

International Telecommunication Union

**ITU-R**  
Radiocommunication Sector of ITU

**Recommendation ITU-R F.1610**  
**(02/2003)**

**Planning, design and implementation of HF  
fixed service radio systems**

**F Series**  
**Fixed service**



## Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

## Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from <http://www.itu.int/ITU-R/go/patents/en> where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

### Series of ITU-R Recommendations

(Also available online at <http://www.itu.int/publ/R-REC/en>)

Series	Title
<b>BO</b>	Satellite delivery
<b>BR</b>	Recording for production, archival and play-out; film for television
<b>BS</b>	Broadcasting service (sound)
<b>BT</b>	Broadcasting service (television)
<b>F</b>	<b>Fixed service</b>
<b>M</b>	Mobile, radiodetermination, amateur and related satellite services
<b>P</b>	Radiowave propagation
<b>RA</b>	Radio astronomy
<b>RS</b>	Remote sensing systems
<b>S</b>	Fixed-satellite service
<b>SA</b>	Space applications and meteorology
<b>SF</b>	Frequency sharing and coordination between fixed-satellite and fixed service systems
<b>SM</b>	Spectrum management
<b>SNG</b>	Satellite news gathering
<b>TF</b>	Time signals and frequency standards emissions
<b>V</b>	Vocabulary and related subjects

*Note: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication  
Geneva, 2010

© ITU 2010

All rights reserved. No part of this publication may be reproduced, by any means whatsoever, without written permission of ITU.

## RECOMMENDATION ITU-R F.1610\*

**Planning, design and implementation  
of HF fixed service radio systems**

(2003)

**Scope**

This Recommendation provides guidance in the planning, design and implementation of HF fixed service radio systems. This Recommendation addresses equipment, system analysis and design, site and field surveys and system testing.

The ITU Radiocommunication Assembly,

*considering*

- a) the need for HF radiocommunication services;
- b) that recent developments in HF system techniques make it possible to achieve the following:
  - a higher quality of service by combining the ability to exploit modern signal processing technology with advanced real-time control software;
  - a reduction in transmission times, thereby securing the most efficient use of the spectrum opportunity to decrease interference between users, and the capability to increase traffic density;
- c) that ITU-R has developed a Handbook on frequency adaptive communications systems and networks in the MF/HF bands which describes the nature of adaptive HF systems and their use;
- d) that the performance of the HF system depends on the engineering design and planning of the radio installation,

*recommends*

**1** that users, who intend to deploy HF systems, should use the information contained in Annex 1 as a guide to planning, system design and implementation.

**Annex 1****Planning, design and implementation  
of HF fixed service radio systems****1 Introduction**

High operational flexibility, easy maintenance of equipment requirements make HF system techniques very useful in world communications; this is particularly emphasized in the case of large geographical areas with low density of telegraph, telephone and data traffic.

---

\* Radiocommunication Study Group 5 made editorial amendments to this Recommendation in December 2009 in accordance with Resolution ITU-R 1.

At the present time, the development of modern high capacity means of telecommunications, such as satellites and cables, has allowed a wide part of the RF spectrum between 3 and 30 MHz to be available for telecommunications systems, even while meeting the needs of the mobile services.

When the need for a new communications capability between two or more points is first envisioned, and HF radio is suggested as a possible solution, a feasibility study is required to analyse and define the whole system. This study will verify that HF is the appropriate means of communication for the set of system requirements pending, based on a comparison of technical and operational alternatives, and that the economic aspects for the new HF system are compelling.

## **2 Definition and analysis of requirements**

A rigorous analysis of the expectations and requirements for the new system should show whether or not this communication medium is proper for this application. Some of the factors that support the use of HF radio over other means of communication are:

- distance
- reliability
- terrain
- message traffic requirements
- message priority requirements
- estimates
- solar cycle and available frequency set
- adequate sites.

A review of the above items will determine if the use of HF radio equipment is appropriate for the proposed application.

### **2.1 Preliminary system design and feasibility study**

Once it has been determined that HF is a viable solution to the communications requirement, then a preliminary system design and feasibility study must be conducted. The items, which the system engineer must consider, make up the remainder of this item.

### **2.2 Trunking/routing plans**

The trunking and routing plans in the design analysis provide information on the number and types of channels needed to interconnect each of the terminals within the HF system. If the radio system is to be a part of larger network of radios, the implementing engineer will work with the network manager to identify all the stations or nodes to be included in the network as well as their geographical locations. The routing plans have to consider the following factors:

- physical location of each node and the relationship to other nodes in the network,
- physical obstacles (i.e. mountains, buildings, antenna, etc.) between nodes,
- equipment located at each node, especially the power and antenna characteristics,

- propagation paths between the stations involved,
- communication interfaces that are connected to each node,
- characteristics and volume and priority of the communications traffic.

