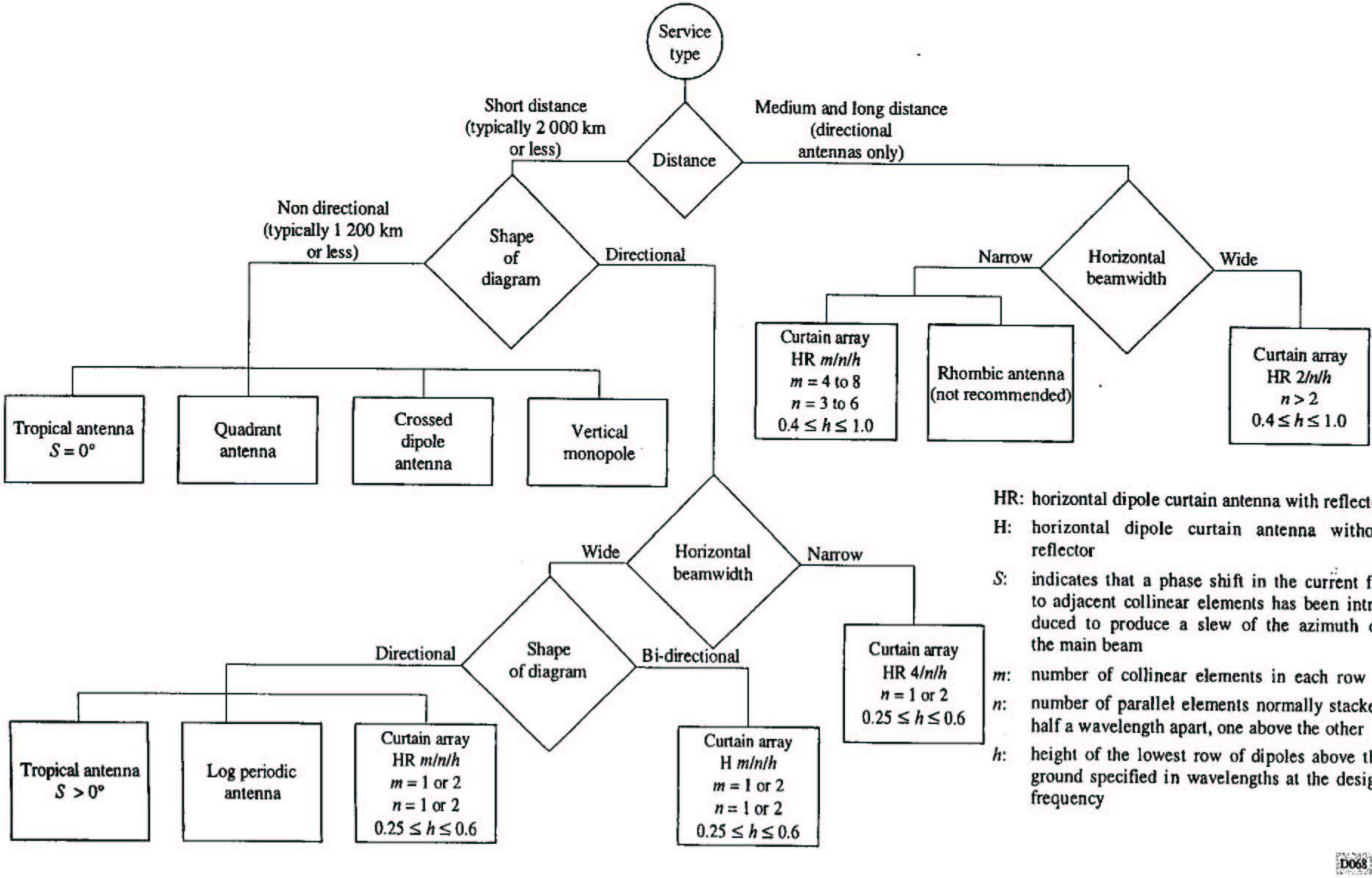
Old transmitters have, in general, a low efficiency in terms of power consumption. Modern transmitters with solid-state parts, high efficiency valves and energy saving devices have a higher efficiency. Replacing the old equipment by such new ones may lead to a significant reduction of the operating costs.

Due to the world-wide increase in HF power, due to the requests of the listeners asking for better receiving conditions, medium power HF transmitters may have to be replaced by high-power HF transmitters, in view to be competitive with those broadcasters using high-power transmitters.

Knowing that HF broadcasting has a political support, assuming that the targets may vary and may be numerous, it appears that a broadcaster having world-wide targets needs a lot of antenna to cover them. Conventional fixed antennas request, in general, a lot of space to be erected, additional expenses to feed them ad to switch them on transmitters. Rotatable antennas may be a good answer to the question of the unknown and varying number of targets on the basis of a 20 to 25 years of operation.

In other words, broadcasters may have the need to replace conventional antennas by rotatable antenna to be as flexible as possible in their future operation.

Assuming that “the closer is the transmitter to the target”, “the stronger is the signal in the target”, it may be valuable to use facilities outside the home land. Relay station is a good answer to the question but may be difficult to achieve due to amount of investment, or to political reasons, or to national (foreign) regulations ... So, exchange between stations may be a good answer to the question of improving the receiving quality in a given distant target. To make this exchange possible, the station must be able to offer a counterpart to the other station able to provide the improved „distant” coverage.



HR: horizontal dipole curtain antenna with reflector

H: horizontal dipole curtain antenna without reflector

S: indicates that a phase shift in the current fed to adjacent collinear elements has been introduced to produce a slew of the azimuth of the main beam

m: number of collinear elements in each row

n: number of parallel elements normally stacked half a wavelength apart, one above the other

h: height of the lowest row of dipoles above the ground specified in wavelengths at the design frequency

FIGURE 6.4

Antenna selection chart

CHAPTER 7

TROPICAL ZONE BROADCASTING

7.1 Introduction

Provision No. S23.5 of the Radio Regulations defines Broadcasting in the Tropical Zone as "a type of broadcasting for internal national use in the countries lying in the Tropical Zone, where it may be shown that because of the presence of high atmospheric noise level and difficult propagation conditions, it is not possible to provide economically a more satisfactory service by using low, medium or very high frequencies". The area lying within the Tropical Zone is defined in the Nos. S5.16 to S5.21 of the Radio Regulations as follows:

a) the whole of that area in Region 2 between the Tropics of Cancer and Capricorn;

b) the whole part of that area in Regions 1 and 3 contained between the parallels 30° N and 35° S with the addition of:

- the area contained between the meridian 40°E and 80°E of Greenwich and the parallels 30° N and 40° N;
- that part of Libya, North of Parallel 30° N;

c) in Region 2, the Tropical Zone may be extended to parallel 3° N, subject to special agreements between the countries concerned in that Region.

High frequencies, which are generally used for long-distance communication and international broadcasting, provide an easy and economical means of satisfactory broadcasting, particularly to the developing countries in the Tropical Zone, under the special conditions prevailing there. By making the radio waves incident at vertical or near vertical angles at the ionosphere, the service can be extended right from the HF transmitter. Thus it is possible to provide an uniform short distance service over the entire service area around a transmitter, using the lower HF bands. In the national context it is therefore more economical for the developing countries to provide broadcast coverage to their nation with a smaller number of transmitters in the HF bands than would be required in the case of the LF, MF bands. This type of service is primarily intended to be a substitute for the higher grade services which are normally provided with the MF band. Another possibility to achieve this objective is to use the VHF/FM-band.

The proposal for using the lower HF bands for national broadcast services in the Tropical Zone with limited coverage and power was first introduced at the Cairo Radio Conference (1938). The idea was further developed at the Atlantic City Conference in 1947. At that Conference the scope of broadcasting for internal national service in the Tropical Zone was defined, bands were allocated and the conditions under which such broadcasting should be carried out in these bands were stipulated. The frequency bands thus allocated for broadcasting in the Tropical Zone are, however, shared bands (with fixed and mobile services) and are defined in No. S23.6 of the Radio Regulations.

These bands are:

2 300 - 2 498 kHz	(Region 1)
2 300 - 2 495 kHz	(Regions 2 and 3)
3 200 - 3 400 kHz	(all Regions)
4 750 - 4 995 kHz	(all Regions)
5 005 - 5 060 kHz	(all Regions)

The conditions attached to the use of these bands for broadcasting are given in Nos. S23.7 to S23.10 of the Radio Regulations.

According to

No. S23.7: the carrier power of the transmitters operating in the bands listed above shall not exceed 50 kW:

No. S23.8: within the Tropical Zone, the broadcasting service has priority over the other services, sharing these bands;

No. S23.9: however in that part of Libya, North of parallel 30° N, the broadcasting service in the bands listed above, has equal rights to operate with other services in the Tropical Zone with which it shares these bands;

No. S23.10: the broadcasting service operating inside the Tropical Zone and other services operating outside the zone are subject to the provisions of No. S4.8;

No. S4.8: where, in adjacent Regions or sub-Regions, a band of frequencies is allocated to different services of the same category (see Sections I and II of Article **S5**), the basic principle is the equality of right to operate. Accordingly, the stations of each service in one Region or sub-Region must operate so as not to cause harmful interference to services in other Regions or sub-Regions.

The planning of a short-distance HF broadcast service in the Tropical Zone is slightly different from the planning of a service in the exclusive HF broadcast bands. Instead of the oblique incidence on the ionosphere normally employed to reflect the radio waves to reach the target, vertical incidence is employed to provide a non-skip service. This demands a proper choice of frequency of operation and special types of antenna. The power of the transmitter is determined by the prevalent noise level, the grade of service desired and the characteristics of the receiver.

Most of the planning parameters used for the design of a HF broadcast service in the Tropical Zone in the shared HF bands, are similar to those used for the design of a broadcast service in the exclusive HF broadcast bands. However, because of the special requirements of the service, comparatively high absorption of the signal, presence of higher levels of noise, fading and difficult propagation conditions etc., there are certain parameters which need to be taken care of while planning a HF broadcast service in this zone. The special attributes of these parameters are described here.

7.2 Propagation prediction

7.2.1 Prediction of MUF

MUF - the Maximum Usable Frequency, represents the highest frequency that can be used for establishing a HF communication circuit between two points by a mode depending on the reflecting layer. Even though the reflections from F2 layer are primarily responsible for establishing long distance HF Broadcast Services, the reflections from the E and F1 layers are also significant for short distance broadcasting. In tropical broadcasting where the service is intended to be provided right from the transmitter to the limit of the service area (maximum distance up to 800 km), vertical or near vertical incidence is required and therefore the MUF in this case coincides with the critical frequency - the extraordinary ray frequency, being higher, is taken as the MUF.

Recommendation ITU-R PI.533 describes a method for the estimation of MUF and sky-wave field strength. It takes into account various aspects of HF propagation including the E-layer screening, effect of solar zenith-angle and electron gyro-frequency, which are required to be considered while determining the bands for tropical broadcasting. Therefore, this method can also be used for the prediction of MUF for tropical broadcasting.

Numerical maps of the parameters f_oF2 and M(3000)F2 for solar index values R_{12} = 0 and 100 and for each month are presented in Recommendation ITU-R PI.372. For long term prediction of MUF, the Oslo coefficients are used to determine the values of f_oF2 and M(3000)F2 for the required locations and times. Linear interpolation or extrapolation is applied for the required index value between R_{12} = 0 and 150.

7.2.2 Prediction of sky-wave field strength

The free-space basic transmission loss and the ionospheric absorption suffered by a radio-wave while passing through the ionosphere between the transmitter and the receiver assume great significance while predicting the sky-wave field strength of a signal operating in the tropical bands (2, 3 and 5 MHz). Absorption in the E-layer is predominant for frequencies below about 6 MHz. The magnitude of absorption depends, among other things, on the frequency of the wave and solar activity. It decreases as the wave frequency is increased and increases with the solar zenith angle.

Recommendation ITU-R PI.533 (referred to above) also gives a generalised method for the prediction of median value of the sky-wave field strength. This method should also be used for predicting field strengths in the tropical region.

7.3 Atmospheric radio noise and signal-to-noise ratio

In most of the countries in the Tropical Zone, which are either under-developed or developing and where man-made noise is comparatively low, atmospheric radio noise is the principal source of noise in the HF bands. Recommendation ITU-R PI.372, which provides estimates of noise in different parts of the world, is most widely used for predicting the atmospheric radio noise. The noise data contained in Recommendation ITU-R PI.372 is largely satisfactory for the temperate, arctic and Antarctic regions of the world but it is not entirely satisfactory for the tropical regions. The "impulsive noise" due to thunder-storm activity, which is significant for substantial periods of time in the tropical regions, has not been fully taken into consideration in this report. Therefore, some margin is required to be provided for Tropical Zone noise values determined from this report.

Atmospheric radio noise arises from the electrical discharges accompanying lightning flashes in which the electrical discharges occur inside the cloud. There discharges are primarily responsible for atmospheric noise at frequency above 0.1 MHz. The electrical discharges accompanying one lightning flash give rise to one noise burst in the receiver, which contains frequency components spread throughout the bandwidth of the receiver. Since cloud discharges occur at heights varying from about 3 km to over 10 km above mean sea level in the tropics, direct ray reception of noise bursts can be expected for source distances of about 300 km. All such sources of noise are described as "local sources". The noise arising from these sources is called "local storm noise" and is high in amplitude and highly impulsive in character. For sources other than local and lying within about 1 000 km from the point of observation, the attenuation due to propagation is not high and the noise received is still impulsive but smaller in amplitude than those from local sources. These sources of noise are called "near sources". The atmospheric noise from a large number of points of observation is of very low amplitude and could be considered as a background noise. In tropical regions, however, local and near thunderstorm sources lying within less than about 1 000 km are usually very large resulting in significant impulsive component of noise. The atmospheric noise encountered in the tropical regions could, therefore, be considered as consisting of a background continuous noise on which is superimposed the impulsive component, which usually shows up prominently over the background noise.

Lightning activity of thunder clouds involves an area of about 10-20 km radius. On a local storm day, several thunder clouds are active during different hours of the day. This activity commences around local noon and continues till the following sunrise or a little later, but there is ordinarily no activity between 0800 and 1200 hours (LMT). In the tropics, the lifetime of a thunder cloud and its average rate of flashing are much higher than the probable corresponding figures for higher latitudes.

At any frequency and bandwidth, the basic parameter used to express the interfering effect of the noise bursts to voice communication is the "Noise level" and is expressed in μV/m. It is defined as the arithmetical average value of the highest amplitude noise present for 10% of the time in a short period of time, like 5 to 10 minutes. The noise level is about 3 dB above the mean value of the quasi-peak amplitudes of all the noise bursts received during a minute. The short- and long-term characteristics of the noise level has log-normal distribution. Studies have shown that during certain hours of the day and certain periods of the year, higher levels of noise exist in tropical region.

For satisfactory listening and determining the grade of service, it is essential to consider the noise response of a broadcast receiver. The characteristics of atmospheric radio noise such as amplitude, duration and repetition rate of individual impulses play an important role in determining the noise response of the receiver. A theoretical analysis of the response of a receiver as a function of fluctuation and impulsive noise shows that:

– the r.m.s. and peak values of the output response produced in a receiver by fluctuation noise are proportional to the square root of the receiver bandwidth;
– the r.m.s. and peak values of the output response in a receiver by a unit impulse are proportional to the bandwidth and square root of the bandwidth, respectively;
– the output wave form is independent of the wave shape of the impulse if its duration is less than the order of the reciprocal of the receiver bandwidth and is dependent only on its time integral.

Measurement of atmospheric noise and the determination of signal-to-noise ratio for satisfactory listening have been carried out in some of the countries in the tropical region. An analysis of these measurements shows that a margin of about 40 dB over the prevailing noise is required for satisfactory listening.

On the basis of the studies carried out so far in the region, it is, therefore, reasonable to recommend a signal-to-noise ratio of 40 dB to ensure satisfactory reception for at least 90% of the time.

7.4 Minimum field to be protected

The minimum field strength of a sound broadcast signal that needs to be protected, depends not only on the level of noise present but also on the signal levels of the fixed and mobile services sharing the bands. Studies carried out for the determination of noise level in tropical regions and the minimum signal required for satisfactory listening have indicated the presence of much higher noise levels during night-time than during the day-time. Based on these studies, the minimum signals required for various frequency bands for different times of the day and seasons are plotted in Figure 7.1.

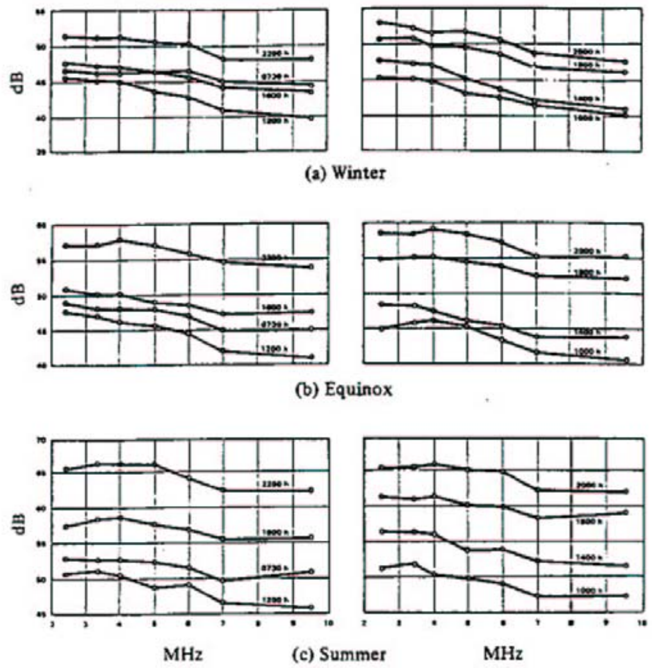


FIGURE 7.1

Minimum signal required for satisfactory listening (dB(μV/m))

An examination of these values shows that for satisfactory reception, higher levels of signal are required during night-time than during the daytime. However, to arrive at a more accurate value of minimum field strength, it is essential to collect more detailed information concerning noise in various parts of the Tropical Zone.

Based on the studies carried out so far, it could be concluded that the minimum field intensity of a broadcast signal to be protected in the tropical shared bands within the local service area, should be 200 μV/m (or any lower value consistent with satisfactory reception). See also Recommendation ITU-R BS.216.

7.5 Transmitting antennas

The main considerations in the design of an antenna for providing a non-skip service are that the radiation from it should be fairly uniform in the service area and it should cause minimum interference outside this area. Accordingly the power radiated at high angles of elevation should be as high as possible to meet the requirements of the service area and at the same time the power radiated at angles of elevation lower than those used to serve the fringe of the service area should be as low as possible. Several type of antenna are used for tropical broadcasting. Methods for calculating the radiation patterns of various antenna types are given in Recommendation ITU-R BR.785.

7.5.1 Dipoles

A horizontal dipole is the simplest form of antenna which can be used for providing a short distance service around the transmitter. The horizontal dipole when erected at a height not exceeding a quarter wavelength above the ground essentially radiates in the vertical direction, though the radiation intensity pattern is broad and the radiation is not negligible at low angles. As the height of the dipole is increased, the lobe tends to flatten and there is considerable energy at low angles. At a height of 0.4λ, the lobe has two maxima at about 40° from the horizontal and the vertical radiation is reduced. At a height of 0.5λ, the lobe splits into two with maximum radiation at about 30° from the horizontal and there is very little radiation vertically upwards. This shows that a dipole at about 0.4λ above the ground would have the necessary radiation pattern to meet the requirements of a tropical broadcasting antenna. In India, an height of 7/16λ has been chosen and a simple dipole with this height has been used for providing service upto about 800 km distance. The radiation diagram of this type of antenna is given in Figure 7.2.

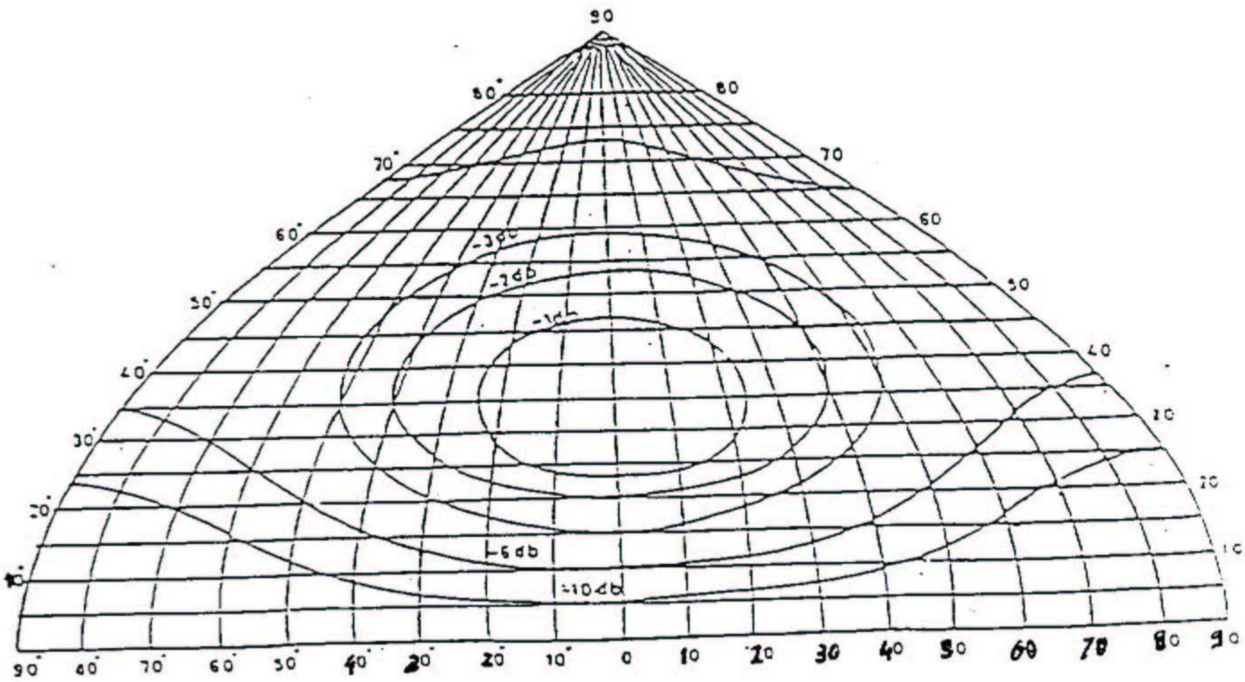


FIGURE 7.2

Energy distribution diagram - aerial type H-1/1/7/16

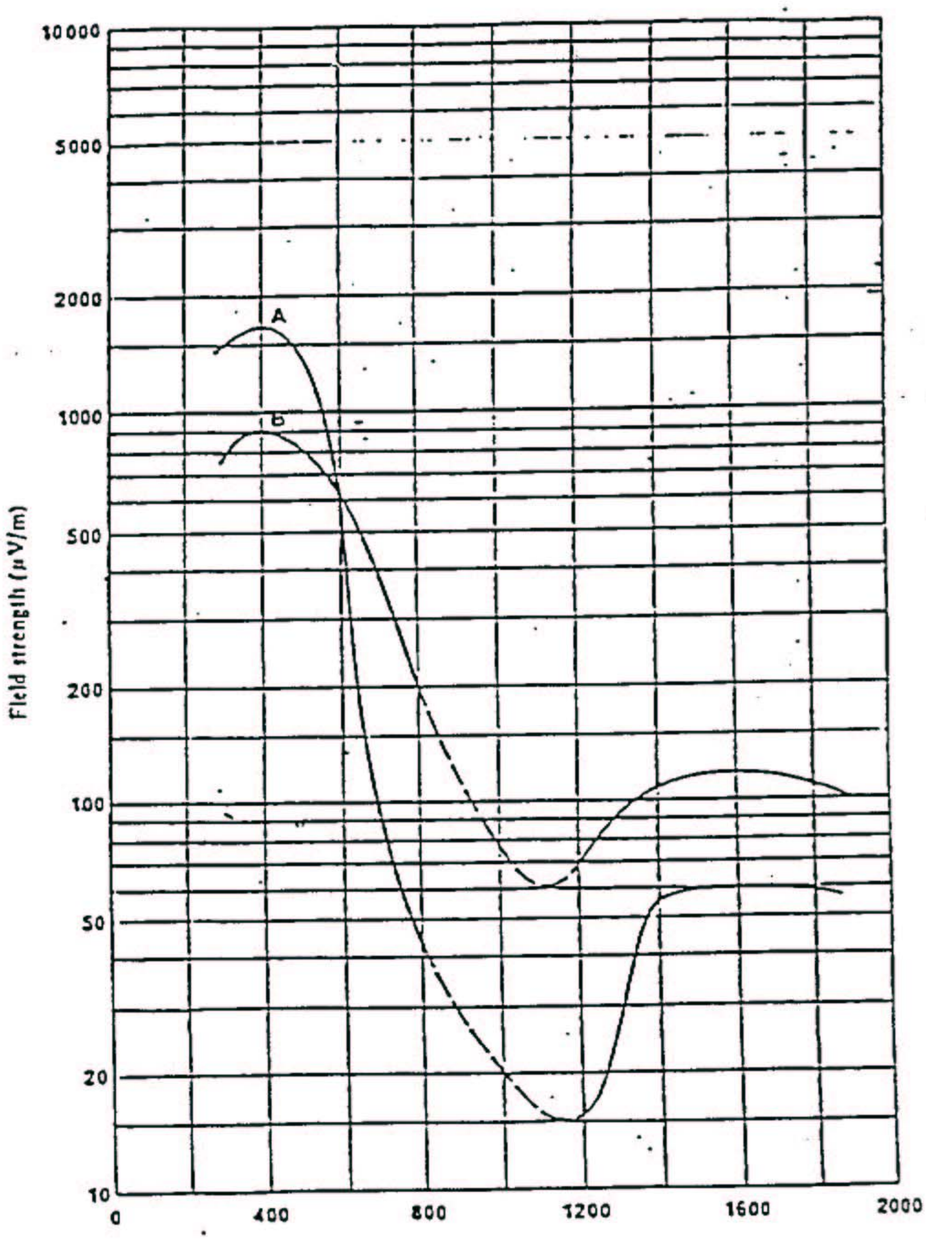
7.5.2 Horizontal arrays of horizontal dipoles

Arrays of horizontal dipoles are also used for short distances broadcasting in the Tropical Zones and it consist of one or more rows of half-wave dipoles at a mean height not exceeding 0.5λ above the ground (typically at about 0.2λ). The rows are separated at λ/2 intervals. The radiation is mainly concentrated at high elevation angles (up to 90°) and in most cases associated with a nearly circular azimuthal radiation pattern. Slewing of the main beam in the z-y plane can be achieved by varying the phases of the feed current in the elements of the same row (along the y axis). The resulting pattern then shows a more of less pronounced main beam tilt in the z-y plane thus providing a directional effect usual for specific coverage requirements.