### **2.3 Frequency plan**

Planning must begin early in the project to secure an adequate list of frequencies to support each link in the HF radio system so that uninterrupted operations are possible both day and night, at any time of the year, and throughout the whole 11-year solar cycle. A frequency prediction program such as Recommendation ITU-R P.533 could be used determining frequency requirements in different conditions.

### **2.4 Personnel manning requirements**

To ensure that each station in the network is operated and maintained properly, an analysis of the numbers, training and experience of the personnel that will be required to staff each of the nodes in the network during the required period of service should be conducted early in the planning process.

### **2.5 Support requirements**

The system designer must select a site having adequate access roads, water and electrical power supply, fuel for generators, telephone service, post office, medical facilities, and adequate housing and shopping areas for site personnel. In the vast majority of cases, the radio site will be located near a city or large town, and the support considerations mentioned above, will normally be available. But in a few cases obtaining these services may require special logistics effort.

### **2.6 Modes of communications required (voice, data, and image)**

The requirement specifications will specify what type(s) of traffic the HF station must be capable of handling. This may be voice only, both voice and data, or may indicate the need to handle other forms of information, such as image, facsimile, or encrypted voice. Each of these types of traffic will indicate additional pieces of equipment that must be considered by the system engineer.

### **2.7 Required $S/N$**

The modes of communications required (i.e. voice, data, etc.) will determine the required  $S/N$ . Recommendation ITU-R F.339 can be used to determine what  $S/N$  is needed for the required grade of service (orderwire quality, marginal commercial grade, or good commercial grade), for the type of signal (analogue, digital).

### **2.8 Modulation types and data rates**

Normally this information will be furnished in the system designer with the equipment specifications. Care must be taken to assure that equipment interfaced together operates at the same data rates and uses the same modulation types. For HF data transmission Recommendations ITU-R F.763 and ITU-R F.436 have suggestions for different techniques to avoid degradations resulting from the radio channel.

In the solution adopted by the ITU-R, a serial to parallel conversion of the high-speed signal (up to 1200 bit/s) is effectuated giving 6-12 channels, FDM multiplexed. The low modulation rate (50-100 Bd) so obtained for each subchannel makes the digital signal practically free from multipath distortion. At the receiving side a data concentrator restores the original signal characteristics.

For higher signal speeds (up to 4800 bit/s), systems based on differential phase keying with frequency shifted tones are sometimes used. In this case the information is derived from the relative difference of phase between two simultaneously transmitted tones. The multipath effects over the two tones are practically the same, because of the small difference value (about 40 Hz). An alternative technique is to transmit the data in serial form and utilize the adaptive equalizer in the receiver to remove to multipath distortion. HF modems for data rates up to 9600 bit/s have been developed with these signalling formats.

The information is transmitted in analogue or digital form through the radio channel, the transmission types described in this section are defined in Table 1.

TABLE 1

**Types of modulation**

<b>Designator</b>	<b>Modulation form</b>	<b>Definition</b>
CW	Continuous wave	Defined as a radio wave of constant amplitude and constant frequency. As a modulation form, CW is defined as an interrupted continuous wave, which is on/off, keyed using Morse code
AM	Amplitude modulation	A form of modulation in which the amplitude of a carrier wave is varied in accordance with some characteristic of the modulating signal
FM	Frequency modulation	Amplitude changes of the modulating signal are used to vary the instantaneous frequency of the carrier wave from its unmodulated value
SSB	Single sideband	A form of amplitude modulation in which the carrier and one sideband are suppressed and the remaining sideband is transmitted. Also designated as USB and LSB, for upper and lower sideband
ISB	Independent sideband	A method of double-sideband transmission in which the information carried by each sideband is different
RTTY	Radio teletypewriter	A teletypewriter used in a communication system using radio circuits. Mark/space teletypewriter signals are modulated on radio systems either by a two-frequency shift of the carrier wave, called frequency-shift keying (FSK) or by a two-frequency audio signal, called voice frequency telegraph (VFT) or audio frequency-shift keying (AFSK)
Data	Binary digital	Information that is represented by a code consisting of a sequence of discrete elements. Digital data is produced by teletypewriters, digital facsimile equipment and computer terminals among other sources. The signals are generally transmitted by digital-to-analog conversion to FSK or phase-shift keying (PSK)

## **2.9 Required circuit reliability**

HF circuits are able to provide circuit reliability of 80% (19.2 h/day) to 95% (22.8 h/day). Modern, adaptive equipment such as automatic link establishment (ALE) will operate near the high end of the reliability spectrum.

## **2.10 Terminal facilities required**

The term terminal facilities are used here to describe all of the physical plant, primary and auxiliary power, and environmental control systems required to support the new HF system.

## **2.11 Required system lifetime of service**

The length of time that the new HF system will be expected to be in service will have an impact on the selection of equipment. If the service is only for a short period of time (several months to a few years), it may be possible to operate with transportable or tactical equipment. Any longer life expectancy will usually require permanently installed equipment.

## **2.12 Facilities site requirements**

Because of the long wavelengths involved with HF operations, large amounts of land are required for HF stations. A simple dipole antenna usually requires at least 0.5 hectares of ground, and a rhombic antenna can require from 2 to 7 hectares. If the new HF system cannot use an existing site, then planning must begin very early in the project to find and acquire a suitable location. Additionally, if operation is contemplated on several circuits or full-duplex operation on one circuit, then various antennas must be separated to prevent co-site interference. This antenna separation compounds the need for additional land.

## **2.13 Environmental impact assessments**

Frequently, the construction of an HF radio site, or the upgrade of an existing site, will require environmental impact assessments. If towers in excess of 50 m are anticipated, or if the site is to be located near an existing airport or heliport, then notification of the aviation authorities is required.

## **2.14 Required operational date**

The date that the station is required to be operational (or the new equipment is required to be operational) may be given in the original statement of requirements, or it may require negotiation with the operational agency. Some of the major system components may have delayed delivery times, so their delivery schedule should be factored into the plans for an operational date.

## **3 Practical aspects**

Development of a new or expanded HF radio capability includes more than just the estimates for the equipment. This section contains the direct and indirect project estimates including details about:

- start-up;
- equipment;
- installation.

### **3.1 Start-up**

#### **3.1.1 Project management estimates**

Estimates must include direct and indirect labour for the project manager and any staff, for the time spent monitoring and managing the project. Also included are other items, such as travel.

#### **3.1.2 System engineering estimates**

Estimates must include direct and indirect labour for the system engineer and any assigned staff, for time spent reviewing the project requirements, and the time devoted to system design work. These estimates may also include other direct items such as travel, printing, drafting, etc.

#### **3.1.3 Real estate/land acquisition estimates**

If the site for the new HF station(s) is/are not owned by the operational agency, the site(s) must be acquired through purchase or lease. These acquisition estimates include all estimates associated with the acquiring of the land for the site(s), including the purchase, yearly lease, legal fees, and any taxes that apply.

#### **3.1.4 Site preparation**

These include estimates associated with levelling or grading the land, constructing fences, digging trenches for antenna cables, constructing concrete piers for antenna towers.

#### **3.1.5 Construction or modifications to equipment building(s)**

If the site is a new one, then an equipment building/control facility must be constructed to house the equipment and to provide a place for the site's personnel to operate. If the site is an existing one, then it may be necessary to construct additional rooms for the site building(s) to house the new capability.

#### **3.1.6 Construction or modifications to the site's primary and auxiliary power system**

The HF system requires a.c. power, from the local power company grid to run the HF equipment and site to provide support for equipment such as heating, ventilation, and air-conditioning. If the site is an existing one, this power may be already provided, but in many cases the power distribution system may have to be upgraded with larger transformers, and additional circuit breakers. The engineering plan may also call for the installation of an auxiliary power source, such as a gasoline- or diesel-powered electrical power generator for emergency use.

### **3.2 Equipment**

#### **3.2.1 Equipment in general**

The estimates of the HF system equipment may or may not be the largest item of the project, depending on how many circuits are required, what power levels the transmitters require and the distances between sites. Equipment is usually purchased through one supplier or vendor, although it is not uncommon for multiple vendors to support a large contract. The usual process is for the operating agency to notify all qualified vendors of intent to purchase equipment and/or services,



through the request for proposal (RFP). The interested vendors respond to the RFP with their proposed solution to the customer's need, and with an estimate. The customer can then choose among several competing solutions, and choose the one that best meets their needs. The vendors, often will propose a turnkey solution, whereby they will provide not only all the required equipment, but will also provide or subcontract the installation and site-preparation work as well. The following is a listing of the most common components of an HF radio system:

- transmitter/receiver or transceiver;
- antenna components;
- antenna switches;
- transmission lines;
- terminating devices;
- multicouplers, filters, preselectors, crossover networks, matching devices;
- RF patching;
- terminal equipment;
- voice terminals;
- audio patching equipment;
- d.c. patching facility;
- spare parts facility;
- test equipment, dummy loads, RF power/field strength meters.