7.5.3 H-1/2 Array fed out-of-phase

A simple H-1/2/0.5 dipole array, fed out-of-phase has an elevation angle of 41° and provides adequate coverage up to about 800 km. Out-of-phase feeding can be easily arranged in such arrays because of the standard 0.5λ spacing between the elements. Theoretical studies have shown that such an array with the lower element at a height of 0.2λ above the ground satisfies the requirements of tropical broadcasting antenna .

Experimental results have shown that antenna system H-1/2/0.4 fed out-of-phase provides higher field strength at distances below 600 km than that from a simple dipole, during daytime. At distances beyond 600 km, the field strength provided by this antenna is lower compared to a dipole (Figure 7.3). During daytime, ionospheric absorption is considerable resulting in propagation being limited to only 1-hop. The absorption also increases with the obliquity of the incidence. An antenna suitable for daytime coverage has to have maximum gain corresponding to the angle required to serve the fringe of the service area. At angles below this, it should have a sharp cut-off. During night-time, the field strength does not fall-off beyond the intended service area as rapidly as during daytime. This is because at night multi-hop propagation is possible due to lower absorption. Fields due to 2-hop mode are, therefore, also to be taken into account while designing such an antenna system.



Distance (km)

FIGURE 7.3

Experimental antenna for broadcasting in the Tropical Zone: field strength as a function of distance: (transmitter power: 5 kW: λ: 49 m)

7.5.4 High incidence array

A high incidence array gives adequate high frequency coverage up to an area of about 1 000 km radius. The array consists of four full-wave dipoles arranged in the form of a square and fed in such a manner that the currents in any two adjoining elements are in phase and are of the same magnitude. The average height above ground is 0.15λ, but this is not critical. The gain of the array relative to an isotropic radiator is 8. The high angle radiation of the array is greater than that of a dipole in the broadside direction at angles of elevation between 50° and 75°, representing improved signal strength between 100 and 400 km. In the end-on direction at angles of elevation between 25° and 75° improved signal strength is available between 100 and 1 000 km. The low angle radiation of the array is less than that of a dipole (h = 0.4λ) in all directions. At any angle of elevation below 30° the radiation from the high incidence array is 16 dB below the maximum radiated by a dipole at that elevation.

7.6 Interference due to sharing of bands

Unlike other HF broadcast bands which are exclusive in nature, the tropical bands are shared with fixed and mobile services. Interference to sound broadcasting service could therefore, be either from:

– A1 and A2 telegraphy;

– A3 telephony and broadcasting or a combination of more than one type of emissions.

In order to protect sound broadcasting service from the above types of interfering signals, it is essential to establish a minimum value of r.f. protection ratio.

Subjective tests have been carried out by various countries to determine the protection ratios for different percentages of listener satisfaction for various carrier frequency separations up to 10 kHz and for permissible frequency tolerances of both wanted and unwanted signals. A comparison of the results of these tests carried out by different countries show a considerable degree of agreement and the values are within ± 5 dB.

Figure 7.4 summarises the results of these studies and represents the values of protection ratio required for just tolerable interference at various values of carrier frequency separation (Report ITU-R BS.302).

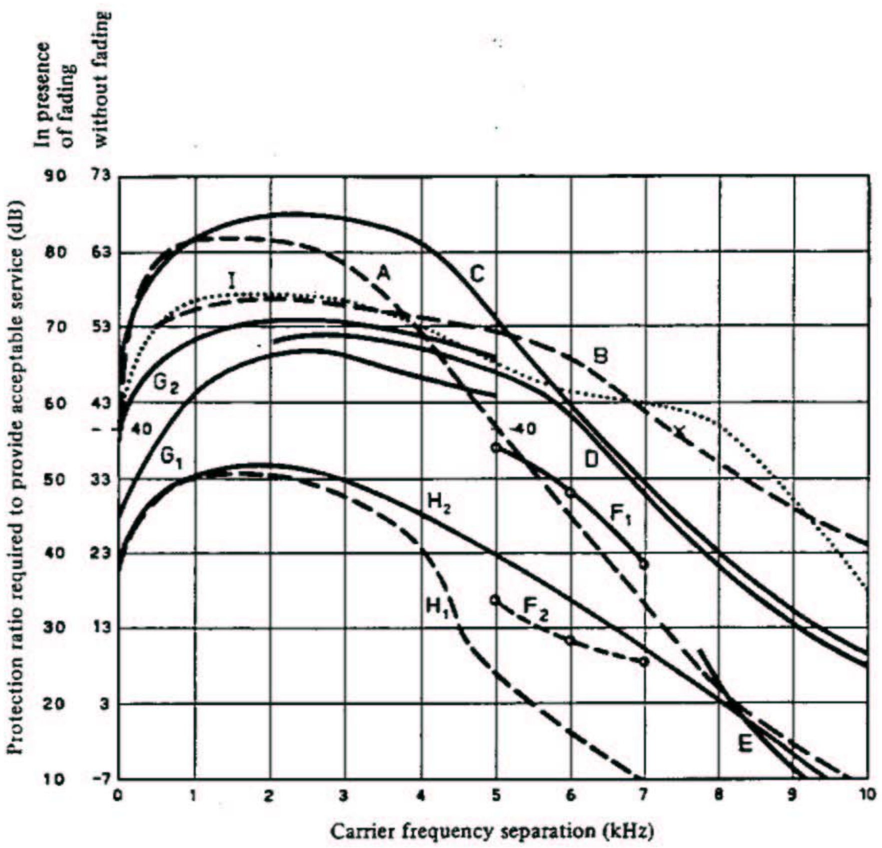


FIGURE 2 – *Protection ratios required to provide acceptable service*

DESIGNATION OF CURVES

A*	VAN DER POL (1933)
B*	BRAILLARD (CCIR, Bucharest, 1937)
C*	B.P.Q tests, 1948
D**	B.P.O. tests, 1950
E**	B.P.O. tests, 1951
F_1 **	B.P.O. tests, 1956 (no filter)
F_2 **	B.P.O. tests, 1956 (whistle filter)
G_1 **	Indian tests (50% satisfaction)
G_2 **	Indian tests (90% satisfaction)
H_1 **	Curve used by the IFRB, 1956, for HF broadcast plans
I***	French tests, 1962
H_2 **	Curve drawn from values of "Receiver Discrimination" given in IFRB Technical Standards Series "A" 1968.

* Criterion of test: Just perceptible interference

** Criterion of test: Just tolerable interference

*** Corresponding to a "tolerable" interference for five different types of receivers.

FIGURE 7.4

Protection ratios required to provide acceptable service

Table 7-1 gives the protection ratio values required to provide 90%, 70% and 50% listener satisfaction for unwanted signals of classes of emission A2 telegraphy, A3 telephony and A3 broadcasting and for frequency separations of 0 kHz and 5 kHz and for maximum permissible frequency tolerances of both wanted and unwanted signals. The measurements were carried out at the output of a receiver with a substantially flat response up to about 4 kHz and fitted with a filter giving an attenuation of about 8 dB at 5 kHz and a sharp cut off above this frequency. An analysis of this table shows that the required protection ratio increases when allowance is made for maximum frequency tolerances. This is more prominent when the unwanted signal is a mobile A3 emission. Further, the interference due to the heterodyne beat note between the carriers of wanted and unwanted signals is always dominant. The data given in Table 7-1 are derived from measurements made under steady-state condition. Therefore, appropriate allowance has to be provided when using these figures to derive protection ratios for use in practical conditions. To provide primary grade service, a protection ratio based on 90% listener satisfaction is desirable. However, because of practical considerations, protection ratios based on 70% to 80% listener satisfaction are sufficient.

TABLE 7-1

Protection ratios required to provide acceptable service

Wanted signal	**Interfering signal**	**Frequency separation (kHz)**	**Desired protection ratio (dB)**
Speech	Music	5	46
Speech	Music	10	22
Speech	Speech	5	44
Speech	Speech	10	16
Speech	A3B telegraphy	5	38
Speech	A3B telegraphy	10	8
Speech	A1B emission	5	38
Speech	A1B emission	10	8
Music	Music	5	38
Music	Music	10	12
Music	Speech	5	38
Music	Speech	10	6

A further study on the required protection ratio for carrier frequency separations of 5 to 10 kHz and 90% listener satisfaction show that the required protection ratio gradually decreases as the carrier separation increases beyond 5 kHz. Table 7-2 gives the values of the protection ratio required when the wanted signal is modulated with speech and music programmes and the interfering signal with speech, music, A1 and A2 Telegraphy (525 Hz tone). The measurements were carried out when no filter was used at the output of the receiver.

TABLE 7-2

I Interfering emission	Maximum frequency tolerance (Appendix S2 to the Radio Regulations) (Hz)	Frequency separation (kHz)	Signal-to-interference ratios for 90%, 70% and 50% listener satisfaction (dB)					
			Ignoring frequency tolerances			Allowing for maximum frequency tolerances		
			90%	70%	50%	90%	70%	50%
A2B-fixed (525 Hz tone)	150	0	35	31	28	42	38	34
A2B-mobile (525 Hz tone)	1000	0	35	31	28	49	45	42
A3E-fixed (3 kHz maximum modulation)	150	0	33	30	28	40	36	33
A3E-mobile (3 kHz maximum modulation)	1000	0	33	30	28	50	47	44
A3E-broadcasting	150	0	33	30	28	44	40	36
A2B-fixed (525 Hz tone)	150	5	39	37	36	43	40	38
A2B-mobile (525 Hz tone)	1000	5	39	37	36	49	46	43
A3E-fixed (3 kHz maximum modulation)	150	5	48	44	40	50	46	42
A3E-mobile (3 kHz maximum modulation)	1000	5	48	44	40	52	48	45
A3E-broadcasting	150	5	48	46	44	49	46	44

Based on these studies, a median-wanted sound broadcasting carrier to median-unwanted carrier ratio of 40 dB has been recommended to provide a signal-to-interference ratio of not less than 23 dB for at least 90% of the hours and 90% of the days (taking into consideration the effect of short-term and long-term fading) (see Recommendation ITU-R BS.216).

7.7 Fading

In tropical regions, the strength of the radio signals propagated through the ionosphere is subjected to random short-period variations, irregular long-period variations and more or less regular variations, collectively called as "fading". For the planning of a sound broadcasting service in this region, it is, therefore, necessary to have precise information on the type and characteristics of fading that may be expected to be encountered in the received signal. Fading is caused by various ionospheric phenomena. Depending on the cause, fading may be classified as Interference Fading, Polarisation Fading, Absorption Fading, Skip Fading and Selective Fading. Besides all these types of fading commonly encountered in the Tropical Zone and at low geomagnetic latitudes, some special types of fading are observed here. These special characteristics are due to:

– a particular type of Sporadic-E layer associated with the equatorial electrojet, which is a regular daytime occurrence;

– irregularities present in the night-time F-layer, called spread-F.

7.7.1 Fading due to sporadic-E

Fading observed during daytime in the equatorial zone is very often attributed to a Sporadic-E layer. Depending on the latitude, two types of Sporadic-E layer are found in the Tropical Zone:

– temperate zone Sporadic-E;

– equatorial zone Sporadic-E.

Temperate zone Sporadic-E, observed at middle latitudes is predominantly a summer time phenomenon occurring both by day and night but more intensively by day.

In a narrow zone near the magnetic equator (±6° magnetic dip), a special type of highly transparent Sporadic-E called equatorial Sporadic-E appears regularly during daytime. It has been observed that there is a narrow zone right at the dip equator where the blanketing type of Sporadic-E is usually absent.

The fading characteristics of radio waves reflected from Sporadic-E layers have been studied in different parts of the Tropical Zone and the observations show that the amplitude distribution of the received signal follow different types of distribution such as Rayleigh, normal, log-normal and m-type, depending on the frequency, time of the day and the place of observation.

The fading rates of signals reflected from the Sporadic-E layer is found to be more than that from the normal-E or -F regions and it exhibits diurnal variations. Rates of 0.2 to 5 Hz are typical. For the equatorial Sporadic-E, the fading rates are of the order of 4 Hz and the fading rate increases almost linearly with increasing wave frequency. For blanketing type of Sporadic-E, the fading rates are smaller than those of the equatorial Sporadic-E and are of the order of 0.8 Hz.

7.7.2 Fading due to F-region irregularities

In the equatorial region after sunset, a peculiar type of very rapid fading is observed. This type of fading is termed as "Flutter Fading" and it occurs due to irregularities in the F-region.

In the equatorial zone after sunset, irregularities develop in the F-region ionisation inside a belt extending approximately between geomagnetic latitudes of 30° N and 30° S. Its occurrence is high within ±20° geomagnetic latitude and both north-south circuits and east-west circuits are affected. It has been observed that just after local sunset, the F-region over the equatorial belt exhibits a marked increase in height and seems to break up progressively into patchy regions or irregularities in patches, generally known as Spread-F. The presence of irregularities in the F-region is manifested as echoes which have a spread in their range in ionograms and are classified as range-spread and frequency-spread. The range-spread which is the equatorial type Spread-F observed after sunset, influences HF propagation in the equatorial region.

Flutter fading is normally observed between evening and midnight starting almost around sunset. It is most intense within two hours of local sunset at the point where the propagation path crosses the magnetic equator. The fades are also very deep. Seasonally, the phenomenon is more pronounced during equinoctial months as compared to other seasons of the year. Definite maxima occur during the two equinoctial periods well after the true equinox. The autumnal equinox shows significantly more flutter fading than the vernal equinox. Flutter fading also shows solar cycle dependence and is more pronounced during sunspot maxima and is almost negligible during sunspot minima. The flutter fading rates are usually high and generally increase with frequency. Typical values of fading rate are about 10 Hz.

The occurrence of flutter fading causes degradation of the HF signal propagated through the ionosphere and affects the overall merit of broadcast programmes to a considerable extent. In the audio spectrum, the voice is still fairly intelligible in the presence of flutter, whereas music becomes very disagreeable and annoying.

7.7.3 Surge fading

Another peculiar type of fading encountered in the Tropical Zone which affects the HF broadcast transmissions is "Surge Fading". This type of fading is characterised by sudden and violent fluctuations of the received signal intensity. As compared to flutter fading, surge fading is slower but deeper and is accompanied by severe distortions. It gives the impression of the signal being received in powerful surges. The signal varies over wide range of amplitude with a recurrence rate of a few surges per minute. Surge fading is at its worst after sunset and its occurrence is more pronounced during winter and equinoctial months preceding winter.

7.7.4 Fading allowance for the planning of HF broadcast services in the tropical bands

While planning a short-wave broadcast service in the Tropical Zone, it is, therefore, essential that appropriate allowances for both short-term and long-term fading are made:

Quantitative estimates of the fading can be obtained from the statistical distribution of a signal which can be characterised by indicating the levels exceeded for a number of specified time percentages. Table 7-3 gives the levels for two time percentages derived theoretically from the Rayleigh, Normal (Gaussian) and Log-normal distributions:

TABLE 7-3

Distribution	**Level (dB) relative to median exceeded for the following percentages of time**	
	10%	**90%**
Rayleigh	5.21	–8.18
Normal and log-normal (where σ is the standard deviation)	1.282 σ	–1.282 σ

The overall fading allowance for the planning of broadcast services can be obtained from the short-term and long-term fading allowances. Intensity fluctuation factor when referred to the received signal take into account the variations of the wanted signal only. However, to arrive at a proper value of the fading allowance for planning a sound broadcasting service for a given service probability, it is necessary to take into account the characteristics and variability of interfering signals also. Considering this aspect, an allowance of 6 dB for short-term fading and 16 dB for long-term fading is recommended, thus giving an overall fading allowance of 17 dB which would ensure that the steady state ratio is attained for 90% of the time (Recommendation ITU-R BS.411).

However, sufficient data relating to the quantitative estimates of short-term and long-term fading in the Tropical Zone is not available and therefore further studies are required to arrive at specific values of allowances to be provided for in the planning of sound broadcasting services.

CHAPTER 8

OPTIMIZATION OF SETS OF ANTENNAE AND SETS OF TRANSMITTERS

8.1 Antenna set optimization

High-frequency antenna arrays are utilized in the range of frequencies from 3 to 30 MHz for medium-and long-distance communications and broadcasting by means of ionospheric propagation. Ionospheric transmission over large distances usually involves high over-all transmission losses, especially under unfavourable propagation conditions. The relatively high initial and operating cost of high-gain transmitting antennas desirable to provide a high degree of directivity in the directions of communications. High-gain antenna arrays are in common use for international broadcasting stations where transmissions are desired to a specified political area or areas. In addition to providing an increase in signal in the target area, the use of high-gain directional arrays decreases radiation in undesired directions, thus reducing potential interference to other services.

The design requirements for a high-frequency transmitting array include the frequency range, vertical and horizontal angles at which maximum radiation is desired, the power input, and mechanical requirements.

The frequency range should be established by a propagation study to determine the Optimum Working Frequency (OWF) for the path involved, which varies according to the distance and location, time of day, season of the year, and with sunspot activity.

The final frequency or range of frequencies specified for antenna design purposes should be based on the propagation study and the availability of frequency assignments.

The range of vertical angles pertinent to ionospheric propagation depends on the distance, effective layer height, and mode of propagation (i.e., one-hop, two-hop, etc.).

Figure 4.8 shows the elevation angles pertinent to one-hop transmission for various virtual layer heights. The height of the E layer may be considered constant at approximately 110 Km, but the height of the F2 layer varies widely according to the time of day, season of the year, and location. A detailed propagation study is required to determine the range of vertical angles for antenna design purposes. As a rough estimate, however, a range of F1 and F2 virtual layer heights of approximately 250 to 400 Km may be used in conjunction with Recommendation ITU-R BS.705 to determine the approximate vertical-angle range. In the case of transmission over distances of more than 4 000 Km, maximum signal results from low-angle transmission in the range from 2° to 15°, with the lower angles generally providing better results.

International broadcasting requires that the horizontal angle subtend the target area with due allowance for path-deviation effects.

Use of horizontal slewed antennas is useful if the azimuthal direction doesn't clash with fixed antenna directions. In this case the beam can be slewed several degrees, up to 30°. The degree of slewing with good performance is limited because of the formation of a relatively large minor lobe as the slewing angle is increased, which results in a reduction of power gain.

Control of the take off angle of the antenna can be accomplished in either of two ways depending on the specific pattern requirements of the broadcaster:

– Exciting only the lower part of antenna curtain, or

– Exciting the upper part of the curtain in antiphase to the lower part.

Vertical patterns with maximum radiation at higher vertical angles may be obtained by changing the phase angles of one or more of the elements, by employing unequal currents, or by exciting only the lower radiator elements.

Use of multiband antenna is useful because to allow the transmission of several frequencies, depending by propagation conditions, with same mechanical structure.

A rotatable antenna is used as multiband antennas, which made it possible to suspend, or a single rotating support, one antenna (or a small number of them), covering all S.W. broadcasting bands.

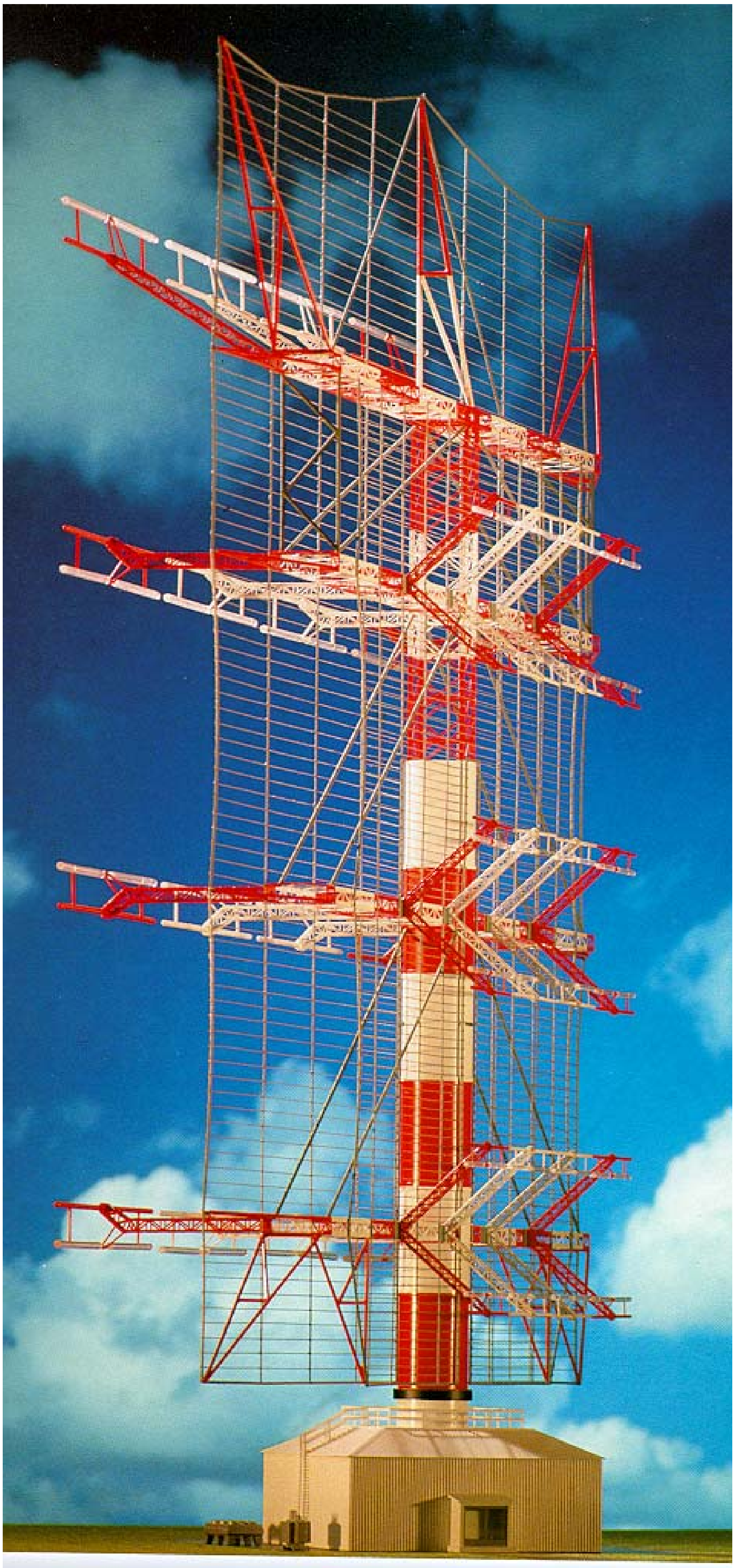


FIGURE 8.1

Example of rotatable curtain antenna

This achievement is not intended for replacing conventional fixed antennas, but its field of application appears from the following considerations:

– It permits simple omnidirectional coverage with a single transmitter.
– In an important station, it may be a useful auxiliary equipment, permitting extra broadcasts that cannot be easily programmed.
– It increases the reliability of the system, since, in case of failure, it can replace any other antenna, thus permitting the execution of a systematic antenna maintenance programme.
– It may be a good solution if unfortunately the ground does not permit a normal layout of antenna system.

A rotatable antenna is a mechanical stucture allowing an HF antenna to be rotated in the horizontal plane and, in some cases, to be tilted in the vertical plane.

Such antennas may be operated for reception purposes or for transmitting purposes. But, it is quite obvious that the mechanical structures will be different in these two cases, assuming that a transmitting antenna designed for broadcasting will have to fulfil high power requirements which lead to a heavily-built structure.

The degree of liberty in the horizontal plane is 360°, allowing the antenna to be beamed to any direction.

When available, the degree of liberty in the vertical plane ± 30° versus the horizontal plane.

8.1.1 Types of rotatable antennas

The radiating antenna itself, which is supported by the mechanical structure, may be identical or close to the fixed radiating antennas. This means that the main types of rotatable antennas are:

– broadband small curtains arrays;
– broadband large curtains arrays with fixed electrical characteristics;
– mixed types;
– broadband large curtains arrays with configurable electrical characteristics;
– horizontal log-periodic, with or without tiltable capability;
– sloping log-periodic.

It should be mentioned that for reception purposes mainly, a type of electrically-rotatable antenna may exist:

– circular network of active antennas (up to 64 antennas).

8.1.2 Electrical characteristics

8.1.2.1 Broadband small curtains

Assuming that it is generally considered that a curtain can not be operated in a range of frequencies higher than 2 to 1, the rotatable antenna includes:

– on one part a small broadband curtain (HR2/2/h) from 6 to 12 MHz, for example

on the other part a small broadband curtain (HR 2/2/h) from 11 to 21 MHz, the two curtains are separated by two aperiodic reflectors with wires located between them.

Average gain at the centre frequency: 13.5 dB/dip [HR 2/2/0.5].

8.1.2.2 Broadband large curtains arrays with fixed electrical characteristics

Assuming that it is generally considered that a curtain can not be operated in a range of frequencies higher than 2 to 1, the rotatable antenna includes:

– on one part a large curtain (HR 4/4/h) from 6 to 12 MHz, for example

on the other part a large curtain (HR 4/4/h) from 11 to 21 MHz. the two curtains are separated by two aperiodic reflectors with wires located between them.

Average gain at the centre frequency: 19 dB/dip [HR 4/4/0.5].

Assuming that the curtain designed for the lowest bands, (6 to 12 MHz), fixes the overall height of the rotatable antenna, it may possible to design a different type of curtain for the highest bands (11 to 21 MHz).

As an example, it is possible to have:

– on one part, a large curtain (HR 4/4/h) from 6 to 12 MHz, for example

– on the other part, a large curtain (HR 4/6/h) from 11 to 21 MHz.

8.1.2.3 Mixed types

In some cases where the need to broadcast in low HF frequencies would lead to a very wide structure if a HR 4/4/h was designed, it is possible to include in a rotatable antenna the following curtains:

– on one part, a small curtain (HR 2/2/h) from 4 to 6 MHz, for example

– on the other part, a large curtain (HR 4/4/h) from 7 to 15 MHz.

8.1.2.4 Broadband large curtains arrays with configurable electrical characteristics

The need to operate a rotatable antenna with a high degree of flexibility in terms of coverage may lead to design antennas which can offer different types of curtains included in the main curtains.