### **3.2.2 Transmitter/receiver or transceivers**

Depending on the power levels required, the station might be equipped with either transceivers or separate transmitters and receivers. For low-power to medium-power operations, say from 100 W to 1 000 W, it is the usual practice to use transceivers (a combination of transmitter and receiver in the same package). For high-power operation, >10 kW, the standard practice is to run a split site, with the transmitters at one location and the receivers at another. This configuration allows for full-duplex operation, if required.

### **3.2.3 Antenna components**

Antennas used in the HF radio operations range from a simple, thin wire, half-wave dipole to large, fixed, or rotatable log-periodic antennas or rhombic antennas, covering many hectares of land. The selection of antennas depends on the number of frequencies to be covered, the RF power levels used, and the circuit reliability requirements. Whether or not the antenna has an omnidirectional or directional pattern is a function of where the stations to be contacted are located. Additional antenna subsystem components that may be needed are transmission line (balanced or coaxial), antenna switching matrix, multicouplers, terminating devices, impedance matching networks, and high- and low-level RF patching.

### **3.2.4 Antenna switches**

Antenna switches are found where there are multiple antennas or where different antennas are to be used for different circuit paths. The switch allows the radio operator to switch antennas by a manual switch, located in the radio room, or electrically, from a control console.

### 3.2.5 Transmission lines

Transmission line is used to connect the transmitters/receivers to the antenna. They are selected during the detailed engineering phase, based on the transmitter power, system impedance, and possibility of coupling with other nearby lines, line loss, economic aspects, and atmospheric environment. In general, low- to medium-power transmitters (100 W to 1 000 W) use some form of coaxial cable for transmission line, while high-power stations (>10 kW) use open wire, balanced transmission lines.

### 3.2.6 Terminating devices

Terminating devices are used with no resonant antennas, such as long wires, Vees, and rhombics to make them unidirectional. There are two types of terminating devices: a lumped constant (no reactive resistance) and a distributed constant (lossy transmission line) terminating device. These terminating devices are provided in the characteristic impedance of the particular antenna, and must be capable of dissipating (at least) the average power of the transmitter.

### 3.2.7 Multicouplers

Multicouplers are devices used to permit two or more receivers or transmitters to share the same antenna. In general, only low-powered transmitters use multicouplers, due to the amount of isolation required between transmitters.

### 3.2.8 RF patching

Low-level RF patching is used to interconnect equipment when frequency synthesizers or exciters are used with linear power amplifiers. The output of the synthesizers or exciters is usually on the order of a few milliwatts. High-level RF patching is used to interconnect low powered transmitters (100 W to 500 W) to linear power amplifiers.

### 3.2.9 Terminal equipment

For the purpose of this Recommendation, terminal equipment will include all other ancillary equipment, such as voice terminals, audio switchboards and patching, d.c. patching and teletype terminals, multiplexers for voice-frequency carrier telegraph, facsimile equipment, HF data modems, and crypto devices.

### 3.2.10 Voice terminals

Voice terminals provide the interface between the customer's equipment and the transmission system, call signalling, electrical isolation between the transmit and receive paths, and signal conditioning.

### 3.2.11 Audio patching equipment

Every HF terminal station should have some form of audio patching. It can be as simple as a single jack strip or many jack strips. The purpose of this patching facility is to give the station personnel the ability to have access to all of the audio circuits for:

- emergency traffic routing;
- switching or substituting equipment;
- monitoring the signal quality;
- circuit test and maintenance.

All incoming, outgoing, and most of the intra-station audio circuits will appear on the audio patch. For small installations, the audio patch may be located with the other equipment. In larger sites the audio patch will be separately located and manned, and may even be in a separate building. The audio patch plugs and jacks must be a different size from the d.c. patching equipment to prevent patching errors.

#### *d.c. patching facility*

A d.c. patching facility is required if teletypewriters or other d.c. equipment is present. This patch may be a single- or multiple-jack strip, and is usually co-located with the other ancillary equipment.

#### *Spare parts*

The mission of the site may dictate at what level spares are kept. If the station has a 24-h/day mission it may need to keep not only spares such as fuses, coaxial jumper cables, etc. but may also need to have spare equipment available to swap out with defective equipment, to keep the station operational agency policy or regulations may also dictate the storage of additional spare parts.

### **3.2.12 Installation**

Other items to be included in the estimate deal with the installation process. These may include the following:

- a) bill of materials for installation;
- b) estimates for outside consultants/professional engineers;
- c) estimates of installation labour;
- d) estimates of acceptance testing;
- e) training of site personnel;
- f) lifecycle estimates.

#### **a) Installation bill of materials (IBoM)**

The IBoM is a list of every piece of equipment and parts needed to construct (or upgrade) the HF station(s). In addition to the major items, such as antennas, transceivers, etc., the IBoM includes such things as wire, cable circuit breakers, cable trays, screws, nails, etc. The IBoM is finalized only after the detailed engineering has been completed. Rules of thumb or previous projects may provide estimate data for the initial stages of system planning.

#### **b) Estimates of outside consultants/professional engineers**

Consultants or professional engineers are frequently employed for specialized tasks, such as locating suitable sites or measuring the local electrical noise levels (both man-made and natural).

**c) Estimates of installation labour**

Unless this service is to be furnished by the equipment vendor (through a subcontract), the project manager must plan for it. Installation estimates includes all construction required to make the site operational (i.e. construction which was not completed during the site-preparation phase).

**d) Estimates of acceptance testing**

Testing equipment is an important part of making the site fully operational. The test plan may call for formal testing of each feature of the new equipment, either by the receiving agency or by the vendor under user agency observation. Or testing may be as simple as providing a period of time, such as 30 days, where the site personnel are expected to check out all of the equipment features. Direct and indirect labour estimates of this testing must be included in overall project estimates. Development of suitable test plans may be required if none exist. If these test plans are required, the effort associated with their development is another project item that must be considered.

**e) Training of site personnel**

Training of site personnel on any new equipment installed during the project must always be considered. Training may be provided under the equipment purchase contract, or if the agency is large enough to have in-house trainers, they may receive training from the vendor, and then provide in-house training for the site personnel. In a small number of cases, the site may have a few personnel already trained, who can provide an on-the-job training program for the site's remaining personnel. No matter how it is accomplished, training must always be included in the project plans.

**f) Lifecycle estimates**

Lastly, the system designer must consider the lifecycle estimates of the system. These may include the recurring items to operate and maintain the new capability.

**4 System analysis and design**

The steps to system engineering a typical HF radio system might include the following three levels of planning:

- the first is an analysis of the requirements for the communications system, to establish that the use of HF radio is feasible;
- the second level of planning is to develop estimated data to substantiate project funding requests and approvals;
- lastly, the third level of planning is the detailed engineering analysis.

**4.1 Approximate geographical coordinates for each station**

Once an approximate location for the station has been selected (or an existing site is selected for use), the latitude and longitude for the station can be determined. If an existing site is to be used, the geographic coordinates will be known (and can be checked by the use of a hand-held GPS receiver). If the site has not yet been firmly determined, an estimate of its geographic coordinates can be made from a recent topographic map.

## 4.2 Tentative site selection

The selection of an HF radio site requires a detailed analysis of the physical surroundings in which the radio site must function. Above all, the site chosen must be technically adequate.

Specifically, the engineer must consider the site's noise environment, ground conductivity, the obstacles in the foreground, and things such as buildings or mountains nearby that would obstruct the received or transmitted signals. Secondary considerations include ease of construction, access to utilities (water, electrical power, etc.) and access to the site. But, the technical adequacy of the site is the most important factor.

## 4.3 Path operational parameters

The purpose of making the propagation forecast is to estimate the optimum frequency to be used and to predict the system performance throughout the 11-year solar cycle and throughout the whole year. These propagation forecasts are used by the design engineer to select the proper equipment for the path.

## 4.4 Propagation forecast

An integral part of system design and analysis for an HF radiocommunication system is determining the atmospheric conditions through the use of a propagation forecast. The following details must be considered before an accurate propagation analysis may be made:

- site noise environment;
- antenna characteristics;
- RF power available;
- system gain.

### *Site noise environment*

Natural and man-made noise at the site should be measured throughout the day. Ideally, a site should be selected that is far from areas of high-noise concentration (i.e. far from industrial and residential areas and airports). Radio noise can be divided into two broad categories: noise internal to the receiving system and noise external to the receiving antenna. The radio noise internal to the receiving system is usually the limiting factor for radio systems operating above 300 MHz. For HF radio systems the external noise is the limiting factor and there can be no advantage in the use of receivers with noise specifications lower than the external noise levels. The external radio noise can be further divided into two broad sub-categories: natural and man-made noise. Examples of natural noise are atmospheric, galactic and solar noise. Sources of man-made noise are ignition systems, industrial equipment, power lines and electrical equipment in general. If it is not possible to measure atmospheric noise throughout the entire year, estimates can be made by reference to Recommendation ITU-R P.372. This Recommendation provides information on local atmospheric noise for different times of the day and for each of the four seasons of the year.