By switching the dipoles of the curtains, a curtain such as a HR 4/4/h can be switched to:

HR 2/2/h HR 2/3/hHR 2/4/h
HR 4/2/h HR 4/3/hHR 4/4/h

In the same way, a curtain such as a HR 4/6/h can be switched to:

HR 2/2/h HR 2/4/hHR 2/6/h
HR 4/2/h HR 4/4/hHR 4/6/h

At the centre-frequency F_o of each curtain:

– the beamwidth (–6dB) can be switched from 70° (HR 2/n/h) to 35° (HR 4/n/h);

– the vertical take-off angle can be switched from 17.5° (HR m/2/0.5) to 6° (HR m/6/0.5).

Therefore, such an antenna becomes able to fulfil the requirements of a broadcaster wishing a wide or a narrow beam for short or medium or long distances.

It must be mentioned that when such an antenna is fed by a 500 kW HF transmitter, the smaller selected unit (HR 2/2/h) must be designed to support 500 kW HF power with 100% modulation.

Quite obviously, it is not mandatory to build broadband curtains with a 2 to 1 frequency-capability. Smaller ratio leads to easiest design of the curtains, but the frequency range is reduced.

8.1.2.5 Horizontal log-periodic antenna, with or without tiltable capability

A self-supporting log-periodic antenna is installed on a vertical shaft able to rotate in 360° in the horizontal plane. (Figure 8.2).

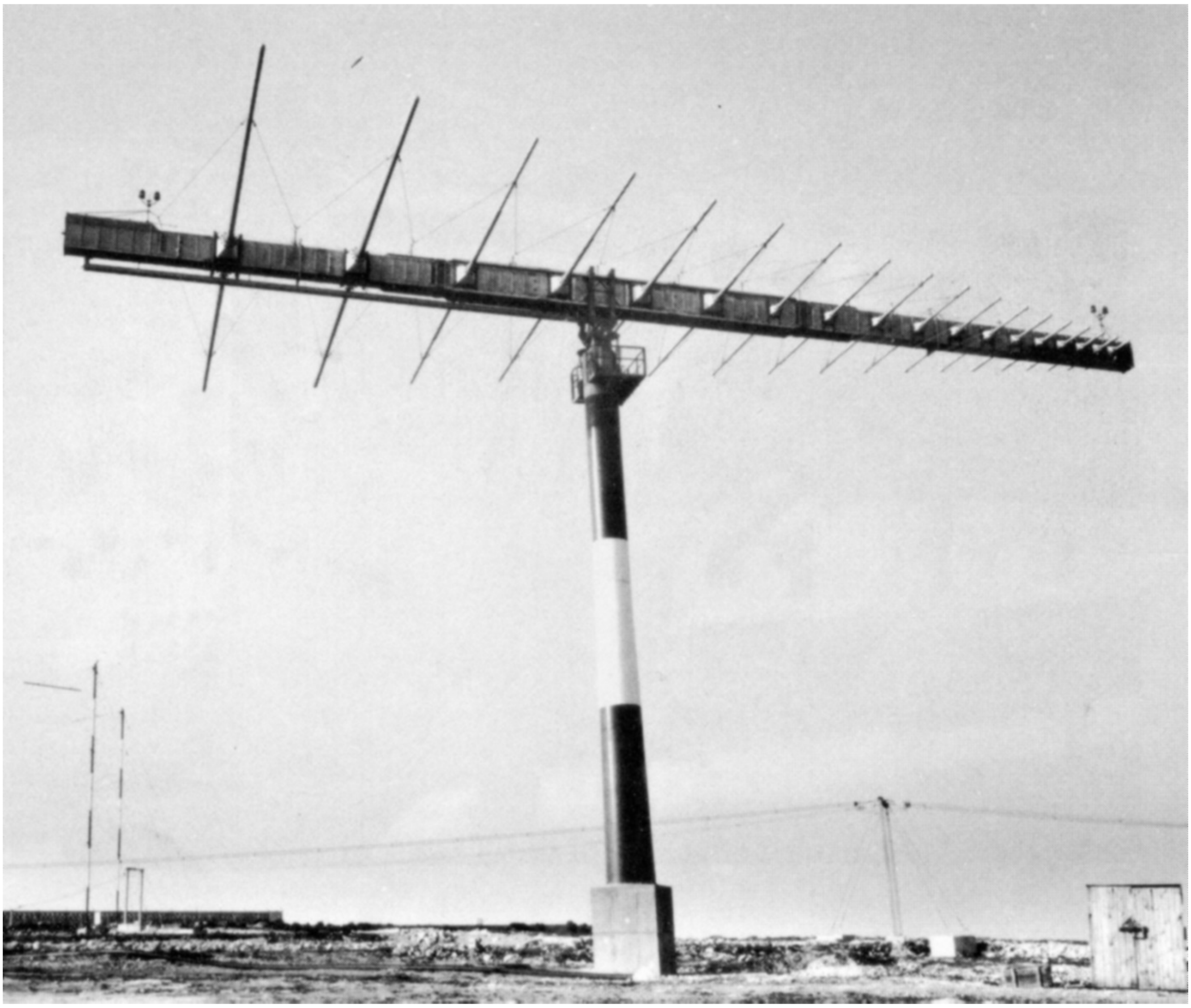


FIGURE 8.2

Example of a self-supporting rotating horizontal log-periodic antenna

When the boom of the log-periodic antenna is horizontal, the vertical diagram is a function of electrical height of the phase-centre above the ground; therefore, the vertical diagram will show considerable variations according to the frequencies in the range 6 to 21 MHz, for example.

In some cases, a sophisticated system of 2 shafts allows the log-per antenna to be tilted in the vertical plane. Accordingly, the height above ground of the phase-centre can be slightly modified. But the range of variation of the TOA is smaller than the range of variation offered by switching groups of dipoles in a large curtain.

Average gain: 8 to 9 dB/dip.

8.1.2.6 Sloping log-periodic antenna

To avoid the need of a sophisticated mechanical system for tilting the log-periodic antenna in view to have reasonable characteristics of the vertical take-off angles according to the operating frequency, the rotatable log periodic antenna may use a sloping boom.

Then, the electrical height above ground can be partially maintained constant versus the frequency.

If a log periodic antenna designed for the range 6 to 21 MHz should have to offer an electrical height of 0.5 above ground, the widest radiating element would be at a height of 25 m above ground, the shortest radiating element would be at a height of 7.5 m above ground.

Remark:

In terms of gain, directivity, front-to-back ratio, log-periodic antennas have lower performances than curtains.

8.1.3 Mechanical characteristics

In all cases, a great attention must be given to the environmental conditions, in particular to the wind-speed conditions, to the likelihood of ice in cold winter conditions and to the seismic conditions.

Even if any type of mechanical structure may be strongly built by manufacturers, it is reasonable to design a mechanical structure for maximum environmental conditions such as:

wind speed not higher than 160-180 km/h.

In the case of rotatable antennas designed with curtains, the mechanical structure can have different types:

- double towers rotatable antenna with copper wires dipoles.
  - Two steel towers linked by an horizontal steel structure are supporting 2 normal curtains made of copper wires separated by 2 aperiodic reflectors. The towers and the horizontal structure can rotate on rails and are moved by electrical motors.
  - Overall width: 90 m to 100 m.
  - Overall height: 90 m to 105 m according to the type and the height above ground of the antenna designed for lowest frequencies.
  - Duration for a 180° rotation: 3 minutes;
- single-axis tower rotatable antenna with copper wires dipoles.
  - One fixed basis supports a vertical rotatable tower which is supporting with adequate arms 2 normal curtains made of copper wires separated by 2 aperiodic reflectors;
- single-axis tower rotatable antenna with rigid or semi-rigid dipoles.
  - One fixed basis supports a vertical rotatable tower which is supporting with adequate arms 2 curtains made of rigid or semi-rigid dipoles separated by 2 aperiodic reflectors.

  - Overall width: 75 m to 85 m according to the type and the range of the antenna designed for lowest frequencies.
  - Overall height: 75 m to 85 m according to the type and the height above ground of the antenna designed for lowest frequencies.
  - Tower diameter: 6 m to 4 m according to the design and the mechanical constraints.
  - Duration for a 180° rotation: 3 minutes;
- single-axis tower rotatable antenna with semi-rigid dipoles and incorporated transmitter;
  - same design as previous type, with the exception that the concrete basis (2000 t) supporting the tower includes the transmitter and associated additional parts;
  - basis dimensions (internal): 14 m x 14 m - height: 4.5 m;
  - tower and radiating structure steel weight: 170 t.

In all cases of curtains, reflectors must provide an acceptable value of HF leakage; therefore, the largest reflector is generally some meters wider and higher than the radiating antenna itself.

- Log periodic rotatable antenna.
  - Most types of rotatable log periodic antenna are built with a single array fitted to a vertical shaft at the top of a vertical tower.
  - Height above ground: 25-30 m, according to the selection of the height above ground of the phase-centre.

8.1.4 HF feeding of a rotatable antenna

There are two main types of HF feeding:

- usage of a symmetrical feeder which may support a twisting effort on a 180° angle;
- usage of a rotatable coaxial joint between the matching device output and antenna input.

8.1.5 Usage of rotatable antennas

8.1.5.1 Usage as a spare antenna

In a classical transmitting station, the need to have a spare antenna able to be operated instead of a damaged fixed antenna or able to be operated for any special requirement may lead to install one rotatable antenna. This antenna will have a range from 6 to 21 MHz and will be connected to a long feeder line to one of the transmitters installed in the transmitting station.

The rotatable antenna will be located at a distance 1.2 to 1.5 km from the fixed antennas, in view to be beamed to any direction without disturbance coming from the fixed antennas.

The longer the feeder line, the highest will be the losses in the feeder (0.8 to 1.5 dB).

8.1.5.2 Transmitting station with several rotatable antennas

In a classical transmitting station, the number of fixed antennas is generally higher than the number of transmitters, in the ratio 3 to 1 up to 5 to 1, and at a given time, many antennas are not operated.

Then, there is an heavy investment in antennas, in towers, in antenna switches, in feeder lines, in switching matrix, in the central transmitters-building.

With rotatable antennas including the transmitter in the basis, it becomes possible to design at a reasonable cost a transmitting station operating rotatable antennas only with configurable capabilities.

Then, heavy investment in fixed equipment will be avoided and there will be no restriction to any usage of the transmitting modules, if the antennas are located 1 km from each other.

Incidentally, there are no HF losses in the feeder lines or switching matrix assuming that the transmitter is very close to the antenna.

Except the construction of the antenna itself, only light civil works are requested:

– High voltage (or medium voltage) power supply for each transmitter;
– Copper cables or glass-fibre cables for remote control operation, program feeding and telephone;
– water supply, if needed.

Such a transmitting station designed with rotatable antennas only offers a high degree of flexibility:

– in the designation of the targets;
– in the number of transmissions dedicated to a target;
– in the range of coverage which may be short (from 750 km), medium or long.

When such a station is being built, there is no need to wait for the completion of all units to start broadcasting: the first module can be operated when the others are under construction.

For very short distances (< 750 km) and wide coverage, fixed antennas are advisable.

8.2 Selection of transmitters

S.W. transmitters are generally designed by manufacturers in order to operate over all frequencies into broadcasting bands from 3 MHz up to 26 MHz according to frequency allocation stated in the ITU Radio Regulation.

Transmitters with variable frequency are used in order to avoid constraints in planning the international service. The frequency change is not generally requested for national service.

In this case the selection of transmitters on the basis of the frequency is not relevant.

The selection of transmitters is made on the basis of the carrier power and modulation mode. The power range available on the market is between 50 kW and 500 kW, and the most common power values are 50, 100, 250, 300 and 500 kW. It is also possible to add more powers using combiner units; the arrangements are made according to the desired field value.

The modern S.W. transmitters are built combining two different technologies: solid state devices and vacuum tubes. The synthesizers to generate the radio frequency and preliminary stages are constituted of semiconductors and are wide-band designed, while the driver and final RF stages are designed with tubes.

Transmitters with power of 50-100 kW are normally utilized for distances less than 4000 Km. The advantages are an easy maintenance and a low dissipation, while the main disadvantage is a general low efficiency. Transmitters with power of 250-500 kW are good for distances greater than 4000 Km. The advantages are a high efficiency with the solid state, while the disadvantages are a more difficult maintenance and a higher power dissipation.

The power level control is connected with the intrinsic characteristics of the equipment (e.g. solid state or valves), the type of working (e.g. class A plate modulation or class C grid modulation) and with the type of modulation (SSB, DSB), which causes the energy dissipation.

Today, in order to increase the efficiency several systems are implemented, such as D.C.C. (Dynamic Carrier Control) and D.A.M. (Dynamic Amplitude Modulation), which are alike. The D.C.C. system achieves an optimum carrier voltage variation dependant on the degree of modulation (see Chapter 3).

Thanks to the higher efficiency and to the absence of insulating problems, it is advisable to use the solid state equipment.

The value of output impedance of transmitters depends on characteristic impedance of the feeding antenna system, usually 50 ohms unbalanced and 300 ohms balanced.

CHAPTER 9

ESTABLISHING AN HF-BROADCASTING PLANT

9.1 Siting considerations

9.1.1 Preliminary site requirements determination

Before looking for a specific site for locating a new HF broadcasting station certain preliminary information must be obtained. At a minimum this comprises the following information.

1) The number of transmitters, deduced from the maximum number of simultaneous transmissions, plus any spare transmitter capacity required.

2) The preliminary numbers and specifications for the transmitting station antennas. This is a prime determining factor for determining the size requirements of the site; space requirements and preliminary layouts for antennas and their foreground requirements are large.

   The input information for the analysis leading to this information comes from the number of required transmissions, the azimuthal transmission directions, the bands, the antenna types, and their vertical beam take-off angles. An adequate description of the preliminary antenna information required for site searches is obtained by applying the process described in § 9.3.8 to this information.

3) Other site factors which would require significant space, like large power plants, housing, golf-courses, etc.

9.1.2 Environmental considerations

Considerable care must be taken from the environmental point-of-view when selecting HF transmitter facility sites. At a minimum the following elements must be taken into account.

1) Most Governments have legal requirements for preserving the environmental ambient of sites. These regulations must be carefully explored and observed. Of particular interest are regulations pertaining to the preservation of archaeological sites.

2) In many places public opinion and environmental groups can exert considerable influence in establishing transmitting facilities. The broadcaster seeking new sites should be aware of these groups, and consult with them. Issues relative to local aesthetics and animal and plant life are of special sensitivity.

3) The site-seeker should search for sites well-away from growing cities and communities, which could expand to engulf the proposed facility.

4) Interference to the electronic subsystems of other organizations such as local airports, industries, telecommunications, communities, and entertainment facilities should be considered.

5) The site-seeker should be especially sensitive to health and safety considerations for the facility staff and the surrounding community. Of special concern in this area are radiation hazard issues, and the presence of high-voltage and other hazards. Local fencing restrictions must be explored.

6) The site-seeker must be aware that space must be obtained which is sufficient not only for preliminary needs but also for any possible future expansions which invariably materialize.

7) Sites in areas of political unrest or chronic instability should be avoided.

8) Areas of chronic disease should be avoided.

9.1.3 Site requirements

9.1.3.1 Antennas

Sufficient linear space for antennas must be obtained. Antenna foreground requirements must be determined and reasonably satisfied. These considerations include the following.

– Immediate foreground must be of sufficient extension, and sufficiently flat to meet requirements.
– No obstacle may be allowed in front of an HF antenna which will provide significant interference with its performance. This particularly includes other HF antennas (especially of the curtain antenna type); tall buildings and other obstacles (hills or mountains) which significantly occlude the horizon above the established limits (a satisfactory rule-of-thumb requires no obstacle above 3°above the horizon within the main beam of any antenna).
– Near field calculations should be performed to assure that the electromagnetic fields generated by the antennas, outside the site boundaries and in the worst conditions, never exceed the limits considered as harmful to the general public. (Careful calculations should also be made to also ensure that the field intensity on site in front of, and around, antennas is known. Field intensities in excess of that considered safe for humans should be carefully marked).

9.1.3.2 Geological requirements for structures

– The geological formation of the terrain of a site under consideration should be evaluated. The weight-bearing capability of the soil must be sufficient to provide good support for the foundations of the antennas, roads, and buildings.
– The potential of the area for natural disasters should be evaluated. Of particular interest is to check for problems relative to severe high tides, salt-spray from ocean beaches, flooding, severe drought, corrosive and abrasive dust, earthquakes, poor drainage and runoff, severe insect and animal infestations, severe heat and/or cold. The corrosive properties of the soil should also be investigated to ensure that antenna foundation structures and grounding systems are not at risk of being corroded.
– The qualities of the site for good and simple ground systems should be evaluated; areas in which it would be difficult to establish good ground systems should be avoided.

9.1.3.3 Total area requirements

Previous steps in the planning process should have established the total facilities requirements of the broadcasting station. At a minimum these should include:

– Broadcast Subsystems and all the buildings housing them.
– Communications and programs feed facilities, including telephone, satellite circuits, radio communications, and studio-transmitter links, and all associated housing.
– Storage facilities for spares and other.

– Automotive facilities, including storage, repair, fuelling, parking.
– Fire and potable water storage, processing, and handling.
– Water sources (wells, river inlets, truck off-loading, etc.).
– Personnel housing, both permanent and transient.
– Health and safety facilities.
– Power generation facilities, both prime and backup.
– Fuel storage, handling, and off loading facilities.
– Waste separating, handling, storage and disposal.
– Sports and entertainment facilities (cinema, football, swimming, golf).
– Site security (fences, gates, communications, guard stations, armoured personnel secure areas, emergency exits).

For each candidate site, a provisional layout of all facilities should be made, with a view of determining if the candidate site will suit the envisioned broadcast facility and will be large enough.

9.1.4 Utility availability

The acceptable site will conform to the following utility availability norms.

1) Site Access - Roads, rails, canals, airports, heliports, ports, etc. will be appropriately available. These must suit both site construction access demands, as well as those made by everyday operations.
2) Power - Ideally, local power grids will be reasonably easily available to supply the power demands of the site. The economics and reliability of this power must be evaluated, and cost estimates of interfacing the site to the local power grid must be made. The quality of the power with respect to voltage and frequency stability, lightning and transient risks must be evaluated for acceptability. In the case in which the local power is not of acceptable quantity or quality, the problems associated with on-site power generation must be evaluated. This will include identification of local fuel availability, transportation, and other cost- and work-related elements associated with power generation on the required scale.
3) Personnel Support - As appropriate, the locality of the site must supply the habitation and support requirements of the staff of the station. These commonly include housing, health, alimentation, education, entertainment, and social and moral support.
4) Water - The site or the locale should be able to supply the water demands of the station.
5) Communications - The site or the locale should be able to supply the communications needs of program feeds, control and monitoring, management, and personnel.

9.1.5 Cost considerations

Each of the considerations of § 9.1.1, 9.1.2, and 9.1.3, and § 9.1.4 have associated with them differential construction and operating costs associated specifically with each specific site. For example, if one site has no local housing and health facilities for staff, then these must be built and operated on site. Or, if there are no local power source, then a prime power station and all fuel facilities must be built and operated on site.

Enough investigation of both the construction and station operation cost implications of each site must be made, in order to support a logical site-selection decision process.

9.2 Transmitting plant infrastructure

Transmitting plants are highly specialized high-technology installations. A large variety of physical plant installations are required to create the physical and technical basis which will support the station function and its efficient operation. This section presents a very brief overview of these infrastructure requirements, and the usual manner of their implementation.

9.2.1 Site planning

Once the site for the construction of a specific transmitting plant has been selected, the work of constructing it must start. The planning of the station is an important activity which will very much influence its operational efficiency, cost effectiveness, maintainability, and staff work environment. Specific important elements to be addressed include the following:

– The layout of a site is critical. It seriously affects the efficiency of the operation of the station, as well as the convenience and safety of the operational staff. Of primary importance is the relation of the antennas and transmission lines to the buildings and roads of the station. Antennas should be placed in such a fashion that their foreground clearance requirements are respected, while assuring that station staff occupied in normal operation and maintenance tasks are not exposed to hazardous levels of electromagnetic radiation.

– It is generally most efficient to concentrate the broadcast system facilities, maintenance facilities, and operational and management facilities in a relatively small and central area, usually surrounded by, <u>and behind</u>, the antennas.

– Access and other roads should be positioned to avoid exposing vehicles and personnel to hazardous levels of electromagnetic radiation.

– Care should be exercised to lay out, design and construct fuel facilities to avoid complications in their use in the electromagnetic radiation environment. In addition, placement of any fuel storage facilities relative to any local water sources, such as wells and rivers should be done with extreme care to avoid contamination of the water sources and environment with fuel.

– Housing and offices should be carefully placed as far as possible from high-noise areas, such as power generating plants, HVAC plants, as well as from RF hazard zones.

9.2.2 Site development

Elements important to the development of a site in the planning and construction phases of a broadcasting facility are as follows:

1) Drains and draining strategy should be carefully developed to assure that all important parts of the facility are free of danger of flooding, and completely available for operation and maintenance at all times.

2) Roads should be laid out to assure safety of the general public and operational personnel at all times, with respect to hazardous levels of electromagnetic radiation, lightning risk, high-tension electric lines, falling ice hazards and hazards of falling ice-loaded structures, and should be kept safely remote from elevated work areas (e.g. towers). The design and layout of the roads and drainage systems should assure that roads are never flooded and that access to all parts of the facility is assured at all times.

3) Terrain modifications for broadcasting facilities is required for the following purposes:
   - To assure appropriately smooth surface for antenna base areas, building and roads.
   - To provide suitable adaptations of antenna foregrounds.

- To provide suitable drainage.
- To provide suitable surfaces for staff buildings, houses, parking, and other activities.
- Site development and construction must take into account the cost and earth-compaction time for all large-scale earth moving terrain modifications.

4) Fencing is required for facility security, assuring the safety of the public-at-large and the station operating staff, and controlling the movement of animals within the station boundaries.

The requirements for types of fencing on broadcast stations is highly dependent on its use. For example, the use of non-metallic fencing in high levels of electromagnetic radiation is required. The station designers should pay specific attention to the functional requirements of the fencing, as well as to the environment in which these must function.

9.2.3 Building requirements

1) **General** - Transmitting facilities are complex industrial environments which combine a great variety of different forms of mechanical, electrical and electronic subsystems. Great care should be exercised in their general planning and execution. Two areas of general interest and importance suggest themselves to the attention of the facility planners and designers.

- **Shielding and Grounding** - All buildings and facilities used for sensitive or high-powered electronics apparatus should be shielded and carefully grounded. Metallic buildings should have their walls and ceilings formed of metal grids or plates which are bonded by soldering or welded to form a continuous electric circuit to a floor grounding grid which is grounded through a matrix of properly installed and bonded ground rods. A commonly used practice to providing a building ground system is to place a conductor around the entire building foundation perimeter connected to ground rods at frequent intervals. The building floor grounding grid must be connected to the perimeter ground ring in multiple points with very short large diameter cables to provide both a low resistance and low inductance path. Connections of the perimeter ground ring to each ground rod can be inside a hand-hole for ease of inspection and maintenance. Reinforced concrete buildings should have all reinforcing steel tacked-welded together to form a clear continuous path from each piece to the building ground system. Other forms of building implementation should have shielding installed which forms a chamber or cage with each element having a clear conductive path to ground.
- **Signal lines** - All signal lines should be formed of differential mode electric circuits with high common-mode rejection, which are all carefully shielded and grounded, and which are housed in metallic ducts which are properly connected to low-resistivity grounding circuits at appropriate intervals.
- **Utilities** - All utilities (among them being electric power lines, water, sanitary sewage lines, and heating gas) should be carefully embedded within the construction and underground. Effective and practical building codes should be used for their specification, and these should be suitably adapted to the power, signal, and RF environment of the installation.

2) **Heating, ventilating and air-conditioning (HVAC)** - All HVAC should be designed to control the internal environment of the broadcast facility. Special attention should be paid to the following.

– The heat load for the HVAC system should provide a sufficient margin to control the internal environment of all electronic subsystems housed in the facility. During the specification phase of the facility design, the HVAC heat loads imposed by all of the station equipment should be analyzed and taken into account. Extreme seasonal weather variations should be taken into account.

– For critical station subsystems, the overall reliability of the total transmission system can be augmented by supplying redundant HVAC systems. This specially applies to key facilities in the interior of a building, such as communications and satellite electronics and transmission control rooms.

3) **Fire protection systems** - Fire alarm systems should be installed in all broadcast facilities buildings and major components. They should report their status to a central control facility and actuate high-powered annunciator systems, as well as report their status to central control facilities.

Fire extinguishing systems should be appropriately specified for the areas which they are to protect. Water systems should not be used in electronic areas.

4) **Control room** - A central control room should be installed within sight of the transmitters, in the transmitter hall. This room should house all the audio control and switching facilities of the station, the automation and control subsystems, the transmitter controls, the RF switchbay controls, the antenna controls, the communications subsystem controls, as well as status reporting panels from the facility security subsystems, the fire protection subsystems, and the telephone circuits. It should be carefully environmentally protected by its own HVAC system. The room (including the ceiling and floor) should be carefully shielded from electromagnetic interference. All circuits entering or leaving the room should do so through a grounding and filtering panel, which will remove all common-mode RF signals from the wires and their external shields, and remove any unnecessary differential mode RF as well. Power to the control room should be supplied by an Uninterruptable Power Supply (UPS) which will maintain critical circuits active through periods when the mains power is not available.

5) **Transmitter hall and building** - This contains the actual transmitters and all their support and control apparatus. It should be designed with the thought in mind that it might be called upon to contain more than one generation of transmitters. Thus, the ground system should be of a general nature, able to connect to more than one physical transmitter configuration; all power, RF, control, audio, monitoring, and alarm circuits should be enclosed in floor trenches or suspended in conduits and cable trays from the ceiling as appropriate. Ceilings should be quite high, and ample surround space should be supplied for all transmitters. Space should be left for easy addition of one or more transmitters to the complement of transmitters.

All transmitters should be installed within easy view of the control room. Fire detection and extinguishing apparatus should be supplied.

Capacious power vaults for the transmitter power supplies and modulators should be supplied. It is important to leave as much space as possible in all transmitter-related facilities areas to facilitate the usually inevitable transmitter systems renovations.

It is particularly important to remember that individual HVAC for each transmitter is required. An individual transmitter should not present any particular heat burden to the transmitter building HVAC. All heat from inside transmitter cabinets should be flushed by a separate ventilating unit which is an integral part of the transmitter.

6) **Battery rooms** - Battery rooms which supply power for UPS systems and for standby power to other electronic systems should be made available. They should be well-ventilated, and supply easy ingress/exit for heavy lifting equipment to easily exchange batteries on a periodic basis.

7) **Storage facilities** - Several types of storage facilities are required for a transmitting facility. Ordinary storage for the normal goods of commercial, industrial, and human activities must be supplied. Specialized storage for electronics instruments and electronics parts storage should be supplied. The ambient of these should be carefully temperature and humidity controlled. Specialized storage for the storage and treatment of vacuum tubes should be supplied. These should contain special storage racks for isolation of the tubes from vibration. A special facility should be supplied for applying High Tension low-current electricity to the tubes to scavenge gases from their interior and maintain them at the proper state of readiness so as to be available for use at any time. This facility should be carefully isolated to protect station personnel from induced X-rays.

   It is to be remembered that many of the components of high-powered transmitters and associated equipment are large and heavy. In all storage areas a careful investigation of parts sizes should be made, and appropriate doors and floor weight-bearing capability should be specified and supplied.

   All storage should be located as close as possible to where the parts will be needed. High security should be maintained in all storage areas, with door locks and barred windows.

8) **Laboratories** - Tool and instrument rooms and equipment repair rooms must be supplied as appropriate. A carefully shielded room for repair of sensitive electronic apparatus should be supplied.

9) **Machine shops** - The repair of large transmitting equipment and its support apparatus frequently requires the manufacture of specialized mechanical parts. For this a well-equipped machine shop should be supplied.

10) **Station management and operational staff support** - a complex of well-designed and comfortable support facilities should be supplied for the station management and operational staff. These should be quiet, well-lit, air-conditioned and support the staff in such a manner as to contribute to their ability to operate and make decisions in a difficult and dangerous work situation. At a minimum, as appropriate, these facilities should be comprised of the following:

   – Offices - These should be quiet, and well-isolated from each other. Wiring for all modes of electronic communications and management devices and equipment should be supplied.
   – Hygienic facilities should be supplied for both male and female workers. These should contain toilet facilities, showers, clothes changing areas, and storage lockers for personal effects.
   – Cooking and Eating Facilities should be supplied as required.
   – Rest and Sleeping facilities should be supplied in case of need for station personnel to work extra shifts.

9.3 Transmitting station subsystems

This section describes the major subsystems which are required for an HF transmitting station. It is meant to apply to a broad range of stations, from small and relatively low-powered facilities to major stations which require many high-powered transmitters and their support subsystems. The station designer must interpolate between the actual level of approach of the intended station and the specifications contained herein.

It is important to note that all buildings and other parts of a broadcast station have the single function of supporting the broadcast function of the facility. In particular, the whole of the facility must be so integrated and interconnected that the interdependencies of all broadcast subsystems are accommodated and operate as a complete system.

This section addresses the choices of the features of the major subsystems, and indicates their major requirements for interdependency and interconnection.

9.3.1 General

Grounding - It should be noted at the outset that one of the most important features of the broadcast system is its ground system. At a minimum, power facilities, transmitter plant, building shields and filter plates, all satellite communications facilities, audio switching and processing, all control and monitoring subsystems, RF switchbays, and baluns, and their associated circuits should be tied into a well-connected and integrated ground system. The antenna subsystem should have its own grounding system, and be very well supplied with grounding rods and pits. Coaxial cable systems should be tied into the ground system of the transmitter building complex.

Control and monitoring cable runs should have grounded guard wires buried in the same trench or accompanying the cable ducts.

Conduits and Ducts - Considerations of systems operational reliability and the safety of station operational personnel indicate that the wiring of the station be implemented in the broad-scale use of conduits and ducts for all subsystem wiring in any area in exposed to RF. This includes all power, control, monitoring, and audio wiring at a minimum. RF circuits should be contained in ducts or conduits separate from those of any other kind of circuit. Metallic conduits and ducts, grounded at short intervals, are to be preferred for all above-ground circuits. Below-ground conduits and ducts should be waterproofed, but need not be metallic, except in specific critical cases.

The station designer should remember that maintenance and future system modifications are universals in transmitting station systems. Thus, easy access into all wiring circuits and their conduits and ducts should be provided. Leaving extra space and a pull wire in ducts and conduits between all station points is excellent practice. All underground ducts and duct-banks should have carefully-spaced hand-holes or other accesses.

9.3.2 Program feeds

Program feeds are defined as those circuits which send the program material from the studio (or other) source to the transmitters of the broadcast stations. In the context of this paper such circuits are commonly comprised of telephone line and cable circuit connections, optical communications systems, or studio-transmitter links (STLs) where the program source is close to the transmitter site. Long-distance telephone circuits or data channels, or satellite circuits are commonly used where the studio-transmitter distance is large.

In the design of all program feed facilities it should be remembered that these subsystems are highly susceptible to interference from the high-level RF output of transmitters. Careful circuit design, isolation, shielding, and grounding practices must be used.

The following sections present information with respect to special considerations with respect to select modalities of transmission of program feeds.

1) **Cable and telephone line feed circuits** - These circuits should be carefully located as remote as possible from the high-level RF circuits. From the point at which these circuits enter the station confines, they should be contained in carefully-grounded buried metallic waterproof conduits. These ducts should conduct the circuits directly into the control room.

   In all circumstances in which it is possible, the use of two-conductor-shielded wire connections is recommended. The two signal-conducting wires should be operated in differential-mode, and all circuits should have a high common-mode rejection, particularly at RF frequencies.

   Optical fibre feed, control, command, and monitoring signals are the most independent of corruption from high-powered RF fields. This mode of communications of low-level signals is recommended.

2) **Studio-transmitter links (STLs)** - STLs are an excellent short-to-medium communications mode for low-level signal communications needs, including, of course, program feeds. However, care should be taken to avoid any interaction between the station transmitting system and the STL system, either from simple RF overloading, or from contamination of the STL signals from transmitter harmonics or spurious signals.

   Naturally the cautions of 1) of this section apply to any feed connection from STL R/T units and the station's program feed inputs and other circuits.

   In addition, in the planning of the station, great care must be taken to ensure a clear line-of-sight between the antennas of the studio side of the link and the transmitter side. In particular, such signals should not be required to go through the wire screens of HF curtain transmitting antennas.

3) **Satellite circuits** - Satellite circuits are commonly used for the control, monitoring, and feed circuit needs of transmitting stations very far removed from the studios. All of the cautions of the preceding section 2) apply to the planning, placement, and implementation of satellite facilities. In addition, it should be noted that it is generally most economical from the operational and maintenance point-of-view to have all or most satellite signal circuits and apparatus inside the control room of the transmitting station, along with all the other critical feed, control and monitoring equipment.

9.3.2.1 Audio control, monitoring and processing

This part of the transmitting station subsystems takes the audio feeds from the audio feed subsystem as inputs and supplies proper switching and processing to them so that the correct and most appropriate audio feed is applied to the audio input of correct transmitter at the correct time. Its most important elements and their applications considerations are as follows.

1) **The audio routing switcher (ARS)** - The ARS supplies the principal audio switching function to the entire broadcast transmission chain. At (some of) its inputs, it accepts audio program feed signals and routes them to the appropriate transmitter (through the appropriate audio processor). It also switches all monitoring and measuring audio circuits, and routes them to the appropriate monitoring and measuring equipment sections.

Modern operational and maintenance strategies often require that the ARS be a wholly electronic switching device, with both manual control and external digital control options. Usually, audio switching function in modern stations is accomplished with the ARS under automatic computer control to minimize operating costs and the possibility of operational error. Manual operation of the ARS is an operational recourse in case of changes in program sequences which are too precipitate to allow reprogramming the station automatic controller, or in case of operational difficulties or breakdowns.

2) **Monitoring and measuring** - The audio subsystem must have a capability of switching any audio signal(s) to amplifiers/loudspeakers for human evaluation of the correctness of the material, and its audio quality. The switching for this function should be under some form of automatic and/or manual control through the ARS. Likewise, all signal levels of all audio signals should be measurable and/or continuously monitor able through the use of audio level meters, or PPM meters. Such parameters are often continuously monitored and displayed for each operational transmitter. The switching for this function should likewise be under some form of automatic and/or manual control through the ARS.

3) **Emergency and maintenance switching** - It is of the utmost importance to allow no program delivery outage due to any control-room malfunction or emergency. Thus, the use of an elaborate system of jack panels and jumper cables which duplicates the function of the ARS is mandatory. The rules for this part of the audio subsystem are as follows.

   – All program inputs to the station should appear on a jack field. All inputs and all outputs of every audio and program-feed-related device in the whole station (including measurement and monitoring devices) should appear on its own jack field. All jack fields should be clearly marked and identified.

   – The jacks should be of the type, which, when there is no plug inserted in it, will connect the audio circuit to the next piece of equipment in the audio control and processing chain. Insertion of a plug must interrupt the circuit, and allow transference of the signal to some other part of the jack field, for its insertion into some other part of the subsystem for continuity, measurement, or trouble-shooting.

4) **Audio frequency, noise, and distortion measurements** - The audio control and processing system should contain a section of equipment which can be used to measure the audio response, the noise level, and the intermodulation and harmonic distortion of any chain of circuits or any device in the subsystem. All inputs and outputs to this section should be through the ARS, and its function should be under automatic control. It should be used on all audio chains a minimum of once a day, although more frequent use is advised.

5) **Audio processing** - An audio processor is an active electronic device which adjusts the level of the audio applied to a transmitter input, and applies appropriate compression and peak-limiting to assure that the modulation level of the transmitter is as high as possible at all times. <u>It is exceedingly important to use audio processors on the input to all transmitters during all broadcast operations</u>, except when measuring its audio frequency response, noise and distortion as a part of maintenance. Appropriate use of correctly adjusted audio processors effectively add to the station's listenability by making it sound louder, effectively increasing the delivered signal-to-noise ratio, and signal-to-interference ratio of the broadcast signal. They do not adversely affect the perceived quality of the audio signal delivered to the listener.

6) **Modulation monitors** - All station audio subsystems should have a good quality modulation monitoring device attached to the output of each operational transmitter during broadcasts. At a minimum, these devices should monitor the percentage of transmitter

modulation, the transmitter carrier shift, and should supply a low-distortion audio sample of the demodulated transmitter output. The audio signals from the modulation monitor should be switched through the ARS for measurement, monitoring, and audio-quality testing purposes.

9.3.3 RF power generating subsystem

The RF power generating subsystem of a transmitting station, in its most general form, is comprised of the station's frequency generating section, its transmitters, the RF switching equipment, any baluns required, any dummy loads desired, and all associated transmission lines required to connect the system. The following sections briefly describe each, and supply important information.

1) **The frequency generators** - In their simplest form, the station's frequency generators may be simple crystal oscillators, which may be an integral part of the transmitter. Since most HF transmitting stations must change frequencies frequently, it is most common to use variable frequency sources in the station control room. The most usual form of such frequency sources are digital frequency synthesizers. There is generally one such synthesizer per transmitter (with a usual spare), with its outputs permanently dedicated to a specified transmitter.

   Care should be taken with all RF leads in the control room to assure system compatibility.

   It is generally advantageous to use frequency synthesizers with digital control line inputs, and independent frequency-verification circuits and outputs, for use in station automation and monitoring.

2) **Transmitters** - The transmitter supplies the high-level RF energy which is to be applied to the station’s antennas. The principal parts of the transmitter are its RF power amplifiers, the modulator, the power supply, and all associated cooling and ventilating sections. Descriptions and recommendations pertaining to these follow:

   – The RF amplifier section of modern transmitters usually contains one or two vacuum-tube amplifier sections with all associated low-level solid-state amplifiers, tuning elements, control elements, and assorted monitoring sections.

   – RF amplifiers with a single vacuum-tube amplifier section are generally the most desirable because of their increased overall efficiency and reliability.

   – The most desirable of today's transmitters have coaxial outputs, have tuning circuits which correctly and automatically tune themselves to new frequencies and load conditions, and which can be remotely controlled from the control-room.

   – Modulators of modern transmitters are generally comprised of some form of high-level solid-state modulator, which is an active switching circuit with associated filters, control circuits, and passive elements. Most often such modulators form the entire high-tension power-supply for the transmitter and eliminate the requirements for traditional power supplies and crow-bar circuits. Any form of modulator other than solid-state should be avoided by anyone building a new transmitter station because of its perceptibly better power efficiency and greater versatility. Another rewarding feature of solid-state modulators is that they themselves also are the transmitter power supply, and replace most if not all the contents of the power vault.

   – Solid-state switching modulators have a variety of useful, and nowadays important, features. Among these should be counted its ability to utilize carrier-level control, and its ability to form different modulation modes.

– Carrier-level control in this context describes the action of the transmitter in adjusting the level of the carrier in response to various levels of the modulating audio input. The overall intention of this form of control is to decrease the overall transmitter power input, with minimal impact on the quality of the delivered program material as perceived by the listener. While there is some disagreement with respect to the overall signal delivery performance of these systems in certain radio reception conditions, there is no doubt that it very effectively decreases total power input to the transmitter, and lowers station operational costs.

– Nowadays, the modulation-mode capability of HF transmitters is of great importance. At a minimum an HF transmitter should be capable of A3 (double sideband with full carrier) modulation. Typical A3 modulation requirements on a transmitter should be, that it will supply 98% modulation with sinusoidal modulation input over the full desired audio frequency modulation bandwidth for at least ten minutes, and will operate indefinitely at 90% sinusoidal modulation input over the frequency range of the modulation input. It should also operate indefinitely with high-level audio-processed audio modulation program material with 100% modulation peaks occurring many times a second.

  In addition, the modulator and its associated transmitter should be capable of operating in single-sideband modes (SSB), through the process of Envelope Elimination and Restoration. This requires a special exciter to work in conjunction with the RF section of the transmitter and the modulator.

– In either A3 or SSB modes, the transmitter should perform within relevant CCIR and ITU recommendations.

– Power Supplies and Crow-Bars for transmitters have largely been supplanted by the use of solid-state switching modulators, which actively supply power to the transmitter. In the old power supply concept, high-tension plate power was supplied to both the modulator and the RF section by a large unit composed of transformers, rectifiers, capacitors, and inductors. It was commonly housed in a power vault which isolated it from personnel. Nowadays the solid-state modulator may be placed in a vault, but is just as likely to be placed in an isolated screened pen near the transmitter RF section.

– In the old power-supply concept for transmitters, a crow-bar was an electronic circuit which rapidly "dumped" the electric energy from the power supply into a resistive load to avoid damage due to melt-downs in case of shorts or arcs within the transmitter. The solid-state modulator has a feature which disconnects the power from the RF sections during any arc or short interval, eliminating the need for the wasteful and noisy crow-bar.

– Cooling and ventilation for transmitters and their associated components should be accomplished by use of systems which are dedicated to each transmitter. The basic space HVAC system of the transmitter building should not be involved in cooling and ventilating transmitters.

– Transmitter cooling and ventilation should be done with air sources and heat exchangers which are located outside the transmitter building. These should be carefully interlocked with the transmitter control system, and the automation system of the station, so that any failure in them shuts down the system, and notifies the station operators of the problem.

– Any source of outside air which might be introduced into the transmitter's interior through the cooling and ventilating system should be carefully filtered against any corrosive or abrasive element.
– It should be noted in passing that sources of ultra-clean water or coolants are required for these systems, and that provisions for their manufacture and/or storage should be made.

9.3.4 RF switchbay

High-level RF switching of the output of individual transmitters is usually required to apply the output of one or more transmitters of the station's ensemble to one or more of the stations antennas. This is a consequence of the fact that every antenna should be sourced by more than one transmitter for reasons of reliability, and of the fact that in general there are far more antennas on a station than there are transmitters.

Such switching is accomplished by a large assembly of switches, called a switchbay(), constructed of either parallel transmission lines or coaxial lines. These switch elements form a matrix into which all transmitter outputs are fed, and out of which all antennas and other station elements designed to receive RF power are supplied.

FIGURE 9.1

Example of switchbay

The selection of either parallel or coaxial switchbay construction is largely a matter of the preference of the station builder. It should be noted, though, that if the parallel line configuration is chosen, enclosed ducted lines should be used, rather than open-frame types. In the latter, impedances are rather hard to control, and the level of radiation hazard to which the station operators would be exposed is uncontrollable.

Several details pertaining to switchbays should be noted.

– A section of relays or other forms of switches which mimic all of the connectivity of the switchbay should be provided. Its purpose is to connect all the various antenna and balun safety circuits and arc-detectors through the switchbay to the transmitter, for safety and damage protection purposes.

– The switchbay should have an elaborate system of interlocks and switch position indicators which provide signals to the transmitters and the station automation system to ensure that no transmitter can turn on if an RF switch is not in correct, stable, and perfect contact.

– Often switchbays have ultra-violet arc detectors within their columns and rows to detect arcs within the switchbay, and turn off the transmitter supplying RF power to them. Such arc detectors should have tell-tales which show in which part of the switchbay the arc occurred.

– The switchbay should have inputs to it allowing the station automation to perform the transmitter-antenna connectivity according to the required schedule.

– The switchbay should have an output which interfaces to the station automation and monitoring system which informs those systems, and displays exactly what its connectivity status is at all times.

– The insertion VSWR of the switchbay is a critical parameter. It should be carefully specified so that the total VSWR of the RF chain from transmitter to antenna falls within acceptable limits.

9.3.5 Baluns

The balance-to-unbalance transformer is a passive element required to make a transition from a coaxial transmission line to a parallel transmission line, with pursuant changes of line impedance. They are required to convert the coaxial output of a modern transmitter to the parallel line configuration used by HF transmitting antennas. If the RF switchbay is of a ducted parallel line construction, the balun is interposed between the transmitter and the switchbay. If the switchbay is coaxial, the balun is interposed between the switchbay and the antenna.

Baluns come in a variety of physical configurations. For low and medium power systems, they may be made as a transformer, with a ferrite core. For higher powers, they are commonly made of sections of ducts and transmission lines. Such baluns are physically quite large.

Often baluns have tuning elements within them which must be connected to the control systems of the transmitter to which they are connected, through the relay mimic sections of the switchbay.

Baluns come in a variety of bandwiths. The bandwidth selected for a given application should agree carefully with the frequency requirements of the application. In addition, its insertion VSWR should be compatible with the VSWR budget projections of the RF system under design.

Arc-detectors in baluns are not uncommon, and are often a sensible insurance against damage to such a (usually) remote and inaccessible element of the high-power RF chain. These are connected to the specific transmitter supplying the RF power to the chain through the mimic switching circuits of the switchbay.

Some care should be taken with the balun specifications to ensure that its conversion of differential mode RF currents to common-mode RF currents is not excessive. A −20 dB isolation factor is usually considered adequate.

It should be noted that careful grounding and physical isolation of the balun is prudent. The RF currents and voltages around such a unit usually contribute to high RF hazard fields.

9.3.6 Dummy loads

A dummy load is a device which is capable of absorbing the entire RF power output of the transmitter in a steady-state operational mode. It is used in place of an antenna when maintenance or adjustments are being made on a transmitter.

The load impedance of the dummy load is nominally equal to that of the transmission line connecting it to the transmitter. Any variation of its actual impedance about this nominal impedance over its operating frequency range should be accommodated within the VSWR tolerances of the RF system.

Often it is useful to use a dummy load which will have a readout of the total power which it is absorbing from the transmitter. This supplies information about the power-generating capabilities of the transmitters which is useful for maintenance purposes.

Cooling and ventilation considerations for the dummy load should conform to the same standards as those of the transmitters.

9.3.7 Transmission lines

The transmission lines of a transmitting station connect all the components of the RF transmission chain to each other. All lines are either of the parallel (either ducted or open-line) line configuration, or are of the coaxial line configuration (Figure 9.2). Several observations are in order with respect to this important element of HF transmitting station integration.

FIGURE 9.2

Example of coaxial transmission

- Transmission lines inside a building, or within the general operating area of the central part of the station usually trafficked by operation personnel should be either coaxial or ducted parallel line. Outside the central area of a transmitting station, it is generally more economical to use parallel lines. In any case transmission lines should be high up out of reach of either personnel or vehicular traffic. A height of 5 m is usually sufficient at road crossing locations. It should be noted that in high-powered transmitting stations the electromagnetic fields underneath and near such transmission lines is hazardous to station operational personnel, and should be so marked.
- The frequency range requirements of all transmission lines, with their attendant insertion VSWRs, should be carefully analyzed and specified.
- The power rating of the transmission lines, along with safety factors, and maximum surface electric field gradient should be carefully specified to meet the operational requirements of the station.
- Mechanical specifications of the transmission line implementations should be made with care to ensure that the spacing of parallel line supports does not contribute to insertion VSWR peaks within the system operating frequency. In addition, it should specify that the line be sufficiently taut not to droop close to the ground and create an operational safety hazard or difficulty in maintaining the grounds under it.
- In addition, these specifications should specify insulator support systems which do not allow transverse transmission line spacing changes or significant deviation of its plane of symmetry with respect to the earth's surface during a wind.
- Insulators should be specified to be mechanically durable to withstand the high stresses inherent in transmission line implementations. In addition, they should be of sufficient size and design to withstand the electrical stresses placed upon them by their use in the transmission line, in the environment of the installation. High grade alumina ceramic is recommended to minimize RF heating of the insulating material.
- Coaxial transmission lines operating at any power above 10 kW should be pressurized with dry air, operating at the recommended manufacturers specifications. Dry air pressurizing systems with tell-tale monitors connected to the station's monitoring and automation subsystems should be provided.
- Coaxial transmission lines should be mounted away from any vehicular traffic, in trenches or on pylons. Their outer shell should be grounded at each support.
- All transmission line support structures should be grounded. All end-bells of insulators should be grounded.
- Transmission line supports should be sufficiently strong to support the total force of the transmission lines in case any other single transmission line support fails.

9.3.8 Power supply

Whenever practical, the normal source of power for all equipment in the station should be the local electric utility power system (commercial power). In some countries, all utility power is supplied by an agency of the government, while in others it may be furnished by privately-owned utility companies. Whenever commercial power is not available, is uneconomical, or is of unacceptable quality, an onsite prime power plant must be furnished.

9.3.8.1 Commercial power quality

The quality of a commercial power source usually refers to the system's ability to maintain voltage and frequency within the limits required for proper operation of the station under usual conditions. The primary factors in making this determination include the following:

1) The utility system must have sufficient excess generating capacity to supply the additional electrical load of the station.
2) The highest voltage available from the utility system should be at least as high as the operating voltage of the transmitters. Step-up transformers should be avoided, since this introduces additional impedance.
3) The utility system equivalent impedance must be low enough such that transient voltage drops due to current inrushes resulting from transmitter turn-ons and "crowbar" operations are less than that which will cause protective devices to trip transmitters offline. If this is unachievable, "step-start" controls should be employed on the transmitters to gradually apply power voltage in steps to limit inrush currents.
4) The utility system must have sufficient generating capacity to take the power swings associated with transmitter carrier modulation without excessive changes in power frequency and voltage.
5) The utility system equivalent impedance must also be low enough such that excessive harmonic voltage components are not generated. Harmonics are created by the voltage drop that results from harmonic components of the transmitter power currents flowing through the utility system equivalent impedance.
6) The system is relatively free of transient voltage and frequency changes associated with load changes, switching, or other transients generated apart from the broadcast station by the utility system itself or other utility customers (loads). This can be best determined by monitoring the voltage with a power disturbance analyzer such as Dranetz model 658.
7) The system is free of frequent scheduled power outages ("blackouts") and significant voltage reductions ("brownouts") required as a result of a shortage of power generating capacity.

9.3.8.2 Distribution system design/protection

Design and protection of electrical distribution systems for broadcast systems is basically conventional in every way. Consideration could be given to providing redundant commercial power services or redundant feeders to main switchboards for greater reliability.

9.3.8.3 Emergency generator

No matter how reliable a utility power system may have been proven to be, it is still subject to an occasional outage caused by unforeseen circumstances such as storms, equipment failures, damage caused by accidents, system repairs, or terrorism attacks. To prevent power loss to loads considered to be essential during such periods of commercial power outage, a backup generator which starts automatically upon loss of utility power should be installed. An automatic transfer switch (ATS) should be provided to automatically switch the essential loads to the generator and back to the utility when it is restored. The essential loads will still experience a brief outage during the period between the onset of a utility outage and the successful transfer of load to the emergency generator.

Loads that should be considered for emergency generator backup include the uninterruptable power supply (UPS), antenna tower lighting, fire alarm systems, emergency lighting systems, emergency communications equipment, security equipment such as gatehouse, perimeter lighting, intrusion detection, etc. Other essential loads that cannot tolerate any outage at all, including the brief one cause by transfers by the ATS, should be supplied by an uninterruptable power supply, also supported by the emergency generator.

9.3.8.4 Uninterruptable power supply

As previously mentioned, a static type UPS should be provided to maintain continuous power supply to those critical loads which cannot tolerate a power outage of any duration, even for a few milliseconds. The UPS provides a bridge to maintain power during the interval following the loss of commercial power and before the successful transfer of emergency load to the emergency generator. The source of power during this period is a battery bank connected to a solid state inverter, which converts the DC battery voltage to AC voltage of the appropriate frequency.

A static type UPS consists mainly of a rectifier/battery charger, a battery, and an inverter. During normal operation, the rectifier is supplied by the normal commercial power supply and produces DC voltage. The DC voltage then supplies an inverter, which converts the DC voltage back to normal AC voltage, 50 Hz or 60 Hz as appropriate, to supply the critical loads. A battery is connected in parallel with the rectifier DC output. Whenever utility power fails, the battery immediately supplies power to the inverter without interruption. When utility power is restored, the rectifier again supplies power to the critical loads via the inverter and recharges the battery. Typical battery capacities range from 5 minutes to 15 m duration. To prevent the batteries from discharging completely, the UPS rectifier input should be supported by the emergency generator.

Due to the inherent nature of the arrangement of the UPS and its battery, it will also provide excellent protection of sensitive electronic equipment against transient voltage surges.

Loads to be supported and protected by the UPS should primarily include any computer-processor-based equipment such as personal computers/file servers, programmable telephone exchanges, programmable controllers, etc. that require a long time to boot up or would cease to function due to the loss of stored data. All sensitive and critical electronic equipment, such as Control Room broadcast control equipment, should also be supported by the UPS. Heavy loads such as lighting and air conditioning should not be supported by UPS, since UPS capacity is relatively expensive.

9.3.8.5 Prime power plant

As mentioned previously, whenever commercial power is unavailable or of unacceptable quality, a dedicated onsite prime power plant must be provided. Generally for the typical sizes of broadcast stations, diesel-engine-driven generators provide the most economical source of power for a prime power plant.