The dominant source of natural noise at HF is the atmospheric noise which is propagated from three main thunderstorm areas of the world, i.e., South America, Africa and south-east Asia. The atmospheric received noise follows propagation trends, which are lowest in the morning and highest in the evening.

A site survey is recommended to determine local man-made noise levels. The noise measurements are made with a monopole antenna connected to an electromagnetic noise meter. The measurements are made over a two-week period during 0800-1200 h and 2000-2400 h local time. The morning measurements give the man-made noise values and night measurements reflect the atmospheric noise levels. The measurements are made from 12 nominal frequencies clear from interference (0.17, 0.3, 0.5, 1, 1.8, 2.5, 5, 7, 10, 20 and 25 MHz). The measured data are averaged and plotted for comparison. A comparison between the values of man-made noise levels for quiet rural, rural, residential, and business areas shows an extreme difference of approximately 25 dB. A judicious choice of antenna site for the base station can improve performance of the system as much as 25 dB. The system availability and grade of service of the proposed system cannot be estimated accurately without the system noise level information.

#### 4.5 Equipment selection

The following is a listing of the most common components of an HF radio system:

- transmitter/receiver or transceiver
- antenna subsystem
- voice frequency interfaces
- digital interfaces
- transmission lines.

##### 4.5.1 Typical HF systems configurations

###### *Continuous wave (CW)*

In the early days of radio, a telegraph key was used to switch the RF carrier on and off in accordance with a telegraph code. Since the RF was a continuous wave when it was on, this form of transmission was called interrupted CW. It is most often referred to simply as CW. Most commercial and military equipment has a backup CW communications capability. The CW form of communication is useful as emergency communications when other forms of transmission cannot be used.

###### *Single sideband (SSB) voice*

SSB voice stations are typically small size, frequently desktop transceivers. Power output is usually about 100 W. Coupled with a linear amplifier, output will normally range from 400 to 1 000 W. There are many military uses for SSB voice systems such as command and control nets, administrative networks, ground-to-air and air-to-ground communications, convoy control nets, other mobile applications, and engineering circuits for transportable communications systems. Typical antennas may be a whip for mobile and transportable applications, a simple dipole, or a rotatable directional array such as a log-periodic or Yagi antenna for fixed station applications.

### *Multi-sited systems medium power station*

Unlike small, low-power installations where transmitters and receivers can be co-sited, larger, higher power (over 1 000 W) multichannel HF facilities usually require separate transmitter and receiver sites with a normal separation of 8 km or more. A third facility, the communications relay centre (CRC) may be necessary. The CRC performs the control, switching, and message processing activities. The sites are interconnected by a multichannel telephone link, either by multipair cable or by microwave radio.

### *Transmitter subsystem*

Transmitting equipment may be procured in a number of configurations with separate components or as completely self-contained end items. Large transmitters are usually configured into functional components including a frequency synthesizer, exciter, and a power amplifier section. Transmitter exciters are available which provide from one to four independent 3 kHz channel inputs. The four voice channels are used to provide the four-channel input to the ISB mode.

### *Receiver subsystems*

Most current receivers designed for larger HF facilities are tuneable by the use of a frequency synthesizer. A synthesizer may be a separate component or it may be an integral component of the receiver. More sophisticated frequency control techniques now available use microprocessor controlled tuning mechanisms for rapid and accurate frequency changes. ISB receivers are designed to provide the four 3 kHz voice frequency channels to the voice frequency termination and multiplex equipment.

### *Transceiver systems*

A transceiver is a transmitter, receiver and interface combination.

## **4.5.2 Antenna subsystem**

A typical large site antenna subsystem consists of all items related to the antennas, including the transmission lines, the antenna curtains, supports, dissipation lines (if applicable), switching and impedance matching devices, and entrance devices to the equipment shelters or site buildings.

## **4.5.3 Voice frequency interface equipment**

Voice frequency interface equipment provides the interconnection between the subscriber and the transmission system. Interface equipment provides the in-band signalling, equalization, attenuation, and amplification, or other signal conditioning that is needed for an interface between the transmission means and the voice frequency end instrument.

## **4.5.4 Transmission lines**

Transmission lines are basically of two types: balanced lines and unbalanced lines. Balanced transmission lines have two identical conductors or groups of conductors operated at equal potential (but opposite polarity) from ground. Unbalanced lines have one conductor above ground potential and the other at ground. Both types of lines may be enclosed in an external shielding conductor.