The plant should include units of equal size and manufacture whenever possible to standardize on parts and provide interchangeability of units. Two units in excess of that required to supply the station should be provided; one to replace a failed unit, and one to simultaneously operate in place of one down for engine overhaul. Engine governors should be of the electronic type with isochronous load sharing control (constant speed under all load conditions, and providing for automatic equal loading of generators). Sufficient generator capacity should be installed to provide enough rotating inertia to absorb transient swings associated with transmitter carrier modulation and fault-clearing operations (consult transmitter manufacturer).

In the case of a station that does not broadcast 24 h a day, the electrical load during non-broadcast periods will be much less than that during broadcast times. It may be desirable in these circumstances to provide a smaller-capacity generator to supply just the station "housekeeping" loads to avoid excessive carbon build-up in lightly-loaded diesel engines and provide better operating efficiency.

No separate emergency backup generator is required whenever a prime power plant is installed.

9.3.8.6 Power plant automation

Power plant switchgear controls should include automatic engine start and automatic synchronizing capability to minimize the effort required to bring a generator on line. Remote controls for starting and stopping generator sets and monitoring generator load and alarms should be provided in the control room.

Consideration should be given to automating the operation of the power plant. This can be accomplished by installing a programmable logic controller (PLC) that automatically starts and stops generators in response to changing load needs and transmitter broadcast schedules without operator intervention. The PLC can be programmed to automatically bring generators on line in advance of transmitter turn-ons, perform emergency load shedding by turning off transmitters, can replace generators that go into alarm status, and can choose the generator with the lowest run time. The PLC can also be programmed to choose another generator when one fails to synchronize and come on line within a reasonable time.

9.3.8.7 Lightning protection

Buildings and other structures should be protected against lightning damage by installing a system of earth terminals (lightning rods) and grounding conductors to conduct lightning strokes to ground. A good source of detailed information is the National Lightning Code, published by the National Fire Protection Association (NFPA 780) of the United States.

All underground cable runs should have a bare grounding counterpoise conductor installed above each underground run to intercept lightning strokes to the ground directly above the cables. The counterpoise will also provide an equipotential surface above the each run to limit the flow of damaging currents along the ground associated with lightning strokes.

Lightning arresters (surge arresters) should be installed at the end of all commercial power overhead lines at the point where they connect to the station underground lines to prevent voltage surges due to lightning strokes to the overhead lines.

9.3.9 Safety and protection

9.3.9.1 RF arc control

RF arcs occur if the potential gradient at the surface of a conductor is higher than a certain value called “critical potential gradient” at which visible corona starts. Coronas can be noisy and are sources of spurious frequencies. They may increase their intensities manifold and develop into RF arcs, which then may cause destructive damage to the equipment.

The critical potential gradient is a function of the geometry of the system, atmospheric pressure, ambient temperature, humidity, and of the physical conditions of the conductor surface such as corrosion, moisture films, and drip water. This critical potential gradient can be increased by a judicious design and careful installation of the equipment, and a regular maintenance schedule to eliminate weak spots.

Even if a system is well designed and maintained, RF arcs are to be expected. High potentials can develop in the system in the presence of overhead charged clouds or by direct lightning strokes. Various schemes have been designed to protect the equipment, either to shield it (overhead ground wire), or to provide or improve a ground path that may bypass the equipment (ball gap, ground wire, counterpoise).

9.3.9.2 Radiation level

Ionizing radiation caused by x-rays radiated from the transmitters may constitute a radiation hazard for workers if the level of radiation is higher than a certain level. As a rule, this level should not be higher than that allowed for home television receivers, i.e about 0.5 mR/hr. Additional shielding of the transmitters is an effective method to reduce x-ray radiations to acceptable levels.

Non-ionizing radiation hazards are caused by electromagnetic fields in the radio frequency range from 100 kHz to 300 GHz. Metallic objects exposed to electromagnetic fields will have currents induced in them. If these objects are not grounded properly induced electric voltages will discharge if a body comes into contact with these objects. These discharges can cause local current densities capable of shock and burns.

RF energy absorbed by the human body exposed to electromagnetic fields will cause biological effects, the most notable being an increase in tissue or body temperature. Whether the exposure to electromagnetic fields is harmful depends on the intensity of the fields and the duration of exposure. A specific absorption rate (SAR) of 0.4 W/kg for 30 minutes is generally considered as safe for workers. For the general public, the accepted safe SAR limit is 0.08 W/kg. Since SAR is not a quantity readily measurable, the maximum permissible exposure levels are given in terms of electric (V/m) and magnetic (A/m) field strengths, and power density (mW/cm^2). These limits are subject to continuous reviews and can be widely different depending on the standard in effect.

9.3.9.3 Interlocking

Interlocking refers to a switching system which connects each part of the transmission system, from antenna to power system. One purpose of interlocking is to prevent damage to the transmission system when any of its component units is not prepared to take power, or to turn on. Another, and extremely important function of interlocking, is personnel safety. In this function, power from all transmission system components whose operation could endanger station personnel is cut-off.

9.3.9.3.1 System protective interlock systems

Many station subsystems are susceptible to damage if power is applied to them when they are not properly disposed to receive it. The most important examples of this are as follows.

– Antennas, baluns, and switchbays must have a system of interlock switches incorporated in them, such that if the RF circuit switches are not correctly positioned or not entirely closed (or opened), or when there is an arc detected in them, that the transmitter is disabled, and cannot be turned on. The antenna and balun interlock switches are relayed to the transmitters through the switchbay mimic circuits to the appropriate transmitter. The normal manner in which the transmitter is disabled is to simply open the mains power relay, assuring that primary power cannot be applied to the transmitter.

– Transmitters have a variety of protective interlock circuits which become active when the part of the transmitter system they represent becomes inactive or defective. For example, transmitter tuning circuits, transmitter cooling systems, transmitter ventilating systems, transmitter arc detector systems, etc. have interlock switches associated with them which ensure that the transmitter cannot be turned on while they are defective.

– Coaxial transmission line pressurization systems have interlocks which are activated when the dry air pressure in the transmission lines falls below a critical level, thus ensuring that RF power cannot be applied to it.

9.3.9.3.2 Personnel protective interlock systems

Elaborate interlock switch systems within transmitting stations are intended to provide the maximum protection to station personnel when they are engaged in duties which could expose them to danger of physical damage from mechanical or electrical systems. The principal systems of a transmitting station subject to such interlocking are as follows.

– Antennas have the full RF power of a transmitter applied to them while they are in normal operation. When an antenna is undergoing maintenance, it is common that the maintenance worker have available to him a series of keylock switches which are designed to ensure that RF power cannot be applied to the antenna. Thus, there is commonly available on the switchbay a keylock switch which when turned off and the key removed by the maintenance worker, inhibits the switch contacts of the switchbay from being activated and sending RF power to the antenna under maintenance. In addition, there is often a switch at the antenna which opens the transmission line to the antenna, and also grounds the antenna. Usually, in the case of antennas with RF switching incorporated into them for beam control purposes, there is another keylock switch which prevents the actuation of any such RF switch.

– Transmitters must have keyswitch interlocks which a maintenance worker can turn off and remove the key. This switch prevents any primary power from being applied to the transmitter during maintenance. Transmitters also have a shorting bar which the worker places across all high-voltage circuits inside the transmitter, ensuring that no part of the circuitry of the transmitter can be activated during maintenance. In addition, all transmitters have a system of door and panel interlocks which, if a door or panel is opened during transmitter operation, shut the transmitter off, and remove all hazardous voltages from its circuits.

– Power vaults also have elaborate interlocking for personnel safety. The door to all vaults has a keyswitch which, when turned to allow access to the vault through the door, turns off all power in the vault. It is also customary that there be a mechanism coupled to the door, which applies a short-circuit to all the power vault circuits when the door is opened while the vault is active.

– Transmitting stations have a great number of mechanical systems associated with them. Many of these, such as ventilators, belt drives, etc. are extremely dangerous, and will also have interlock switches which deactivate them upon access to them.

9.4 Minimization of the numbers of transmitters and antennas

Procedures described in previous sections enabled the HF transmitting plant designer to identify all the frequency ranges and transmitter powers, and all the antenna performance characteristics required for successful transmission of all the projected broadcasts from the projected transmitting station. This provides a bewildering array of information which treats each broadcast as though it required its own individual transmission system. Obviously this is not the case. Antennas and transmitters certainly serve for more than one transmission.

This section provides information about a routine procedure which results in the specification of a minimum set of transmitters and antennas which meet the specified broadcast objectives of the projected station. In addition, it provides some advice for a reasonable low-cost station connectivity specification which avoids over-costly switchbays and transmission-line layouts.

9.4.1 Number of transmitters and their power ratings

In general, the total number of transmitters on an HF transmitting station should be equal to the maximum number of transmissions to be made at one time from the transmitting station, plus one or two more for redundancy in case of a transmitter failure.

Unless the power requirements of the propagation analyses specify the power of the transmitters to be a reasonable and economical number, the transmitter powers should be established on the following rules-of-thumb.

1) For the maximum achievable coverage and reliability in a one-hop coverage requirement in the HF transmitting bands from 6 to 22 MHz., the transmitter power should not exceed 100 kW.

2) For occasional extensions of the coverage requirement into two-hop regions, but with its principal coverage still in the one-hop region, 100 kW transmitters are still preferred, although 250 kW transmitters confer more reliability in the two-hop coverage areas.

3) For general-purpose coverage requirements in which coverages may be arbitrarily in the one-, two-, or more-hop coverage ranges from the station, 500 kW transmitters are required in today's high-interference broadcast environment.

   Some general comments about transmitters and transmitter complements should be made.

4) Unless they are specifically required by the transmissions to be made, high powered transmitters, particularly those operating at 500 kW carrier power, are to be much avoided. They are exceedingly costly to run; their input energy requirements are stupendous. Their reliability is not as high as that of lower powered transmitters, and their maintenance costs are exaggeratedly high. Their complexity is sufficiently higher than that of lower powered transmitters so that more skilled technical operational and maintenance personnel are needed. They are much more dangerous to work on than are lower-powered units.

5) It is generally simpler and more economical to use the same type and power rating transmitter throughout the whole system unless such a provision tends to require all 500 kW transmitters in the plant.

9.4.2 Number of antennas required to support a given transmission schedule

HF transmitting antennas are typically costly, difficult to install, and difficult to maintain. Classically they represent the highest cost element of an HF transmitting station. This section informs the reader how to take advantage of the characteristics of modern antennas to minimize the total cost and complexity of the set of antennas required to support a specific broadcast schedule from a specific transmission site.

Several assumptions are made. First, it is assumed that high-powered broadcast transmissions are involved, and that all or most of the antennas to be used are of the aperiodic curtain type.

It is further assumed that multiple broadcasts are made during the course of the day, in a variety of directions, under variable radio propagation conditions requiring different frequencies and antenna beam take-off angles.

Under these assumptions, it is likely that the collection of antenna performance parameters prescribed under the radio propagation analysis phase of the identification of broadcast parameters identified in the procedures specified in Chapters 4, 5, 6 and 7 of this treatise can be condensed to the point where a minimal set of antennas can be identified to fulfil all broadcast requirements.

This comes about because of the horizontal beam slewing, the horizontal beamwidth control, and the vertical mode control which allows varying the beam takeoff angle of modern antennas.

The basic elements of deriving the minimal antenna set from the plural antenna beams required to support the broadcasts of a given broadcast schedule suggests a method to more easily visualize the directions of coverage required. A diagrammatic approach to accomplish this goal is as follows:

Step 1 - Make a polar diagram of the azimuthal direction to the centre of each broadcast's designated contiguous service area, for each separate broadcast.

Step 2 - On each entry for each broadcast on the polar diagram, mark the azimuthal direction to both sides of each service area. Join the two extremes of the angular range with an arc, shade the enclosed area, and mark with the time period(s) of the transmission(s).

Step 3 - Taking into account the azimuthal slew range of the antenna required to deliver the signal to the service areas, the number of antennas and their boresight azimuths will become evident. If the broadcast schedule requires multiple broadcasts to specific areas of service during the same time period(s), more that a single antenna is required to cover those service areas. This may be accomplished by overlapping the slewable coverage of two or more antennas. If the broadcast schedule requires multiple broadcasts on the same azimuth in different broadcast bands within the bandwidth (approximately one octave) of an antenna array, it may be cost effective to multiplex two or more transmitters into the same antenna array.

There are two aperiodic antennas types to be considered for use. They are fixed boresight-electrically slewable curtain array and mechanically slewable-rotatable. Each type has distinctive advantages and disadvantages for a specific application.

The fixed boresight electrically slewable antennas are of the aperiodic curtain antenna type. They may have two or more vertical-take-off beam angles, which are achieved by switching in different combinations of dipole radiators at different heights above ground. They also may have a variety of horizontal slew angles which can vary the horizontal direction of the beam of the antenna. Generally such antennas are useful for stations which require a large number of simultaneous transmissions, and from which a variety of frequency bands must be used, and from which a variety of radial transmission ranges are required.

For the stations of fewer number of simultaneous broadcasts, rotatable antennas should be considered. This is due to the near 360° slewability of the rotatable antenna. Care must be taken not to radiate in azimuths that will create a hazard to the site access or to occupied buildings on the site.

The advantage of the rotatable antenna diminishes as the required number of antennas increases because the limitation in azimuth coverage by shading of coverage sectors by other antennas and the restriction of coupling between antennas which would result in excessive intermodulation products. This condition may be avoided by placing the rotatable antennas with a large spacing between them.

It is, however, prudent to consider the use of rotatable antennas in any specific situation to determine if there is an arrangement of the required number of rotatable curtain antennas that is a cost effective solution to meeting the broadcast mission.

9.4.3 Selection of transmitter

When considering the characteristics of transmitters for selection, the most obvious are those characteristics necessary to meet the mission requirements of the broadcast schedule.

1) Acquisition cost is always an important criteria, however, life cycle cost should also be considered and is driven largely by operation and maintenance costs. A significant part of the operating cost is the energy consumption which is a result of the output power level at which the transmitter is operating and the transmitter’s efficiency at that output power level.

2) If real time monitoring of the signal reception in the target area is practical, it is likely that less than the maximum output power will be required during periods when propagation parameters are favorable. The ability to operate the transmitter at power levels below the rated maximum not only saves energy consumption but also reduces the stress to components of the transmitter, which results in reduced maintenance costs.

3) Experience has proven that the use of a controlled carrier modulation mode offers an energy saving by reducing the carrier level during time periods that the modulation is below one hundred percent. Various transmitter manufacturers call this mode of modulation by different names such as dynamic amplitude modulation (DAM), dynamic controlled carrier (DCC), controlled level carrier modulation (CCM) and by other similar names. As there is no industry standard for dynamic carrier control, each transmitter manufacturer implementation is proprietary and slightly different, while achieving approximately the desired result. For example, the attack and release time constants for carrier level control to instantaneous changes in program audio and the limits and amount of carrier change may be different.

Although controlled carrier offers a reduction of transmitter consumed energy over a period of time, instantaneous modulation peaks result in an instantaneous increase in carrier power and an instantaneous increase in input power. A low impedance power source is required, and should be capable of the dynamic peak demand. For stations that generate their own power for general usage or as emergency power, caution is advised for the use of controlled carrier modulation mode due to the transient response of the generator governor to the dynamic changes in load.

CHAPTER 10

STATION START-UP

10.1 Organization of operation

It is necessary, depending on the staff actually available at the transmission station, to define the tasks of the following groups of staff:

– fixed staff (possibly permanent staff);
– management staff: apart from everyday personnel management, the management group is responsible for:
  – national relations;
  – international relations;
  – distributing work to the operators by listing daily tasks.

10.2 Technical resources required for operational conditions of work

The provision of suitable measurement equipment is essential for the operation of a transmitting station.

Among other basic measurement equipment it is advisable to have:

– spectrum analyzer;
– audio analyzer;
– oscilloscopes;
– multimeters;
– field strength measurement equipment.
– For the maintenance of the antenna and feeder systems a mechanical workshop should be equipped with the necessary tools for the work envisaged.

10.3 Documentation

At least two copies of the relevant documentation should be kept for:

– site layout;
– buildings and constructions;
– roads;
– feeder systems;
– antenna systems;
– power systems;
– generators (if applicable);
– transmitters;

– audio equipment;
– auxillary systems.

In addition to the above mentionend documentation the following documents should be available on the station:

– Radio Regulations;
– International Frequency List;
– Great circle map related to the antennas used on the station;
– List of international monitoring stations;
– HF-broadcast schedule;
– Broadcasting schedule of the administrations using this station.

10.4 Training

In order to keep the breakdowns on the transmitting station as low as possible there should be a constant and permanent training of the staff dealing with the technical transmission equipment.

It is desirable to start the training of the staff involved in station operations and maintenance as early as possible.

Already during the buildup of transmitters and antennas own staff should be included in the process by the manufacturer.

CHAPTER 11

FREQUENCY MANAGEMENT AND COORDINATION

11.1 General considerations

– Identification of the available facilities that are suitable to provide an acceptable service.

– Identification of existing limitations of the available facilities in terms of:

1) Frequency tuning capabilities of the transmitter.
2) Frequency band limitations of the individual antennas.
3) Direction or azimut of the antennas.
4) Slewing of the antennas.
5) Possible switching matrix limitations.
6) Impossibility to use a particular combination of antennas or transmitters, e.g. 2 or more antennas having the same feeder line, one antenna would be radiating through other antennas in operation.

11.2 Selection of frequency

– On the basis of a suitable propagation model (Recommendation ITU-R PI.533) and of existing reception reports and evaluations the suitable band(s) have to be determined.

– While choosing a broadcasting band, make sure, that the receivers available in the target area facilitate the reception on these particular bands.

11.3 Assessment of the interference situation

A database that should be maintained by the frequency planner makes it possible to identify possible sources of interference and long term occupied channels that are very often used by small organisations. This database should also carry information on when a particular transmission has been installed or taken off the air.

11.4 Coordination of frequency usage

11.4.1 Summary of existing planning methods and identification of relevant ITU-R Recommendations and Resolutions

11.4.1.1 Article 17

The procedures for use of the HF bands allocated exclusively to the broadcasting service are contained in Article 17 of the Radio Regulations. These procedures have been in place since 1959 but were modified by WARC-HFBC-87.

11.4.1.2 HFBC planning system

WARC HFBC-84 adopted technical criteria and planning principles for an HFBC Planning System. Based on these guidelines, the IFRB developed a computerized planning system which was used to carry out planning exercises.

WARC HFBC-87 reviewed the results of the planning exercises and found the planning system unsatisfactory. Given the limited spectrum and the large number of requirements, a significant number of broadcasts were not provided with an acceptable reception quality. Consequently, WARC HFBC-87 adopted a revised Article 17, together with Resolution 515 (HFBC-87), containing planning principles, an Improved HFBC Planning System and a revised consultation procedure, and, by its Resolution 511 (HFBC-87) instructed the IFRB to undertake the improvements in the software of the HFBC planning system, to test the system and to submit the results to administrations and to the recommended future HFBC planning conference.

In 1991 the IFRB reported on the tests and improvements requested by the successive world administrative radio conferences and concluded that, even with additional allocations, a planning method based on all the requirements of administrations could not be developed and implemented in an economical way.

Alternative planning procedures.

The 1993 Radiocommunication Assembly approved and assigned Question ITU-R 212/10 on “Planning Procedures for HF Broadcasting” to the ITU-R Study Group 10 with a request to complete the studies by 1997, so that an alternative planning procedure might be adopted by WRC-97. This task was assigned to Task Group 10/5.

Although not utilized by the HF broadcasting service, frequency allotments could be considered as a planning method for this service. It is noted that frequency allotment plans exist for services such as the maritime mobile service (Appendix S25 of Radio Regulations), in some bands of the aeronautical mobile services (Appendices S26 and S27), space services (Appendix S30B), and certain broadcasting services.

11.5 HF bands allocated to the broadcasting service

WARC-79 allocated the additional HF bands listed in No. 531 of the Radio Regulations to the broadcasting service and, by its Resolution 8 took action for the transfer of existing fixed-service stations to other bands.

WARC-92 allocated further additional HF bands to the broadcasting service, as listed in No. S5.134 of the Radio Regulations, but limited their use to single-sideband transmissions. By its Resolution 21 (WARC-92), it took action to transfer existing fixed and mobile-service stations to other bands. The transfer is currently in progress, but the relevant bands are allocated to these services on a primary basis until 1 April 2007 under the provisions of Nos. S5.136, S5.143, S5.146 and S5.151 of the Radio Regulations.

WARC-79, in its Resolution 508, WARC HFBC-87, in its Resolution 511 (HFBC-87), and WARC-92, in its Resolution 523 (WARC-92), recommended the convening of a world radiocommunication conference for the planning of the HF bands allocated to the broadcasting service.

Resolution 20 of the Plenipotentiary Conference (Kyoto, 1994) stipulated that broadcasting in both the WARC-79 and WARC-92 bands shall not be allowed until planning is completed and the conditions stipulated in the Radio Regulations are fulfilled.

WARC HFBC-87, in its Resolution 517 (HFBC-87), provided a timetable for double sideband emissions to be replaced by single sideband emissions by the year 2015. It specified that this date should be periodically reviewed by competent future world administrative radio conferences in light of the latest available statistics on the distribution of SSB transmitters and receivers, and that at least one such review shall take place before the year 2000.

11.5.1 Decisions of WRC-95

WRC-95, in its Resolution 529 (WRC-95), resolved that the broadcasting service may use the WARC-79 bands on an interim basis from 1 January 1996, on the basis of the consultation procedure of Article 17 of the previous Radio Regulations until new procedures are adopted by WRC-97 and taking into account the provisions of No. 531 of the previous Radio Regulations. In this Resolution WRC-95 also requested ITU-R to carry out the following studies and to prepare a report for consideration by WRC-97:

– review the planning principles contained in the previous Article 17 and continue to develop the new procedure to be applied to the bands allocated to the HF broadcasting service (except in the bands to be used in the Tropical Zone), taking into acount the provisions of 1737, 1738 and 1739 of the previous Radio Regulations;

– devise means by which other primary services in the additional bands allocated by WARC-92 to the broadcasting service continue to be protected taking into account Nos. S5.136, S5.143, S5.146 and S5.151 of the Radio Regulations;

– recommend a date or dates by which other primary services in the above additional allocations will no longer be protected;

– recommend the criteria which may be used by the Bureau for carrying out a test of the recommended procedure;

– consider a flexible timetable for the introduction of SSB transmissions incorporating a progressive increase in the parts of the HF bands allocated to the broadcasting service for use by SSB transmissions, so that countries in difficult economic situations can continue using their DSB transmitters.

11.5.2 Decisions of WRC-97

WRC-97 approved new Article S12 of the Radio Regulations on “Seasonal planning of the HF bands allocated to the broadcasting service between 5 900 kHz and 26100 kHz”.

11.6 Notification to the appropriate bodies/organisations

Article 17 provides a procedure for the collection and dissemination of HFBC scheduling data. It also allows for the coordination of transmission requirements by administrations to resolve incompatibilities on a bilateral or multilateral basis prior to and after submitting their requirements to the Bureau for inclusion in the Tentative HF Broadcast Schedule.

11.7 Immediate evaluation of the success of the transmission

It is essential for an effective operation to immediately get a feedback from the transmissions being installed during a new seasonal schedule. Also coordination of the frequencies have been carried out beforehand, there are still lot of factors that can impair the success of the transmission.

The most effective way will be to assess the performance of the transmission directly in the target area.

This can mean:

– install receivers in the target area that can be operated remotely, or

– maintain a network of monitors in the target area, or

– send experts to the target area.

11.8 Practical aspects of frequency planning

– Maintain a database of all frequencies and settings of your operations in the past.

This database should be kept for at least on sunspot-cycle (11 years) and contain all relevant information such as:

  – transmitting station;
  – time of operation;
  – season;
  – antenna bearing;
  – assessment of the service;
  – possible interferences.

– Monitor the spectrum and keep track of all changes during a transmission schedule in order to be able to quickly react on changes in the interference situation;

– try to make as few frequency changes as possible in order to keep listeners with your broadcast;

– make sure when frequency changes are necessary to provide listeners with all the relevant information.

Figure 11.1 shows the basic functions that should be followed in the frequency planning process.

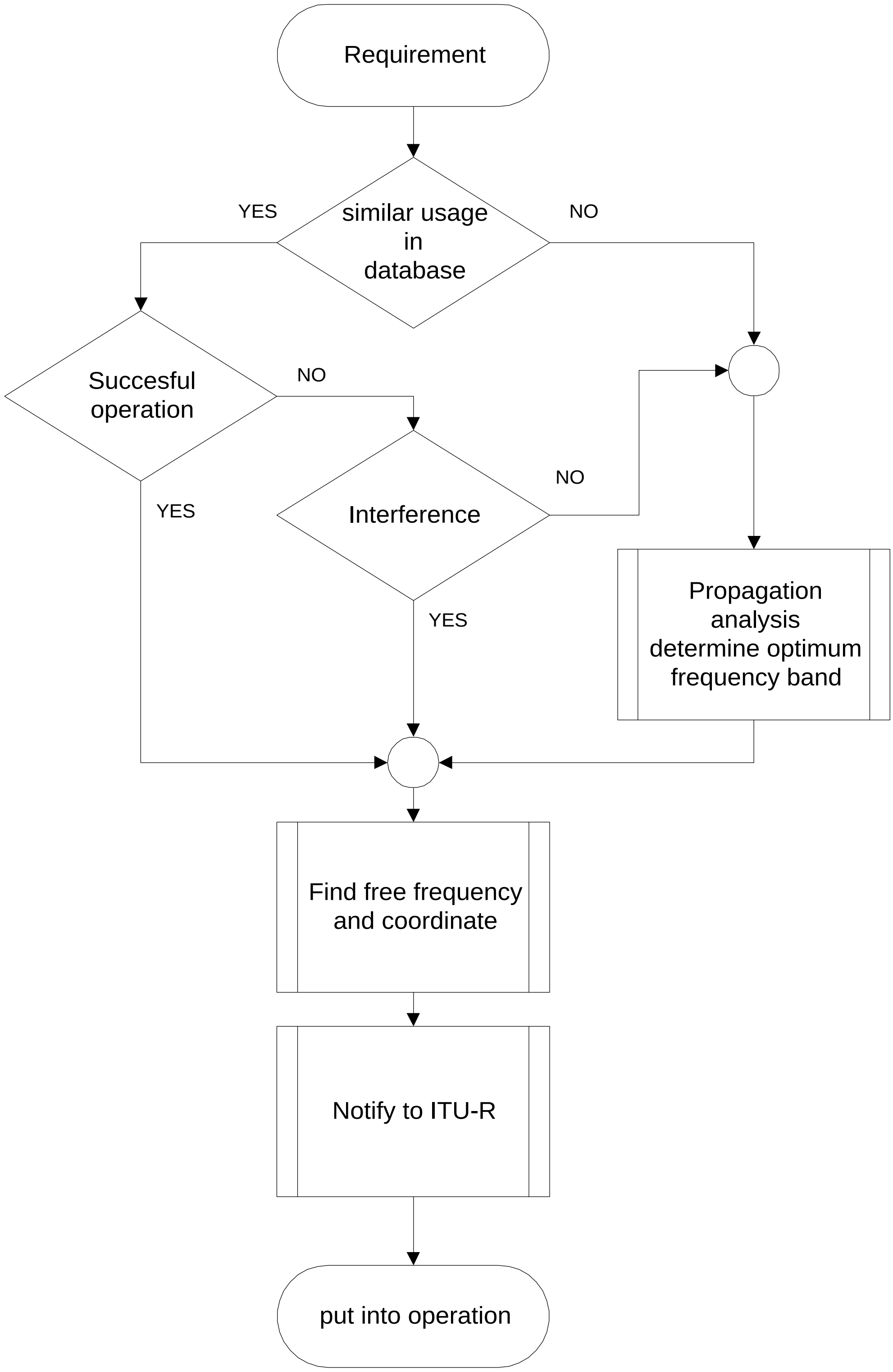


FIGURE 11.1

Flowchart showing the basic structure of frequency planning

CHAPTER 12

VERIFICATION OF OVERALL SYSTEM PERFORMANCE AND SERVICE ACHIEVED

For any broadcasting service, it is very important to determine if the required level of service is actually achieved in practice. It is pointless to transmit programmes if the intended audience can not hear them.

To determine if the required level of service is achieved in practice, the transmission will need to be assessed within the service area. There are two basic methods available to a broadcaster.

12.1 Objective method

Verifying the technical performance of the transmission is very complex. A large number of measurements of the received signal level, using calibrated equipment, at a number of locations throughout the required service area, over a large number of days is required. These measurements will then need to be analysed to determine the technical performance of the received service.

In practice, it is virtually impossible to make such measurements particularly at sufficient locations within the required service area. At best, field strength measurements are only likely to available from very few locations world-wide. Such measurements, if collected on most days over a month, can only be compared to the predicted field strength at the specific location.

12.2 Subjective method

As a full technical examination is very difficult to achieve, a less rigorous method is often used to determine if the transmission can be heard.

This requires a number of listeners to send in regular assessments of audibility of the transmission. These assessments can then be analysed to indicate the performance of the transmission.

Ideally, the reports should be from a number of locations scattered throughout the required service area. If this is not possible, at least a few reports from the area of primary interest will be required.

As propagation conditions change on an hour-to-hour, day-to-day and month-to-month basis, an assessment of the transmission should be made at least every hour and if possible every day. This may not be practical so fewer reports from a wide range of individual listeners will be needed to provide sufficient reports to properly assess a transmission.

CHAPTER 13

PREVENTIVE MAINTENANCE

13.1 Maintenance of transmitter

13.1.1 Introduction

The operating costs of a high-power transmitter are considerable. To this contribute energy costs and maintenance costs. Reliable transmitters with only a limited number of moving parts need less maintenance. With well trained staff repairment time can be short.

Modern transmitters show mean time between failures (MTBF) of more than 500 h. The mean time to repair (MTTR) can be less than 30 min. Automated transmitters need maintenance personnel with higher skill. The maintenance work can be facilitated by transmitter design which incorporate:

– modularity;
– trouble shoot indications;
– measuring points and alarms;
– built-in test equipment;
– good accessibility, lighting.

13.1.2 Physical maintenance

In order to guarantee trouble-free operation, systematical preventive and corrective maintenance of a transmitter is needed. This involves the proper maintenance of both mechanical and electrical parts. Especially under severe climatic conditions, such as high humidity, high ambient temperatures, aggressive atmosphere, dusty and dirty air, insects, etc. preventive maintenance can increase the MTBF considerably. The high voltage in the transmitters can cause flashovers where foreign material and dust is present. These do not necessarily cause tripping of the transmitter but traces which they leave (carbon soot, metal beads, metallized vapour) increase the likelihood of further flashovers which finally lead to an operational failure of the transmitter.

Regular cleaning of the complete installation is therefore of vital importance. Keeping track of all information concerning maintenance and usage of the transmitter in a log-book will facilitate the maintenance task.

A good maintenance working scheme involves (among other things):

– **Daily maintenance**: keeping track of modulation depth using an oscilloscope, all metre settings and water marks before and after operating the transmitter and on top of every hour, is essential.
– **Weekly maintenance**: removal of dust and other foreign material is important; checking for tracks left by arc discharges; contact positions and electrical connecting points must be given special attention and action should be taken when needed.
– **Monthly maintenance**: checking of oil levels of transformers, chokes, checking of filters.

Before commencing any maintenance job, the following must be observed carefully:

– the transmitter must be switched off and the earthing switch closed;
– both the primary switch to the auxiliary transformer and the anode breaker must be switched off;
– all maintenance personnel must be instructed as to devices powered by high voltage.

13.1.3 Operability

Short-wave transmitters may operate on five to fifteen separate frequencies every day. Broadcasting schedules of many of the broadcasting organizations are very tight, thus necessitating built-in automatic frequency changing circuitry which allows the transmitter to tune to several programmed frequencies in approximately 10 to 30 s, with minimum or no operator intervention.

The trend in short-wave transmitter operation is toward unattended or minimum attended sites, with programme and frequency changes done by remote and/or computer control. This clearly offers savings on staffing, thus reducing the overhead costs.

Automated operation asks for transmitter designs in which the need for operator intervention is minimized. Control units collect the data for controlling, monitoring and insuring frequency, power, modulation mode, internal security of the transmitter, etc. They are based on a computer central unit surrounded with several interface boards to shape data exchanged with the transmitter, the operator or a remote control system through a computer interface such as RS 232 or IEEE 488. In an automated system, auto-tuning is needed and the possibility to store frequencies in the transmitter control circuit improves reliability.

A further step in reduction of operational costs is unattended or minimum attended sites, with programme and frequency changes done by remote and/or computer control. Such a control system includes:

– transmitters status control (on/off, stand-by or actual transmitted frequency);
– RF output control (using demodulated audio);
– antenna selection and antenna slewing;
– surveillance monitoring (comparing actual state with the operational schedule);
– programmed action to continue service in case of equipment failures.

Unattended, automated operation requires redundancy in the transmitting facilities (hot stand-by reserve transmitters, antennas and computer control). High reliability is reached by transmitter configurations using passive reserve, active reserve or (n + 1) reserve.

13.1.4 Safety

To ensure the safety of all personnel often a combination of mechanical and electrical interlocks is used. Attention should be paid to acoustic noise levels, system grounding, ionizing and non-ionizing radiation and toxic substances.

Systematic training and instruction of all personnel having access to transmitter rooms, HV rooms, etc. is vital in order to ensure maximum personnel safety. Many modern transmitters comply to IEC 215-1 Recommendations

13.2 Maintenance of antenna system

13.2.1 General

The maintenance of antennas is an essential element of reliable broadcasting and communications. Maintenance is the routine work performed which allows the antenna to be utilized effectively. This handbook provides the information necessary to establish a viable antenna maintenance programme which includes:

1) Establishment of standard practices and procedures for the upkeep of the electronic and structural performance of each radiator.

2) Establishment of continuous maintenance and repair procedures.

3) Continuing evaluation of the electronic performance of each antenna.

4) Routine inspection and survey of all antennas to determine structural condition.

Maintenance, therefore, is a programme of prevention to help ensure that it is unlikely or impossible for an antenna to fail or deteriorate.

13.2.1.1 Maintenance scheduling

A maintenance programme, no matter how well planned, is of no value unless the work is actually performed. To insure that the programme is carried out, there must be a reasonable, realistic schedule that will enable preventive maintenance to be accomplished. It should allow time for corrective as well as emergency maintenance which may be required from time to time.

Maintenance scheduling must take into account the broadcasting schedule, the number and type of antennas, the number of maintenance personnel available, and the number and types of vehicles available to the maintenance crews. The mission of the station must be considered, since this may dictate which antennas are most critical. Weather and climate conditions are also factors to consider in scheduling maintenance. Maintenance does not cease during periods of inclement weather. Emergency corrective maintenance may have to be done regardless of weather conditions. Always conduct a visual inspection of the antenna field after severe storms or high winds. Specifically look for broken wires and insulators, loosened guys, anchors, foundations, and pedestals.

13.2.1.2 Inspection

Maintenance requirements and needs will vary with the type of antenna being serviced and with the climate and location of the antenna site. A visual inspection of the antenna structure on a regular basis (every six months) will prevent small problems from becoming large ones. Corrective action can be taken before the structure fails.

13.2.2 Maintenance of antenna

13.2.2.1 Curtain antennas

Maintenance of curtain antennas consists of periodic inspection and cleaning. The radiating curtain should be inspected for proper sag. Where counterweights are used, their suspension cables should be checked for worn and frayed spots. The pulleys should be checked to see that they turn freely and are lubricated with a light oil. If a hand winch and cable assembly are used to hold the curtain in tension, they should be checked and the winch oiled periodically. Antenna wires, wire connections and hardware, feed and maintenance systems, and RF or other structural elements should be inspected for deterioration and deficiencies. Utilize infrared thermography to verify loose or hot connections.

The sag in the radiating curtains between towers is important; if too small, it does not allow for contraction during extremely cold weather nor for the accumulation of radial ice on the conductors. If too loose, it will cause the radiating wire to swing in the wind putting excessive strain on the supporting structure.

For radiator curtains and reflector screens, check that the sag for horizontal conductors between supports is less than .005 times the design wavelengths, 171 mm for low-band antennas. The best means of controlling sag is through the use of counterweights, or hand winches.

13.2.2.2 Monopole antennas

Maintenance of monopole antennas consists of periodic inspections. On the lower frequency, larger antennas, binoculars should be used to facilitate inspections. Look for loose RF or other structural elements or guys, broken or dirty insulators, loose or broken connections, and obvious improper tensioning of guy lines or support elements. Utilize Infrared thermography to verify loose or hot connections. Check for rust and corrosion and inspect ground screen for loose or broken leads.

13.2.2.3 Log periodic antennas

13.2.2.3.1 Fixed vertical log periodic antennas

Maintenance of fixed vertical log periodic antennas (Figure 13.1) consists of periodic inspection, cleaning and tightening. Binoculars should be used to facilitate inspection. Look for loose RF or other structural, broken, or corroded elements, dirty and broken insulators, loose clamps, clips, or turnbuckles, and obvious improper tensioning of catenaries or guy lines. Utilize infrared thermography to verify loose or hot connections.

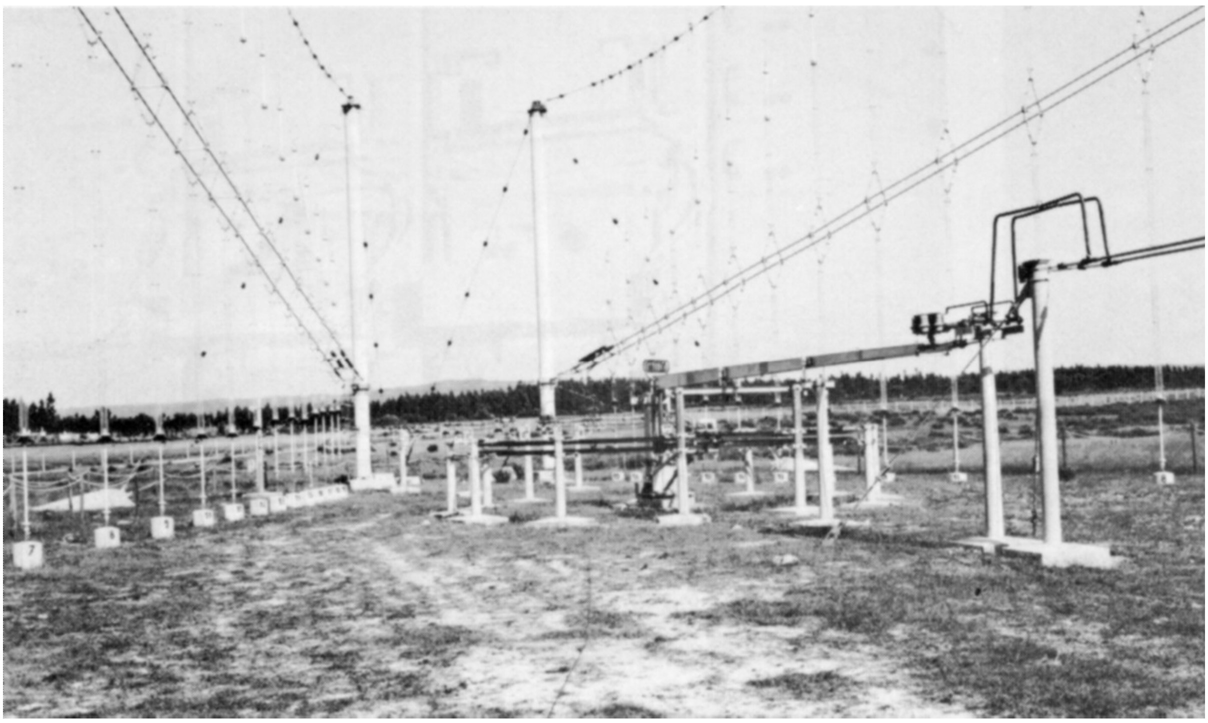


FIGURE 13.1

Maintenance of fixed vertical log periodic antennas: typical structure

If the antenna tower is equipped with a tower lighting system, it must be checked for proper operation and replacement of bulbs and lenses. The tension of the guy lines, catenaries, and radiating elements must be checked and adjusted as necessary. The tower itself must be inspected for rust, loose bolts, and for loose or missing hardware.

On the transmitting antennas the balun should be checked periodically for oil leaks. Fibreglass rods must be checked, cleaned, and preserved. An electrical check on the performance of the antenna, transmission line, and balun should be made on an annual basis.

13.2.2.3.2 Fixed horizontal log periodic antennas

Maintenance of fixed horizontal log periodic antennas (Figure 13.2) consists of periodic inspection, cleaning and tightening. Binoculars should be used to facilitate inspection. Look for loose RF or other structural, broken, or corroded elements, dirty or broken insulators and radiators, loose clamps, clips or turnbuckles, and obvious improper tensioning of catenaries or guy lines. Check the feeding for poor or loose connections. Utilize infrared thermography to verify loose or hot connections.

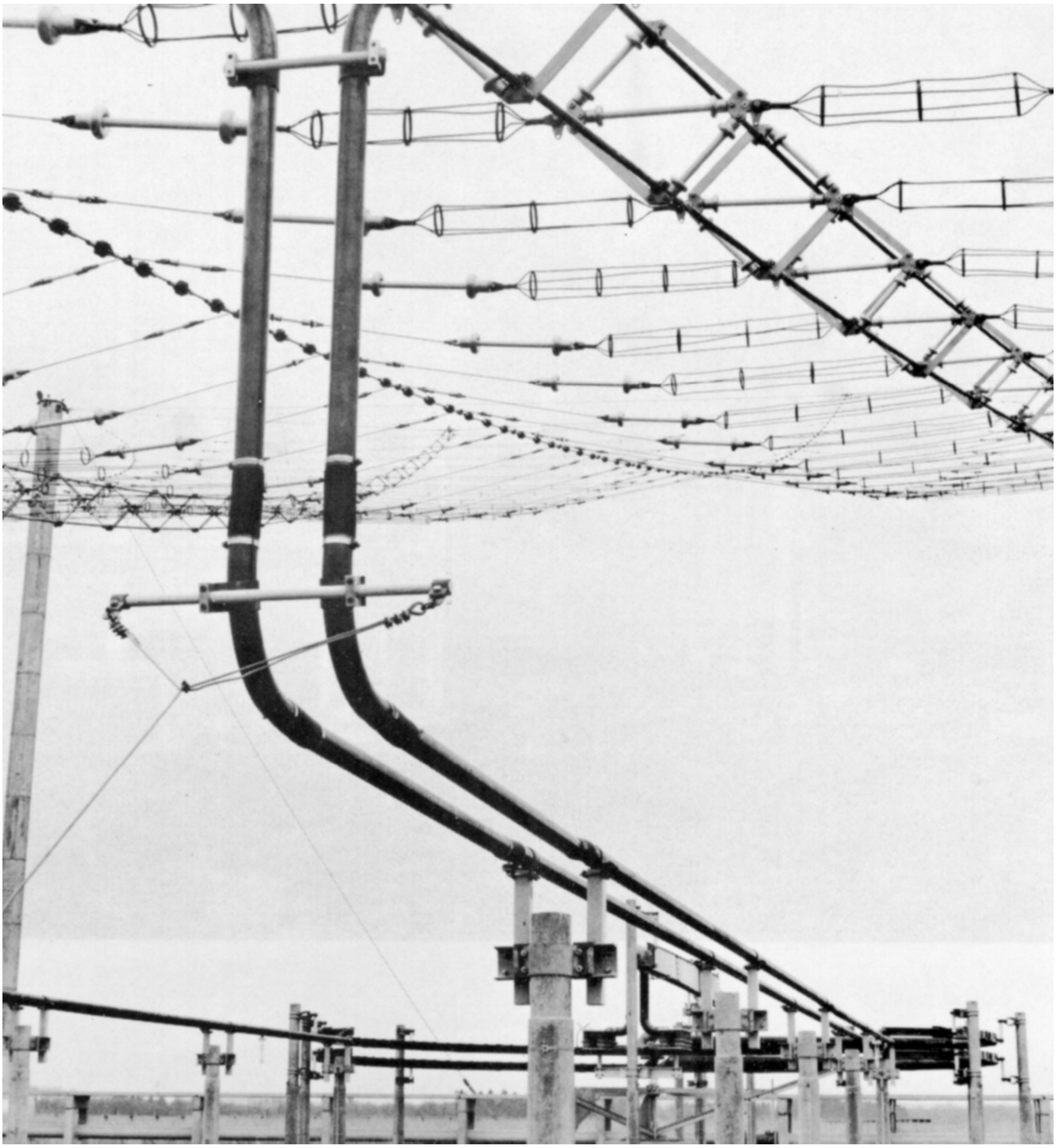


FIGURE 13.2

Maintenance of fixed horizontal vertical log periodic antennas: typical structure

If the antenna tower is equipped with a tower lighting system, it must be checked for proper operation and replacement of bulbs and lenses. The tension of the guy lines, catenaries, and radiating elements must be checked and adjusted as necessary. The tower itself must be inspected for loose bolts, and for loose or missing hardware.

On the transmitting antennas the balun should be checked periodically for oil leaks. Fibreglass rods of the catenaries and drops must be checked, cleaned, and preserved. An electrical check on the performance of the antenna, transmission line, and balun should be made on an annual basis.

13.2.2.3.3 Rotatable log periodic antennas

Maintenance of rotatable log periodic antennas consists of periodic inspection and cleaning. Binoculars should be used to make inspection easier. Look for loose RF or other structural, broken or corroded elements, dirty or broken insulators, obvious improper tensioning of guy lines and to check for tightness of hardware and for rust and corrosion. Utilize infrared thermography to verify loose or hot connections. Because of its rotating mechanism, the requirements for preventive maintenance are more stringent than on that of a fixed structure. The rotator mechanisms must be checked periodically for proper lubrication and the rotator fly wheel, sprockets, and chain must be checked for tightness. The gear box lubricant must be changed at regular intervals. The rotating co-axial joint is a potential source of trouble and must be inspected periodically. The fibreglass insulators in the elements or supporting the elements deteriorate excessively in some climates and must be cleaned and preserved at regular intervals.

To perform this maintenance properly, it is sometimes necessary to lower the antenna. This should be done only by experienced antenna mechanics or riggers using the proper equipment. To facilitate the lowering of the structure, it is suggested that the winch point and the position of the supports required when the antenna is on the ground be permanently marked. Furthermore, it is suggested that the antenna be modified to allow a quick disconnect of the AC power and the remote rotator cable.

Since many of the potential sources of trouble in this antenna cannot readily be inspected, an electrical check on the antenna and the transmission line should be made a minimum of every six months.

13.2.2.4 Rhombic antennas

Maintenance of the rhombic antenna consists of periodic inspection and cleaning. Insulators must be inspected for cracks, pits, RF or other structural damage and must be cleaned periodically. Poles should be inspected for dryrot, cracks, etc., and metal towers inspected for rust and corrosion. Inspect the terminating resistor or dissipation line for proper connection and obvious damage. Verify that lightning protection wires on poles are intact and spark gaps properly spaced. Inspect the terminating line for loose connections or a loose or broken wire. Utilize infrared thermography to verify loose or hot connections. If a matching transformer is used with co-axial line, it should be inspected and the desiccant replaced if it has turned pink. The transmitting antenna balun, if used, should be inspected for oil leaks.

13.2.3 Maintenance of antenna field

13.2.3.1 Grounds maintenance

The condition of the area in and around and under the antenna can have an adverse effect on the electrical performance of the antenna itself. Control of vegetation growth within the ground screen and immediate area is essential to proper antenna performance, and should be limited to a height of six inches. This will permit easy access to the antenna tower and guy system, and will reduce the possibility of damage by fire. At locations where it may be necessary to stabilize the soil and prevent wind or water erosion, vegetation should not be permitted to grow beyond six inches in height.

13.2.3.2 Ground system

Virtually vertically polarized antennas depend somewhat on the ground screens surrounding them for proper performance. This ground screen generally consists of a number of wires extending radially outward from the base of the antenna. Since most soils are relatively poor conductors, it is necessary to provide wires or a wire grid over the surface of the soil extending out to a distance approximately equal to the antenna height.

Maintenance of the tower ground screen (minimum annually) located at the base of each antenna tower consists of periodic inspection. Ground screens should be inspected for deformations, looseness, breaks, and other deficiencies. Ground screen connections, splices, welds, should be inspected for defects, breaks, and looseness and repairs made immediately.

13.2.3.3 Fire breaks and fuel breaks

Proper vegetation control within the antenna field is also essential for effective fire prevention and control. This is particularly important in many areas of the world where extended periods without appreciable rainfall are usual and where heavy brush and other woody vegetation normally exist. Fire control in these areas includes the use of vegetation control so as to provide FUEL BREAKS. A fuel break is a relatively wide strip of land on which native vegetation has been permanently modified so that fires burning into it may be readily controlled. The vegetation allowed to grow within the fuel break strip is generally a low-growing ground cover to protect soil against erosion and yet offers a light fuel volume so that if it burns the heat output will be low.

A FIRE BREAK is an interior strip or access roadbed kept clean to mineral soil or surfaced road which stops the spread of fire and permits ready access to the area.

13.2.4 Maintenance of tower systems

Maintenance of the tower subsystem consists of periodic inspection and cleaning. Towers should be inspected for safety hazards, structural deflections and deformations, looseness, missing items, twist, and other deficiencies. Tower members, including ladders, work platforms, and maintenance catenaries, should be checked for corrosion, lamination deficiencies, cracking, and other damage. Tower connections, splices, welds, bolts, nuts and rivets should be inspected for defects and looseness. Base insulators, jumper cables and associated fittings should be checked for cracks, flaws and other damage. Foundations should be inspected for cracks, excessive ponding of water and other damage.

Guyed towers should be inspected for plumb, verticality, straightness, and other dimensional deviations. Look for loose, broken, or corroded elements, loose clamps, clips or turnbuckles, and obvious improper tensioning of guy lines.

Tower counterweight systems should be inspected to insure counterweights do not bind and that they move freely.

13.2.4.1 Maintenance of guy systems

Maintenance of guy subsystems consists of periodic inspection (minimum annually) and cleaning. Tower guy wires should be inspected using binoculars or a telescope with special emphasis given to insulator connections. Guy wire connections on the tower and at anchorage locations should be inspected for corrosion, deterioration, looseness, improper installation, damage, deficiencies and other defects. Tower guy grounding, guy anchors, hairpins, vibration dampers, and pull-off plates should also be inspected for corrosion, deterioration, looseness, improper installation, damage deficiencies and other defects.

Guys which appear slack should first be carefully inspected to determine the cause of loosening. The area around the anchors should be inspected for earth heaving. The anchors should be examined for rust. Fibreglass guys should be inspected at the point where the rod enters the socket. Examine wire rope guys for broken strands or insulators.

Slackened or loose guys should always be retensioned to original design specifications.

Mylar or polyester rope guys are generally unsatisfactory. They tend to flake and are difficult to keep in tension. They should be replaced with fibreglass rods.

13.2.4.2 Painting

Tower painting should be inspected for any peeling, chipping or flaking paint. Particular attention should be given to adequate paint coverage, and if the tower paint system conforms to the requirements of the local aviation administration.

13.2.5 Maintenance of transmission lines

For the purposes of this handbook and maintenance, the transmission line feeding the antenna from the antenna switching matrix is considered part of the antenna, and its maintenance is the responsibility of the antenna maintenance staff. While most of the older antennas have open wire transmission lines, in new installations, the antennas are fed by co-axial lines. This is usually a 9 inch, air dielectric heliax line. Co-axial lines are trouble free, provided they are pressurized with nitrogen or a "dry air" compressor to prevent moisture from entering the line.

13.2.5.1 Open wire transmission line

Where copperweld wire is used on unbalanced open-wire line, the constant vibration of the line will cause the copper to wear away where the wire passes through the "candlestick" insulator. When this happens, the steel portion of the line will be exposed to rust. To prevent breakage, a close inspection is necessary, and the wire should be replaced if it shows excessive wear at the insulator points. Any open wire line should be inspected for burned, dirty, or cracked spreaders and insulators, as well as corona and pitting, and transmission discontinuities. Discontinuities can be checked using Time Domain Reflectrometry (TDR). They should be cleaned or replaces as necessary. Check for corrosion and rust on clamps, and for excessive wire sag and separation between wires.

13.2.5.2 Air dielectric heliax transmission line

The air dielectric heliax transmission line is an airtight and moisture-proof transmission line, and requires only that proper dry air pressure be maintained.

Antenna maintenance personnel should make a complete weekly check of pressurization as follows.