*Coaxial line*

A coaxial line is an unbalanced, shielded transmission line designed with one conductor in the centre and the other as a hollow cylinder completely enclosing the centre conductor. When properly designed, the outer conductor gives near perfect shielding since it is normally grounded, resulting in very little pickup of outside interference. This characteristic, more than any other, makes the coaxial transmission line the best choice for receiving use. In transmitting applications, coaxial lines have little radiation loss and are not affected by objects, conductors, or other transmission lines in the vicinity. Compared to open wire lines, however, coaxial lines generally have significantly higher line losses and, for high power applications, are more expensive. The loss characteristics and the power handling capabilities depend largely on the dielectric material separating the conductors. Power handling capability is related to the distance between the inner and outer conductors and the ability of the dielectric to withstand the heat generated in the inner conductor. Coaxial lines are divided into rigid, semirigid, and flexible.

- Rigid coaxial line is normally used: to connect high-power transmitter outputs to an antenna switching matrix, to an impedance matching device such as a balun or transformer, or to another type of 50  $\Omega$  coaxial line; or to enter or exit buildings. Rigid line has a tubular centre conductor supported concentrically with respect to the outer conductor by discs or crossed pins made of dielectric material. The line sections are connected by flanges and use manufactured elbows to change direction. Diameters generally range from 2.2 to 15.6 cm. Attenuation loss is generally less than open wire lines.
- Semirigid coaxial line is generally used in moderate sized power systems to approximately 20 kW. The semirigid cable can be carefully bent on a radius of 10 to 15 times the diameter of the line. The inner conductor is tubular, except for the smallest lines, where it is solid. The inner conductor is supported within the outer conductor by a helix of polystyrene. The outer conductor is frequently of a spiral wrap semiflexible armoured construction and is generally covered with a polyethylene or a vinyl protective covering. Attenuation losses are somewhat higher than those of open wire lines.
- Flexible coaxial cable is the most popular transmission line for small and medium HF station applications. There are types of flexible coaxial lines available to meet more requirements. They range in size from 0.3 to 3.2 cm and they range in impedance from 50 to 150  $\Omega$ . Attenuation loss is quite high when compared to open wire, especially for the smaller cables.
- A flexible coaxial line consists of a solid or stranded wire inner conductor surrounded by a polyethylene dielectric. Copper braid is woven over the dielectric to form the outer conductor. The copper braid should be capable of providing at least 95% shielding. Commercially available, inexpensive coaxial cable, providing only 60% to 80% shielding, should not be used. A waterproof vinyl or polyvinyl covering is placed over the woven braid. This outer insulating jacket is used solely as protection from dirt, moisture, and chemicals. These substances, if allowed to penetrate the insulating jacket, will contaminate the dielectric and will cause the cable to become lossy.



- As antenna transmission lines, flexible coaxial lines have their largest application in receiving systems. Receiving antennas with higher impedance, such as the log-periodics, ordinarily use coaxial cable with a matching transformer at the antenna end. Although coaxial cable makes a good impedance match to the centre of a balanced half-wave antenna, without a balun the unbalanced nature of the coaxial line will cause a skew in the antenna radiation pattern.
- One advantage of flexible coaxial line is that it can be installed with almost no regard for its surroundings. It requires no insulation, can be run on or in the ground or in piping, can be bent around comers with a reasonable radius, and can be “snaked” through places such as the space between walls where it would be impractical to use other types of line. Outside of the building, all permanent coaxial cable runs should be underground. The cable should be buried at least 50 cm in cold climates. The minimum burial depth is determined by the frost line or surface load. The cable should be cushioned with about 8 cm of sand below and above the cable, and planks should be laid above the top layer of sand prior to filling the trench. In this way the cable is protected from cuts if excavation is required. Concrete markers should be placed beside the trench at all turns to assist in location and protection of the cable. To minimize radio noise pickup on the receiving transmission lines, the matching balun should be installed on the termination pole of the antenna. The connecting coaxial cable is then run, preferably underground, to the receiver building. Cables for RF signals within the site building should be standardized at the same characteristic impedance, normally 50  $\Omega$ . Equipment with other characteristic impedances are matched to the 50  $\Omega$  RF line system by impedance matching transformers. Throughout the station, the RF cables should be physically grouped by service such as exciter cables, monitor cables, or patch panel cables.

### *Open wire line*

An open wire line consists of two or more parallel wires of the same size, maintained at a uniform spacing by insulated spreaders or spacers at suitable intervals. These lines can be balanced or unbalanced.