1) At the transmission line dry air manifold, turn on the compressor and pump the lines to about 10 pounds per square inch. Observe the gauges and record the pressure on each line.
2) Shut off the dry air feed to the lines.
3) After 24 hours, observe gauges and record their value. Pressure should be maintained between 5 and 10 pounds per square inch. If not within this range, the line or lines should be investigated for leaks.
4) Open the dry air valve to maintain automatic pressure. Unless physically damaged, a leak in the transmission line is usually associated with a splice. The antenna maintenance crew should maintain a list indicating which transmission lines have splices, the number of splices in each line, and their location from the antenna. Splices should be physically marked with a marker post of some type.

When transmission line trouble is suspected, a fault finder (time domain reflectometer (TDR)) should be used to determine the location of the fault. The TDR will indicate the fault and its distance from the antenna.

If the transmission line is above ground, it will be a simple matter to visually locate the fault. If the cable is buried, it will be necessary to refer to cable location drawings to determine the location of the cable and the approximate area of the fault. Then use a cable fault locator to determine the exact location of the fault.

13.2.5.3 Solid dielectric "RG" transmission line

Solid dielectric "RG" type co-axial cable requires no pressurization and because no high voltages are present, it is usually trouble free unless physically damaged. Again, a record should be kept of all splices and their locations should a fault occur.

13.2.6 Maintenance of wooden poles

Wooden poles should be visually examined semi-annually for splits, dry rot, decay at the base, and termites. Pole caps should be inspected to ensure they are secure.

If poles are set in metal sockets, pentachlorophenol should be applied annually to that portion of the base in the socket to prevent decay. Mounting of poles on concrete pads is the most effective way of preventing decay.

Every two years, a core sampling should be taken from a random selection of poles to determine if pole rot or termites are present. A hole should be bored into the centre of the pole one metre above the ground line. If a hollow heart condition or insect galleries are found, one to three pints of B wood preservative (pentachlorophenol in a petroleum solvent) should be pumped into the hole by using the nozzle of a sprayer or stirrup pump. Bore holes should be plugged with treated or heartwood plugs.

Care should be taken in retensioning wooden poles. It is possible to over tension after they are set, causing them to twist. A slack guy may not necessarily need tightening. Check the plumb first.

13.2.7 Safety

The subject of safety cannot be overemphasized. The business of maintaining large antenna systems is so hazardous that specific safety precautions must be observed. Although dangerous, the work must be done, and this section discusses the potential hazards and describes procedures and devices to minimize the risk.

13.2.7.1 Preliminary

Each time maintenance is performed on an antenna, the following steps must be taken:

– Arrange with the Watch Supervisor in writing, to take the antenna out of service.

– If antenna multicouplers are installed, it will be necessary to disconnect the antenna at the multicoupler and tag it "Out of Service".

– On unbalanced systems, at the antenna connect a grounding strap or wire from the antenna feed point or center conductor of the transmission line to the ground mat.

13.2.7.2 Climbing

The most dangerous part of antenna maintenance is the climbing of the structure and working aloft. While this should be done only by experienced riggers, before climbing, observe the following precautions:

– **Don't climb alone** - At least two qualified riggers must be present even if only one is required to go aloft.

– **Don't climb wet steel** - If weather conditions threaten rain, snow, or fog, postpone the climb.

– **Wear safety belt, hard hat, and safety shoes**.

– Insure the rescue harness is in maintenance vehicle and available at the climbing site.

– Test the two-way radio, sound power phone, bullhorn, or other communications devices.

– Don't rely on safety devices without first checking the belts and any block and tackle or tools that are to be used aloft.

– Check the antenna structure itself and the guy wires to insure they are safe before beginning to work aloft.

– Before placing weight on pole steps or ladder rungs, inspect them for corrosion.

– Insure that a first-aid kit is in the maintenance vehicle.

13.2.7.3 Grounds maintenance

Safety precautions are frequently overlooked in the process of clearing vegetation from antenna fields. It is important the personnel wear adequate personal protection apparel, such as gloves and boots, when cutting heavy vegetation by either machine or machete. If herbicides are being applied in the area, goggles and respirators should be worn. Personnel should also be qualified in the application of herbicides, and the herbicides themselves must be approved for use. Special emphasis should be given where poisonous plants, reptiles, or biting insects are concerned. Safety also means keeping stray animals and children away from antennas.

CHAPTER 14

CONCLUSION

Although HF-broadcasting is undergoing a drastic change in terms of actual usage and attractivity, this part of the broadcasting spectrum will always being used by international and national broadcasters. The unique propagation behaviour that is typical to the HF-bands will always be attractive for the coverage of remote target areas from terrestrial transmitting stations.

The development of digital techniques will probably change the HF-world very soon.

Then the poor quality of HF-broadcasting will certainly be enhanced and consequently increase the demand and attractivity of short-wave.

The basic technics however will remain the same so that this hand-book will also be valid in the future.

CHAPTER 15

ANNEX

TABLE 15-1

Table of stations

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
1	AFG	KABUL	35	N	0	69	E	0
2	AFS	BLOEMFONTEIN	29	S	13	26	E	13
3	AFS	MEYERTON	26	S	35	28	E	8
4	AFS	PRETORIA	26	S	10	28	E	4
5	AGL	BENGUELA	12	S	35	13	E	25
6	AGL	CABINDA	5	S	32	12	E	11
7	AGL	CARMONA	7	S	35	15	E	4
8	AGL	DUNDO	7	S	24	20	E	47
9	AGL	HUAMBO	12	S	47	15	E	45
10	AGL	KWANZA SUL	11	S	12	13	E	50
11	AGL	LOBITO	12	S	18	13	E	36
12	AGL	LUANDA	8	S	53	13	E	20
13	AGL	MALANGE	9	S	30	16	E	25
14	AGL	MOCAMEDES	15	S	11	12	E	5
15	AGL	MOXICO	11	S	51	19	E	56
16	AGL	N.LISBOA	12	S	45	15	E	49
17	AGL	N.REDONDO	11	S	7	13	E	54
18	AGL	SA DA BANDEIRA	14	S	58	13	E	34
19	AGL	SILVA PORTO	12	S	24	16	E	56
20	ALB	KRUJA	41	N	36	19	E	37
21	ALB	LUSHNJA	40	N	57	19	E	40
22	ALG	ALGER	36	N	42	3	E	11
23	ALG	BOUCHAOUI	36	N	44	2	E	56
24	ALG	OULED FAYET	36	N	43	2	E	57
25	ALS	ANCHOR POINT	59	N	45	151	W	44
26	AOE	EL AAIUN	27	N	10	13	W	12
27	ARG	GRAL PACHECO	34	S	36	58	W	22
28	ARG	HURLINGHAM	34	S	35	58	W	39
29	ARG	LOMAS MIRADOR	34	S	40	58	W	38
30	ARG	MALARGUE	35	S	30	69	W	35
31	ARG	MENDOZA	32	S	53	68	W	52
32	ARG	S.FERNANDO	34	S	27	58	W	34
33	ARS	DIRIYYA	24	N	39	46	E	37
34	ARS	JEDDAH	21	N	32	39	E	10
35	ARS	RIYADH	24	N	30	46	E	23

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
36	ASC	ASCENSION	7	S	54	14	W	23
37	ATG	ANTIGUA	17	N	6	61	W	48
38	ATN	BONAIRE RNW	12	N	13	68	W	19
39	ATN	BONAIRE TWR	12	N	6	68	W	17
40	ATN	WILLEMSTAD	12	N	8	68	W	55
41	AUS	BRANDON	19	S	31	147	E	20
42	AUS	BRISBANE	27	S	19	153	E	1
43	AUS	CARNARVON	24	S	54	113	E	43
44	AUS	DARWIN	12	S	25	130	E	37
45	AUS	LYNDHURST	38	S	3	145	E	16
46	AUS	MELBOURNE	37	S	48	144	E	58
47	AUS	PERTH	31	S	51	115	E	49
48	AUS	SHEPPARTON	36	S	20	145	E	25
49	AUS	SYDNEY	33	S	57	150	E	54
50	AUT	INNSBRUCK	47	N	15	11	E	27
51	AUT	WIEN	48	N	0	16	E	28
52	B	APARECIDA	23	S	0	45	W	0
53	B	BELEM	1	S	27	48	W	31
54	B	BELO HORIZONTE	19	S	55	43	W	56
55	B	BRASILIA	16	S	0	47	W	0
56	B	CACHOEIRA PAUL	22	S	40	45	W	1
57	B	CURITIBA	25	S	23	49	W	10
58	B	FLORIANOPOLIS	27	S	35	48	W	31
59	B	FORTALEZA	3	S	44	38	W	32
60	B	FOZ DO IGUACU	25	S	34	54	W	33
61	B	GOIANIA	16	S	40	49	W	17
62	B	MANAUS	3	S	4	60	W	0
63	B	PELOTAS	31	S	46	52	W	20
64	B	POCOS CALDAS	21	S	47	46	W	35
65	B	PT.ALEGRE	30	S	3	51	W	9
66	B	RECIFE	8	S	4	34	W	53
67	B	RIBEIRAO PRETO	21	S	10	47	W	44
68	B	RIO DE JANEIRO	22	S	57	43	W	13
69	B	S.GONCALO	22	S	8	43	W	3
70	B	S.JOSE CAMPOS	23	S	11	45	W	54
71	B	S.LUIZ	2	S	31	44	W	16
72	B	S.PAULO	23	S	38	46	W	37
73	B	S.VICENTE	23	S	58	46	W	22
74	B	SALVADOR	12	S	58	38	W	31
75	BDI	GITEGA	3	S	29	29	E	56
76	BEL	WAVRE	50	N	44	4	E	34
77	BEN	COTONOU	6	N	21	2	E	25
78	BEN	PARAKOU	9	N	20	2	E	38

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
79	BFA	BOBO DIOULASSO	11	N	10	4	W	17
80	BFA	OUAGADOUGOU	12	N	22	1	W	31
81	BGD	DHAKA	23	N	43	90	E	26
82	BLR	BREST	52	N	20	23	E	35
83	BLR	MINSK	53	N	53	27	E	31
84	BLR	ORCHA	54	N	31	30	E	27
85	BLZ	BELIZE	17	N	29	88	W	13
86	BOL	ANIMAS	20	S	53	66	W	17
87	BOL	COCHABAMBA	17	S	20	66	W	20
88	BOL	HUANUNI	18	S	47	66	W	48
89	BOL	LA PAZ	16	S	20	68	W	7
90	BOL	LLALLAGUA	18	S	37	67	W	34
91	BOL	ORURO	17	S	55	67	W	19
92	BOL	POTOSI	19	S	30	65	W	50
93	BOL	S.CRUZ	17	S	46	63	W	11
94	BOL	SUCRE	19	S	2	65	W	17
95	BOL	TARIJA	21	S	32	64	W	45
96	BOT	SEBELE	24	S	34	25	E	58
97	BRM	YANGON	16	N	52	96	E	10
98	BRU	BERAKAS	4	N	57	114	E	56
99	BUL	SOFIA	42	N	40	23	E	20
100	CAF	BANGUI	4	N	21	18	E	35
101	CAN	CALGARY	50	N	54	114	W	3
102	CAN	HALIFAX	44	N	41	63	W	40
103	CAN	MONTREAL	45	N	49	73	W	18
104	CAN	S.JOHNS	47	N	34	52	W	48
105	CAN	SACKVILLE	45	N	53	64	W	19
106	CAN	SYDNEY	46	N	11	60	W	11
107	CAN	TORONTO	43	N	30	79	W	38
108	CAN	VANCOUVER	49	N	11	123	W	4
109	CBG	PHNOM PENH	11	N	34	104	E	51
110	CHL	ANTOFAGASTA	23	S	25	70	W	24
111	CHL	ARICA	18	S	30	70	W	18
112	CHL	CALAMA	22	S	30	68	W	55
113	CHL	CHILE CHICO	46	S	33	71	W	42
114	CHL	CHUQUICAMATA	22	S	18	68	W	56
115	CHL	CONCEPCION	37	S	3	73	W	10
116	CHL	COPIAPO	27	S	20	70	W	21
117	CHL	COYHAIQUE	45	S	24	72	W	43
118	CHL	COYHAIQUE 2	45	S	30	72	W	6
119	CHL	PT.AYSEN	45	S	22	72	W	41
120	CHL	PT.MONTT	41	S	30	72	W	50
121	CHL	SANTIAGO	33	S	27	70	W	41

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
122	CHL	TALCA	35	S	26	71	W	40
123	CHL	TEMUCO	38	S	41	72	W	35
124	CHL	VALPARAISO	33	S	1	71	W	38
125	CHN	BAODING	38	N	39	115	E	44
126	CHN	BAOJI	34	N	30	107	E	10
127	CHN	BAYENHAOTE	38	N	58	105	E	35
128	CHN	BEIJING	39	N	57	116	E	27
129	CHN	CHANGCHUN	43	N	48	125	E	24
130	CHN	CHENGDE	40	N	58	117	E	35
131	CHN	CHENGDU	30	N	42	104	E	0
132	CHN	FUZHOU FJ	26	N	6	119	E	24
133	CHN	GUIYANG	26	N	25	106	E	36
134	CHN	HAILAR	49	N	2	119	E	45
135	CHN	HARBIN	45	N	49	126	E	52
136	CHN	HEZUO	35	N	6	102	E	54
137	CHN	HUHHOT	41	N	12	111	E	30
138	CHN	HWALIEN	24	N	0	121	E	38
139	CHN	JINHUA	28	N	7	119	E	39
140	CHN	KUNMING	25	N	10	102	E	50
141	CHN	LANZHOU	36	N	2	103	E	50
142	CHN	LHASA	29	N	30	90	E	59
143	CHN	LINGSHI	36	N	52	111	E	40
144	CHN	NANCHANG	28	N	38	115	E	56
145	CHN	NANJING	32	N	2	118	E	44
146	CHN	NANNING	22	N	47	108	E	11
147	CHN	QIQIHAR	47	N	2	124	E	3
148	CHN	SHANGHAI	31	N	15	121	E	29
149	CHN	SHIJIAZHUANG	38	N	4	114	E	28
150	CHN	TIAN SHUI	34	N	33	105	E	42
151	CHN	URUMQI	43	N	35	87	E	30
152	CHN	WUHAN	30	N	36	114	E	20
153	CHN	XIAN	34	N	12	108	E	54
154	CHN	XICHANG	27	N	49	102	E	14
155	CHN	XINING	36	N	38	101	E	36
156	CHN	YINCHUAN	38	N	30	106	E	12
157	CKH	RAROTONGA	21	S	11	159	W	48
158	CLM	BOGOTA	4	N	36	74	W	4
159	CLM	CALI	3	N	27	76	W	31
160	CLM	EL ROSAL	4	N	51	74	W	12
161	CLM	ESPINAL	4	N	9	74	W	54
162	CLM	FLORENCIA	1	N	36	75	W	26
163	CLM	IBAGUE	4	N	24	75	W	15
164	CLM	MEDELLIN	6	N	15	75	W	45

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
165	CLM	NEIVA	3	N	1	75	W	19
166	CLM	PASTO	1	N	14	77	W	17
167	CLM	PEREIRA	4	N	49	75	W	43
168	CLM	POPAYAN	2	N	23	76	W	47
169	CLM	SUTATENZA	5	N	2	72	W	27
170	CLM	TUMACO	1	N	48	78	W	46
171	CLM	TUNJA	5	N	32	73	W	22
172	CLM	TURBO	8	N	5	76	W	46
173	CLM	VILLAVICENCIO	4	N	9	73	W	28
174	CLN	COLOMBO	7	N	6	79	E	54
175	CLN	EKALA	7	N	6	79	E	54
176	CLN	PERKARA	8	N	44	81	E	10
177	CME	BAFOUSSAM	5	N	28	10	E	24
178	CME	BERTOUA	4	N	34	13	E	43
179	CME	BUEA	4	N	9	9	E	14
180	CME	DOUALA	4	N	4	9	E	41
181	CME	GAROUA	9	N	18	13	E	25
182	CME	YAOUNDE	3	N	51	11	E	32
183	CNR	LAS MESAS	28	N	28	16	W	15
184	COG	BRAZZAVILLE	4	S	15	15	E	18
185	COG	PNT NOIRE	4	S	51	12	E	1
186	COM	MORONI	11	S	41	43	E	17
187	CPV	PRAIA	14	N	55	23	W	30
188	CTI	ABIDJAN	5	N	21	3	W	57
189	CTR	CARTAGO	9	N	51	85	W	54
190	CTR	FARO DL CARIBE	9	N	56	84	W	5
191	CTR	PT.LIMON	10	N	0	83	W	2
192	CTR	S.JOSE	9	N	56	84	W	5
193	CUB	HABANA	23	N	0	82	W	30
194	CVA	CITE VATICAN	41	N	54	12	E	27
195	CVA	S.M.GALERIA	42	N	3	12	E	19
196	CYP	LIMASSOL	34	N	43	33	E	19
197	CYP	NICOSIA	35	N	8	33	E	22
198	D	BAD DUERRHEIM	48	N	0	8	E	31
199	D	BERLIN	52	N	30	13	E	20
200	D	BIBLIS	49	N	41	8	E	30
201	D	BREMEN	53	N	57	8	E	53
202	D	HOLZKIRCHEN	47	N	52	11	E	44
203	D	ISMANING	48	N	15	11	E	45
204	D	JUELICH	50	N	57	6	E	22
205	D	LAMPERTHEIM	49	N	30	8	E	33
206	D	MUEHLACKER	48	N	57	8	E	51
207	D	NORDENOSTERLOG	53	N	38	7	E	12

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
208	D	ROHRDORF	48	N	1	9	E	7
209	D	WERTACHTAL	48	N	5	10	E	41
210	D	K.WUSTERHAUSEN	52	N	18	13	E	37
211	D	LEIPZIG	51	N	14	12	E	22
212	D	NAUEN	52	N	38	12	E	54
213	DNK	KOEBENHAVN	55	N	41	12	E	21
214	DOM	PT.PLATA	19	N	40	70	W	41
215	DOM	S.CRISTOBAL	18	N	24	70	W	6
216	DOM	S.DOMINGO	18	N	18	69	W	53
217	DOM	S.PEDROMACORIS	18	N	26	69	W	18
218	DOM	SANTIAGO	19	N	29	70	W	42
219	E	ARGANDA	40	N	18	3	W	31
220	E	MALAGA	36	N	43	4	W	24
221	E	NOBLEJAS	39	N	57	3	W	26
222	E	PLAYA DE PALS	42	N	0	3	E	10
223	EGY	ABIS	31	N	10	30	E	5
224	EGY	ABU ZAABAL	30	N	16	31	E	22
225	EGY	MOKATTAM	30	N	3	31	E	15
226	EQA	LATACUNGA	0	S	56	78	W	37
227	EQA	MACAS	2	S	21	78	W	8
228	EQA	QUITO	0	S	14	78	W	20
229	ETH	ADDIS ABABA	8	N	58	38	E	43
230	ETH	GEDJA	8	N	47	38	E	38
231	F	ALLOUIS	47	N	0	2	E	0
232	FJI	SUVA	18	S	10	178	E	40
233	FJI	TAMAVUA	18	S	8	178	E	26
234	FNL	PORI	61	N	28	21	E	52
235	G	CROWBOROUGH	51	N	2	0	E	6
236	G	DAVENTRY	52	N	15	1	W	8
237	G	RAMPISHAM	50	N	48	2	W	38
238	G	SKELTON	54	N	44	2	W	54
239	G	WOOFFERTON	52	N	19	2	W	43
240	GAB	FRANCEVILLE	1	S	36	13	E	33
241	GAB	LIBREVILLE	0	N	25	9	E	26
242	GAB	MELEN	0	N	25	9	E	28
243	GAB	MOANDA	1	S	32	13	E	16
244	GAB	MOYABI	1	S	40	13	E	31
245	GHA	ACCRA	5	N	31	0	W	10
246	GHA	EJURA	7	N	23	1	W	22
247	GHA	TEMA	5	N	42	0	E	1
248	GMB	BANJUL	13	N	27	16	W	35
249	GNE	BATA	1	N	48	9	E	46
250	GRC	ATHINAI	38	N	2	23	E	42

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
251	GRC	FLORINA	40	N	48	21	E	25
252	GRC	IOANNINA	39	N	40	20	E	49
253	GRC	KAVALLA	40	N	58	24	E	21
254	GRC	KOZANI	40	N	20	21	E	48
255	GRC	LARISSA	39	N	32	22	E	25
256	GRC	RHODOS	36	N	27	28	E	16
257	GRC	SERRAI	41	N	8	23	E	35
258	GRC	THESSALONIKI	40	N	31	22	E	57
259	GRC	TRIPOLIS	37	N	35	22	E	23
260	GRD	GRENADA	12	N	0	61	W	46
261	GRL	GODTHAAB	64	N	10	51	W	44
262	GTM	ESCUINTLA	14	N	22	90	W	47
263	GTM	FLORES PETEN	16	N	45	90	W	7
264	GTM	GUATEMALA	14	N	34	90	W	31
265	GTM	MAZATENANGO	14	N	21	91	W	18
266	GTM	QUEZALTENANGO	14	N	49	91	W	30
267	GTM	S.MARCOS	14	N	57	91	W	46
268	GUF	CAYENNE	5	N	0	52	W	0
269	GUF	MONTSINERY	5	N	0	53	W	0
270	GUI	CONAKRY	9	N	32	13	W	40
271	GUM	AGANA	13	N	17	144	E	40
272	GUM	AGAT	13	N	20	144	E	39
273	GUY	SPARENDAAM	6	N	49	58	W	5
274	HKG	CAPE DAGUILAR	22	N	13	114	E	15
275	HKG	TSANG TSUI	22	N	25	113	E	55
276	HND	COMAYAGUELA	14	N	15	87	W	20
277	HND	JUTICALPA	14	N	15	87	W	20
278	HND	LA CEIBA	15	N	45	86	W	50
279	HND	S.BARBARA	14	N	53	88	W	14
280	HND	S.PEDRO SULA	15	N	29	88	W	1
281	HND	S.ROSA COPAN	14	N	47	88	W	46
282	HND	SUYAPA	14	N	15	87	W	19
283	HND	TEGUCIGALPA	14	N	4	87	W	14
284	HNG	BUDAPEST	47	N	31	19	E	0
285	HNG	DIOSD	47	N	25	18	E	57
286	HNG	JASZAGO	47	N	35	19	E	52
287	HNG	JASZBERENY	47	N	35	19	E	52
288	HNG	SZEKESFEHERVAR	47	N	10	18	E	24
289	HOL	FLEVO	52	N	21	5	E	27
290	HOL	LOPIK	52	N	1	5	E	2
291	HTI	C.HAITIEN	19	N	45	72	W	11
292	HTI	CAYES	18	N	12	73	W	40
293	HTI	PT.AU PRINCE	18	N	42	72	W	20

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
294	HWA	HONOLULU	21	N	25	158	W	11
295	I	CALTANISSETTA	37	N	30	14	E	4
296	I	ROMA	41	N	48	12	E	31
297	IND	AIZAWL	23	N	43	92	E	43
298	IND	ALIGARH	28	N	0	78	E	6
299	IND	BHOPAL	23	N	10	77	E	30
300	IND	BOMBAY	19	N	11	72	E	49
301	IND	CALCUTTA	22	N	27	88	E	18
302	IND	DELHI	28	N	43	77	E	12
303	IND	GAUHATI	26	N	11	91	E	50
304	IND	HYDERABAD	17	N	20	78	E	33
305	IND	JAMMU	32	N	45	75	E	0
306	IND	KOHIMA	25	N	39	94	E	6
307	IND	KURSEONG	26	N	55	88	E	19
308	IND	LUCKNOW	26	N	53	81	E	3
309	IND	MADRAS	13	N	8	80	E	7
310	IND	RANCHI	23	N	24	85	E	22
311	IND	SIMLA	31	N	0	77	E	5
312	IND	SRINAGAR	34	N	0	74	E	50
313	IND	TRIVANDRUM	8	N	29	76	E	59
314	INS	AMBOINA	3	S	42	128	E	5
315	INS	BANDA ACEH	5	N	30	95	E	22
316	INS	BANDJARMASIN	3	S	22	114	E	40
317	INS	BANDUNG	6	S	53	101	E	37
318	INS	BENGKULU	2	S	44	102	E	18
319	INS	BIAK	1	S	0	135	E	30
320	INS	BUKITTINGGI	0	S	18	100	E	22
321	INS	DENPASAR	8	S	45	115	E	15
322	INS	DILI	8	S	33	125	E	35
323	INS	FAKFAK	3	S	51	132	E	20
324	INS	JAKARTA	6	S	12	106	E	51
325	INS	JAMBI	1	S	38	103	E	34
326	INS	JAYAPURA	2	S	35	140	E	41
327	INS	KENDARI	3	S	38	125	E	26
328	INS	KOTABARU W IR	2	S	31	140	E	44
329	INS	KUPANG	10	S	10	123	E	30
330	INS	MANADO	3	S	58	125	E	26
331	INS	MANOKWARI	0	S	48	134	E	0
332	INS	MATARAM	8	S	9	115	E	30
333	INS	MEDAN	3	N	35	98	E	41
334	INS	MENADO	1	N	12	124	E	54
335	INS	MERAUKE	8	S	33	140	E	27
336	INS	NABIRE	3	S	15	135	E	36

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
337	INS	PADANG	0	S	6	100	E	21
338	INS	PADANG CERMIN	3	N	34	98	E	26
339	INS	PAKANBARU	0	N	15	101	E	30
340	INS	PALANGKARAYA	0	S	27	117	E	10
341	INS	PALEMBANG	0	S	18	104	E	22
342	INS	PALU	0	S	36	129	E	36
343	INS	PONTIANAK	0	S	5	109	E	16
344	INS	SAMARINDA	0	S	28	117	E	11
345	INS	SEMARANG	6	S	59	110	E	23
346	INS	SERUI	1	S	48	136	E	26
347	INS	SINGARADJA	8	S	7	115	E	5
348	INS	SORONG	0	S	52	131	E	25
349	INS	SUKARNAPURA	2	S	40	140	E	40
350	INS	SURABAJA	7	S	13	112	E	43
351	INS	SURAKARTA	7	S	33	110	E	48
352	INS	TANDJUNGPINANG	0	N	55	104	E	29
353	INS	TANJUNGKARANG	5	S	24	105	E	15
354	INS	UJUNGPANDANG	5	S	10	119	E	25
355	INS	WAMENA	3	S	48	139	E	53
356	INS	YOGYAKARTA	7	S	47	110	E	26
357	IRN	AHWAZ	31	N	20	48	E	40
358	IRN	KAMALABAD	35	N	46	51	E	27
359	IRN	MASHHAD	36	N	15	59	E	33
360	IRN	SHAHRIVAR	35	N	46	51	E	27
361	IRN	SIRJAN	29	N	27	55	E	41
362	IRN	TABRIZ	38	N	15	46	E	22
363	IRN	TEHERAN	35	N	41	51	E	27
364	IRN	ZAHEDAN	29	N	28	60	E	53
365	IRQ	ABU GHRAIB	33	N	19	44	E	15
366	IRQ	BABEL	32	N	30	44	E	30
367	IRQ	BAGHDAD	33	N	19	44	E	15
368	IRQ	SALAH EL DEEN	33	N	58	44	E	10
369	IRQ	SALMAN PACK	33	N	9	44	E	35
370	ISL	REYKJAVIK	64	N	5	21	W	50
371	ISR	JERUSALEM	32	N	4	34	E	47
372	J	FUKUOKA	33	N	32	130	E	27
373	J	HIROSHIMA	32	N	26	132	E	28
374	J	KUMAMOTO	32	N	50	130	E	44
375	J	MATSUYAMA	33	N	49	132	E	45
376	J	MOMOTE	35	N	46	139	E	36
377	J	NAGOYA	35	N	3	136	E	58
378	J	OKINAWA	26	N	44	128	E	9
379	J	OSAKA	34	N	33	135	E	31

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
380	J	SAPPORO	43	N	5	141	E	36
381	J	TOKYO	35	N	46	139	E	37
382	J	TOKYO KAWAGU	35	N	50	139	E	43
383	J	TOKYO NAGARA	35	N	28	140	E	13
384	J	TOKYO NAZAKI	36	N	11	139	E	51
385	J	TOKYO OYAMA	36	N	17	139	E	48
386	J	TOKYO SHOBU	36	N	4	139	E	38
387	J	TOKYO TODA	35	N	48	139	E	42
388	J	TOKYO YAMATA	36	N	10	139	E	50
389	JOR	AL KARANAH	31	N	44	36	E	26
390	JOR	AMMAN	31	N	57	35	E	56
391	KEN	KISUMU	0	S	7	34	E	45
392	KEN	KOMA ROCK	1	S	16	37	E	9
393	KEN	LANGATA	1	S	21	36	E	47
394	KEN	NAIROBI	1	S	21	36	E	45
395	KIR	TARAWA	1	N	21	172	E	56
396	KOR	BUPYEONG	36	N	59	126	E	43
397	KOR	GUNSAN	35	N	55	126	E	37
398	KOR	HWASUNG	37	N	13	126	E	47
399	KOR	KIMJAE	35	N	50	126	E	50
400	KOR	KYUNG SAN	35	N	54	128	E	49
401	KOR	SUWON	37	N	16	127	E	1
402	KOR	YUNHI	37	N	33	126	E	55
403	KRE	KANGGYE	40	N	58	126	E	36
404	KRE	KUJANG	40	N	5	125	E	5
405	KRE	PYONGYANG	39	N	5	125	E	33
406	KWT	JEWAN	29	N	11	48	E	1
407	KWT	KUWAIT	29	N	16	47	E	53
408	KWT	MAGWA	29	N	10	48	E	2
409	KWT	SULAIBIYAH	29	N	16	47	E	53
410	LAO	VIENTIANE	17	N	58	102	E	33
411	LBN	BEYROUTH	34	N	8	35	E	38
412	LBR	CAREYSBURG	6	N	25	10	W	32
413	LBR	MONROVIA	6	N	14	10	W	42
414	LBY	BEIDA	32	N	45	21	E	45
415	LBY	BENGHAZI	32	N	8	20	E	4
416	LBY	SEBHA	25	N	52	14	E	50
417	LBY	TRIPOLI	32	N	54	13	E	11
418	LSO	LANCERS	29	S	19	27	E	32
419	LUX	JUNGLINSTER	49	N	40	6	E	19
420	MAU	MAURITIUS	20	S	19	57	E	31
421	MCO	MT.CARLO	43	N	44	7	E	26
422	MDG	FENOARIVO	18	S	37	47	E	26

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
423	MDG	TALATA VOLON	18	S	45	47	E	37
424	MDG	TANANARIVE	18	S	50	47	E	35
425	MEX	ACAPULCO	16	N	55	99	W	58
426	MEX	CD.JUAREZ	31	N	42	106	W	29
427	MEX	CD.MANTE	22	N	45	99	W	57
428	MEX	CHIHUAHUA	28	N	34	106	W	2
429	MEX	CUERNAVACA	18	N	57	99	W	9
430	MEX	CULIACAN	24	N	46	107	W	27
431	MEX	GUADALAJARA	20	N	40	103	W	20
432	MEX	HERMOSILLO	29	N	4	110	W	55
433	MEX	LEON	21	N	9	101	W	40
434	MEX	LINARES	24	N	50	99	W	34
435	MEX	MATAMOROS	25	N	52	97	W	30
436	MEX	MERIDA	21	N	53	89	W	30
437	MEX	MEXICO	19	N	16	99	W	3
438	MEX	MIXQUIHUALA	20	N	14	99	W	13
439	MEX	MONTERREY	25	N	37	100	W	18
440	MEX	MORELIA	19	N	42	101	W	10
441	MEX	NOGALES	31	N	16	110	W	53
442	MEX	PT.PENASCO	31	N	15	113	W	25
443	MEX	PUEBLA	19	N	2	98	W	10
444	MEX	S.LUIS POTOSI	22	N	1	100	W	59
445	MEX	SISOGUICHI	27	N	48	107	W	35
446	MEX	TAMPICO	22	N	13	97	W	51
447	MEX	TAPACHULA	14	N	57	92	W	8
448	MEX	TEXMELUCAN	19	N	17	98	W	26
449	MEX	TIJUANA	32	N	27	117	W	2
450	MEX	TLAXIACO	17	N	15	97	W	40
451	MEX	TORREON	25	N	33	103	W	25
452	MEX	VERACRUZ	19	N	10	96	W	7
453	MLA	KAJANG	3	N	1	101	E	46
454	MLA	KOTA KINABALU	6	N	11	116	E	11
455	MLA	KUALA LUMPUR	3	N	8	101	E	41
456	MLA	MIRI	4	N	23	113	E	59
457	MLA	PENANG	5	N	25	100	E	19
458	MLA	SIBU	2	N	18	111	E	49
459	MLA	STAPOK	1	N	33	110	E	20
460	MLA	TEBRAU	1	N	32	103	E	48
461	MLA	TUARAN	6	N	11	116	E	12
462	MLD	MALE	4	N	10	73	E	30
463	MLI	BAMAKO	12	N	38	7	W	58
464	MLI	BAMAKO 1	12	N	39	8	W	1
465	MLI	BAMAKO 2	12	N	39	8	W	1

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
466	MLT	CYCLOPS	35	N	50	14	E	34
467	MNG	ULAN BATOR	47	N	55	107	E	0
468	MOZ	BEIRA	18	S	49	34	E	52
469	MOZ	MAPUTO	25	S	57	32	E	28
470	MOZ	NAMPULA	15	S	7	39	E	13
471	MOZ	PEMBA	13	S	2	40	E	45
472	MOZ	PT.AMELIA	13	S	2	40	E	45
473	MOZ	QUELIMANE	17	S	52	36	E	53
474	MRA	AGINGAN POINT	15	N	7	145	E	41
475	MRA	MARPI	15	N	16	145	E	48
476	MRC	NADOR	34	N	58	2	W	55
477	MRC	RABAT	34	N	0	6	W	51
478	MRC	SEBAA AIOUN	33	N	54	5	W	23
479	MRC	TANGER	35	N	41	5	W	56
480	MRL	MAJURO	7	N	4	171	E	22
481	MRT	FT.DE FRANCE	14	N	30	61	W	0
482	MSR	MONTSERRAT	16	N	41	62	W	11
483	MTN	NOUAKCHOTT	18	N	7	15	W	57
484	MWI	LIMBE	15	S	42	35	E	2
485	MWI	NGUMBE	15	S	45	35	E	2
486	MYT	DZAOUDZI	12	S	46	45	E	17
487	NCG	BLUEFIELDS	12	N	2	83	W	46
488	NCG	BONANZA	14	N	10	84	W	35
489	NCG	GRANADA	11	N	51	85	W	57
490	NCG	JINOTEGA	13	N	5	85	W	59
491	NCG	LEON	12	N	25	86	W	52
492	NCG	MANAGUA	12	N	10	86	W	26
493	NCG	MATAGALPA	12	N	55	85	W	57
494	NCG	OCOTAL	13	N	36	86	W	33
495	NCG	PT.CABEZAS	14	N	2	83	W	25
496	NCG	S.JOSE CUSMAPA	12	N	35	86	W	38
497	NCG	SOMOTO	13	N	29	86	W	36
498	NCL	NOUMEA	22	S	16	166	E	26
499	NGR	NIAMEY	12	N	30	2	E	6
500	NIG	BENIN	6	N	20	5	E	38
501	NIG	CALABAR	4	N	58	8	E	19
502	NIG	ENUGU	6	N	27	7	E	27
503	NIG	IBADAN	7	N	23	3	E	54
504	NIG	IKORODU	7	N	23	3	E	56
505	NIG	JAJI	10	N	45	7	E	33
506	NIG	JOS	9	N	52	8	E	53
507	NIG	KADUNA	10	N	31	7	E	25
508	NIG	LAGOS	6	N	34	3	E	21

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
509	NIG	MAIDUGURI	11	N	53	13	E	55
510	NIG	SOGUNLE	6	N	34	3	E	21
511	NIG	SOKOTO	13	N	4	5	E	16
512	NMB	HOFFNUNG	22	S	33	17	E	13
513	NMB	WINDHOEK	22	S	33	17	E	13
514	NOR	FREDRIKSTAD	59	N	11	10	E	58
515	NOR	JELOEY	59	N	26	10	E	36
516	NOR	KVITSOY	59	N	8	5	E	15
517	NOR	SVEIO	59	N	37	5	E	19
518	NOR	TROMSOE	69	N	41	18	E	55
519	NPL	JAWALAKHEL	27	N	45	85	E	20
520	NPL	KATHMANDU	27	N	42	85	E	12
521	NPL	KHUMALTAR	27	N	30	85	E	30
522	NZL	RANGITAIKI	38	S	50	176	E	25
523	NZL	WELLINGTON	41	S	5	174	E	50
524	OCE	PAPEETE	17	S	0	149	W	0
525	OMA	MASIRAH	20	N	36	58	E	53
526	OMA	SEEB	23	N	40	58	E	10
527	OMA	THUMRAIT	17	N	38	53	E	56
528	PAK	ISLAMABAD	33	N	27	73	E	12
529	PAK	KARACHI	24	N	55	67	E	0
530	PAK	LAHORE	31	N	35	74	E	20
531	PAK	PESHAWAR	34	N	0	71	E	30
532	PAK	QUETTA	30	N	15	67	E	0
533	PAK	RAWALPINDI	33	N	30	73	E	0
534	PHL	BAMBAN	14	N	47	120	E	53
535	PHL	BOCAUE	14	N	48	120	E	55
536	PHL	IBA	15	N	20	119	E	58
537	PHL	MALOLOS	14	N	52	120	E	48
538	PHL	MANILA	14	N	40	120	E	58
539	PHL	MARULAS	14	N	41	120	E	59
540	PHL	PALAUIG	15	N	28	119	E	50
541	PHL	PORO	16	N	37	120	E	17
542	PHL	S.FERNANDO	16	N	48	120	E	32
543	PHL	TINANG	15	N	21	120	E	37
544	PHL	VALENZUELA	14	N	42	120	E	58
545	PNG	ALOTAU	10	S	18	150	E	28
546	PNG	DARU	9	S	5	143	E	10
547	PNG	KIETA	6	S	20	155	E	40
548	PNG	LAE	6	S	40	146	E	54
549	PNG	MT HAGEN	5	S	50	144	E	55
550	PNG	PT.MORESBY	9	S	27	147	E	11
551	PNG	RABAUL	4	S	13	152	E	12

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
552	PNG	WEWAK	3	S	35	143	E	40
553	PNR	CHITRE	7	N	58	80	W	25
554	PNR	COLON	9	N	21	79	W	54
555	PNR	DAVID	8	N	26	82	W	25
556	PNR	PANAMA	8	N	57	79	W	30
557	POL	WARSZAWA	52	N	4	20	E	52
558	POL	WARSZAWA H	52	N	13	21	E	1
559	POR	LISBONNE	38	N	45	8	W	40
560	POR	MUGE	39	N	5	8	W	41
561	POR	PAREDE	38	N	42	9	W	19
562	POR	PORTO ALTO	38	N	55	8	W	50
563	POR	S.GABRIEL	38	N	45	8	W	40
564	POR	SINES	37	N	57	8	W	45
565	PRG	ASUNCION	25	S	16	57	W	38
566	PRG	CONCEPCION	23	S	24	57	W	27
567	PRG	ENCARNACION	27	S	21	55	W	52
568	PRG	P J CABALLERO	22	S	33	55	W	45
569	PRG	VILLARRICA	25	S	45	56	W	26
570	PRU	AREQUIPA	16	S	25	71	W	32
571	PRU	CALLAO	12	S	1	76	W	6
572	PRU	CERRO DE PASCO	10	S	40	76	W	15
573	PRU	CHACHAPOYAS	6	S	10	77	W	50
574	PRU	CHICLAYO	6	S	44	79	W	51
575	PRU	CUZCO	13	S	30	72	W	0
576	PRU	HUANCAYO	12	S	5	75	W	10
577	PRU	HUARAZ	9	S	30	77	W	32
578	PRU	ICA	14	S	5	75	W	43
579	PRU	IQUITOS	3	S	45	73	W	12
580	PRU	JULIACA	15	S	28	70	W	6
581	PRU	LA OROYA	11	S	30	75	W	56
582	PRU	LIMA	12	S	0	77	W	0
583	PRU	PIURA	5	S	15	80	W	40
584	PRU	PUCALLPA	8	S	25	74	W	32
585	PRU	PUNO	15	S	56	70	W	1
586	PRU	SICUANI	14	S	15	71	W	12
587	PRU	TACNA	18	S	0	70	W	13
588	PRU	TALARA	4	S	35	81	W	18
589	PRU	TARAPOTO	6	S	28	76	W	27
590	PRU	TRUJILLO	8	S	8	79	W	1
591	PRU	TUMBES	3	S	32	80	W	30
592	QAT	AL KHAISAH	25	N	25	51	E	25
593	QAT	DOHA	25	N	17	51	E	32
594	REU	S.DENIS	20	S	55	55	E	30

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
595	ROU	BUCURESTI	44	N	25	26	E	6
596	RRW	KIGALI	1	S	58	30	E	4
597	S	GRIMETON	57	N	7	12	E	24
598	S	HOERBY	55	N	49	13	E	44
599	S	KARLSBORG	58	N	29	14	E	29
600	S	MOTALA	58	N	33	15	E	3
601	S	VARBERG	57	N	6	12	E	24
602	SDN	JUBA	4	N	52	31	E	37
603	SDN	OMDURMAN	15	N	30	32	E	28
604	SEN	DAKAR	14	N	39	17	W	26
605	SEN	S.LOUIS	16	N	0	16	W	29
606	SEN	TAMBACOUNDA	13	N	47	13	W	41
607	SEN	ZIGUINCHOR	12	N	36	16	W	16
608	SEY	MAHE	4	S	36	55	E	28
609	SHN	ST.HELENA	16	S	56	5	W	45
610	SLM	HONIARA	9	S	25	160	E	3
611	SLV	S.ANA	14	N	0	89	W	35
612	SLV	S.MIGUEL	13	N	29	88	W	12
613	SLV	S.SALVADOR	13	N	44	89	W	9
614	SNG	KRANJI	1	N	25	103	E	44
615	SNG	SINGAPORE	1	N	24	103	E	51
616	SOM	HARGEISA	9	N	33	44	E	3
617	SOM	MOGADISCIO	2	N	2	45	E	20
618	SRL	FREETOWN	8	N	30	13	W	14
619	SRL	GODERICH	8	N	30	13	W	14
620	SRL	WATERLOO	8	N	17	13	W	5
621	STP	S.TOME	0	N	21	6	E	45
622	SUI	BEROMUNSTER	47	N	12	8	E	10
623	SUI	GENEVE	46	N	24	6	E	15
624	SUI	LENK	46	N	27	7	E	27
625	SUI	SARNEN	46	N	53	8	E	12
626	SUI	SCHWARZENBURG	46	N	49	7	E	24
627	SUI	SOTTENS	46	N	39	6	E	44
628	SUR	PARAMARIBO	5	N	49	55	W	12
629	SWZ	MANZINI	26	S	34	31	E	59
630	SWZ	MBABANE	26	S	38	30	E	48
631	SYR	ADRA	33	N	27	36	E	30
632	SYR	SABBOURA	33	N	30	36	E	7
633	TCD	N DJAMENA	12	N	8	15	E	3
634	TCH	LITOMYSL	49	N	48	16	E	10
635	TCH	PRAHA	50	N	9	15	E	9
636	TCH	RIMAVSKA	48	N	23	20	E	0
637	TCH	VELKEKOSTOLANY	48	N	31	17	E	44

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
638	TGO	LAMA KARA	9	N	35	1	E	9
639	TGO	LOME	6	N	7	1	E	12
640	TGO	TOGBLEKOPE	6	N	16	1	E	12
641	TGO	YADE	9	N	35	1	E	9
642	THA	BANGKHEN	14	N	55	102	E	5
643	THA	BANGKOK	13	N	47	100	E	30
644	THA	LAKSI	13	N	52	100	E	34
645	THA	NAKHONRATCHASI	14	N	56	102	E	10
646	THA	PATUMTHANI	14	N	3	100	E	43
647	THA	PITUKSUNTIRADS	14	N	50	100	E	35
648	THA	SURAJDHANEE	9	N	7	99	E	19
649	TUN	DJEDEIDA	36	N	50	9	E	57
650	TUN	SFAX	34	N	48	10	E	53
651	TUN	TUNIS	36	N	50	9	E	56
652	TUR	ANKARA	39	N	54	30	E	42
653	TUR	IZMIR	38	N	24	27	E	10
654	TZA	DAR ES SALAAM	6	S	50	39	E	14
655	TZA	DOLE	6	S	5	39	E	14
656	TZA	MARHUBI	6	S	9	39	E	12
657	UAE	ABU DHABI	24	N	23	54	E	17
658	UAE	DUBAI	25	N	14	55	E	16
659	UAE	MAKTA	24	N	21	54	E	34
660	UGA	KAMPALA	0	N	20	32	E	36
661	UGA	SOROTI	1	N	40	33	E	40
662	UKR	IVANOFRANKOVSK	48	N	56	24	E	48
663	UKR	KHARKOV	50	N	0	36	E	17
664	UKR	KIEV	50	N	27	30	E	13
665	UKR	LVOV	49	N	50	24	E	0
666	UKR	SIMFEROPOL	44	N	56	34	E	6
667	UKR	STANISLAV	48	N	56	24	E	48
668	UKR	STAROBELSK	49	N	13	37	E	57
669	UKR	VINNITSA	49	N	13	28	E	26
670	URG	COLONIA	34	S	26	57	W	51
671	URG	MELO	32	S	26	54	W	13
672	URG	MONTEVIDEO	34	S	47	56	W	8
673	URS	ACHKHABAD	37	N	57	58	E	23
674	URS	ALMA ATA	43	N	17	77	E	0
675	URS	ARMAVIR	45	N	0	40	E	49
676	URS	BAKU	40	N	24	49	E	45
677	URS	BLAGOVECHTCHEN	50	N	16	127	E	33
678	URS	DUCHANBE	38	N	40	68	E	50
679	URS	EREVAN	40	N	10	44	E	30
680	URS	FRUNZE	42	N	54	74	E	37

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
681	URS	GORKII	56	N	17	44	E	0
682	URS	IAKUTSK	62	N	1	129	E	48
683	URS	IAMBURG	59	N	27	28	E	43
684	URS	IRKUTSK	52	N	18	104	E	18
685	URS	IUJNSAKHALINSK	46	N	55	143	E	10
686	URS	JIGULEVSK	53	N	26	49	E	30
687	URS	KALATCH	50	N	26	40	E	40
688	URS	KALININ	56	N	52	35	E	35
689	URS	KAUNAS	54	N	55	24	E	0
690	URS	KAZAN	55	N	47	49	E	8
691	URS	KENGA	57	N	25	80	E	56
692	URS	KHABAROVSK	48	N	33	135	E	15
693	URS	KHILLY	39	N	28	48	E	57
694	URS	KINGHISEPP	59	N	27	28	E	43
695	URS	KOMSOMOLSKAMUR	50	N	30	137	E	5
696	URS	KONEVO	60	N	12	36	E	53
697	URS	KRASNOIARSK	56	N	1	92	E	54
698	URS	KURSK	51	N	46	36	E	12
699	URS	LENINGRAD	59	N	57	30	E	1
700	URS	MITCHURINSK	52	N	54	40	E	11
701	URS	MOSKVA	55	N	45	37	E	18
702	URS	MURMANSK	68	N	58	32	E	46
703	URS	NIKOLAEVSKAMUR	53	N	10	140	E	47
704	URS	NOVOSIBIRSK	55	N	4	82	E	58
705	URS	OKHOTSK	59	N	30	143	E	0
706	URS	OMSK	54	N	59	72	E	23
707	URS	ORENBURG	51	N	46	54	E	47
708	URS	PETROPAVLO KAM	52	N	59	158	E	39
709	URS	PETROZAVODSK	61	N	48	34	E	20
710	URS	RIAZAN	54	N	37	39	E	41
711	URS	RIGA	56	N	58	24	E	7
712	URS	SERPUKHOV	54	N	54	37	E	25
713	URS	SVERDLOVSK	56	N	50	60	E	36
714	URS	SYKTYVKAR	61	N	41	50	E	31
715	URS	TACHKENT	41	N	19	69	E	17
716	URS	TAICHET	55	N	48	97	E	35
717	URS	TALLIN	59	N	27	24	E	47
718	URS	TBILISI	41	N	40	45	E	45
719	URS	TCHITA	52	N	5	113	E	20
720	URS	TOMSK	56	N	30	85	E	2
721	URS	TULA	54	N	12	37	E	48
722	URS	VLADIVOSTOK	43	N	12	131	E	51
723	URS	VOLGOGRAD	48	N	42	44	E	28

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
724	URS	VOLOGDA	59	N	12	40	E	0
725	URS	VORONEJ	51	N	38	39	E	14
726	USA	BETHANY	39	N	21	84	W	21
727	USA	BETHEL	40	N	29	76	W	17
728	USA	CINCINNATI	39	N	21	84	W	21
729	USA	CYPRESS CREEK	32	N	41	87	W	1
730	USA	DALLAS	33	N	13	96	W	52
731	USA	DELANO	35	N	45	119	W	17
732	USA	DIXON	38	N	23	121	W	45
733	USA	FURMAN	32	N	41	81	W	7
734	USA	GREENVILLE	35	N	35	77	W	22
735	USA	NEW ORLEANS	29	N	50	90	W	7
736	USA	NEW YORK	40	N	49	73	W	15
737	USA	NOBLESVILLE	40	N	1	85	W	57
738	USA	OKEECHOBEE	27	N	46	80	W	39
739	USA	RANCHO SIMI	34	N	15	118	W	38
740	USA	RED LION	39	N	54	76	W	34
741	USA	REDWOOD CITY	37	N	33	122	W	14
742	USA	SALT LAKE CITY	40	N	39	112	W	3
743	USA	SCHENECTADY	42	N	48	74	W	1
744	USA	SCITUATE	42	N	13	70	W	44
745	USA	SCOTTS CORNERS	45	N	8	68	W	34
746	USA	SEATTLE	47	N	21	122	W	27
747	USA	VADO	32	N	8	106	W	35
748	VEN	ANACO	9	N	28	64	W	27
749	VEN	BARQUISIMETO	10	N	4	69	W	20
750	VEN	CARACAS	10	N	30	66	W	55
751	VEN	CD.BOLIVAR	8	N	10	63	W	33
752	VEN	CD.GUAYANA	8	N	24	62	W	40
753	VEN	LOS TEQUES	10	N	23	66	W	57
754	VEN	MACHIQUES	10	N	3	72	W	32
755	VEN	MARACAIBO	10	N	39	71	W	56
756	VEN	MATURIN	9	N	18	63	W	12
757	VEN	MERIDA	8	N	35	71	W	5
758	VEN	S.CRISTOBAL	7	N	46	72	W	14
759	VEN	TARIBA	7	N	47	72	W	14
760	VEN	TOVAR	8	N	21	71	W	44
761	VEN	VALERA	9	N	18	70	W	28
762	VTN	CANTHO	10	N	5	105	E	46
763	VTN	DALAT	11	N	45	108	E	23
764	VTN	DANANG	16	N	4	108	E	15
765	VTN	HA BAC	21	N	16	106	E	12
766	VTN	HA SON BINH	21	N	20	105	E	45

TABLE 15-1 (CONTINUED)

TSITE CODE	COUNTRY CODE	STATION NAME	LATITUDE DD	NS	MM	LONGITUDE DD	EW	MM
767	VTN	HANOI	20	N	59	105	E	52
768	VTN	HO CHI MINH V	10	N	51	106	E	38
769	VTN	HUE	16	N	25	107	E	40
770	VTN	NHATRANG	12	N	15	109	E	10
771	VUT	PORT VILA	17	S	44	168	E	33
772	YEM	SANAA	15	N	22	44	E	11
773	YEM	ADEN	12	N	50	45	E	2
774	YUG	BELGRADE	44	N	34	20	E	9
775	YUG	BIJELJINA	44	N	42	19	E	10
776	YUG	ZAGREB	45	N	42	16	E	29
777	ZAI	BANDUNDU	3	S	18	17	E	21
778	ZAI	KANANGA	5	S	53	22	E	25
779	ZAI	KIKWIT	5	S	1	18	E	49
780	ZAI	KINSHASA	4	S	23	15	E	23
781	ZAI	KISANGANI	0	N	30	25	E	11
782	ZAI	LUBUMBASHI	11	S	41	27	E	32
783	ZAI	MBANDAKA	0	N	4	18	E	17
784	ZAI	MBUJIMAYI	6	S	9	23	E	35
785	ZMB	LUSAKA	15	S	30	28	E	15
786	ZWE	GWELO	19	S	26	29	E	51
787	ZWE	SALISBURY	17	S	50	31	E	1

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Printed in Switzerland
Geneva, 2008
ISBN 92-61-06651-8