#### – *Unbalanced open wire line*

The characteristic impedance of unbalanced, open wire lines ranges from 20 to 200  $\Omega$  depending on the construction. Unbalanced open wire lines are used primarily for impedance matching.

#### – *Balanced open wire line*

For transmission, balanced open wire lines are frequently preferred instead of coaxial transmission lines. At all but very low power levels, the open wire line is more economical than coaxial line.

### *Transmission line runs*

For long transmission line runs, open wire balanced lines will have considerably smaller attenuation than will coaxial lines of comparable value. The velocity of wave propagation is nearly that of free-space. The maximum voltage rating depends on the spacing of the wires and the type, size, and condition of the insulators.

### *Feeder lines*

Open wire line is especially suited for feeding most broadband balanced antennas such as the Vee antenna. Open wire feeders are relatively simple to construct. Materials required are two conductors of copper-clad steel or hard-drawn copper wire long enough to reach from the antenna feed connection to the balun, along with spacers and insulators. The spacers need to be of high quality insulating material such as polystyrene or phenolic material and long enough to keep the feeder conductors at a uniform 15 cm spacing. The spacers are installed at intervals sufficiently frequent to preserve the spacing and prevent the line from twisting and shorting out. The intervals between spacers vary from 1 to 2 m. The balun should be connected as close to the lower insulators as is safe and practical. Open wire lines should be treated with caution. At a transmitter power output of 1 000 W, there are approximately 775 V on the wires.

## **4.6 Antenna specifications**

An HF communication network must be capable of operating on several different frequencies in the 3-30 MHz range as required to maintain communication. The physical size of a transmitting antenna is inversely proportional to the operating frequency and can be between 50-5 m in length. An antenna-matching network (antenna tuner) is required to make the antenna appear as a resistive load to the transmitter output. The antenna tuning has to be performed when the transmitter changes the frequency of operation. It is common practice in HF communications to use the same antenna for transmitting and receiving. However, the RF powers handled by receiving antennas are many orders of magnitude lower than those handled by transmitting antennas. Consequently, the high voltage insulation problems that must be considered in transmitting antenna systems are not present in receiving antenna systems. In general, an HF antenna with a given pattern can be made physically smaller for receiving applications, because the decreased efficiency (greater fractional power loss) that usually accompanies the smaller size can be tolerated in HF receiving applications. A more lossy antenna can be tolerated because the ambient external noise level is usually greater than the thermal noise level in a receiver; i.e., the power loss in the receiving antenna reduces both the signal and the atmospheric noise levels at the receiver input, but does not significantly change the  $S/N$  atmospheric and receiver ratio, provided the loss is not excessive. An example of a smaller size, single element receiving antenna is an unrolled loop that is a small fraction of a wavelength in diameter. Arrays of such elements can be used to provide gain and directivity.

To provide maximum radiated power a transmitting antenna is required to present to its drive source an impedance that remains inside certain limits. Typical values of impedance are 50, 70, 300 and 600  $\Omega$ . When the antenna is not exactly matched to the power output impedance, a portion of the output signal is reflected back to the transmitter. The reflected signal can undergo a phase change and add to the output signal of the transmitter, resulting in damage to the transmitter in the process. The impedance mismatch and the resulting reflected signal from the antenna is specified as the permissible voltage standing wave ratio (VSWR). The maximum VSWR value for commercial transmitters is 3:1. When the antenna impedance is not matched to the transmitter output impedance, the effective radiated RF power is reduced by the reflected power. The measurement of

forward and reflected power from an antenna system with an RF wattmeter is part of the periodic maintenance of the radio system to ensure peak performance of the communication equipment. The system should present an acceptable load impedance (VSWR < 2:1) to the HF transmitter to obtain reasonable transmitter efficiency. It is also desirable to concentrate the radiation of the antenna near the azimuth and elevation where ionospheric propagation to other receiving stations is effective.

The primary selection factors, which determine the antenna best, suited for a particular application are:

- frequency range;
- gain;
- directivity, take-off angle, vertical and horizontal radiation pattern;
- total radiated power;
- size and complexity, land area requirements;
- beamwidth;
- antenna bandwidth, input impedance.

#### 4.6.1 Antennas and ancillary equipment

Typical antennas used for HF communications are rhombic, log-periodic and half-wave dipole antennas. The first and second types of antennas are used in HF point-to-point services. The third antenna type, typically used in rural areas because of low-cost and easy installation and maintenance, will be described in the following.

##### 4.6.1.1 Half-wave dipole antennas

The half-wave dipole represents a fundamental form of resonant antenna and it is the unit from which many other complex forms of antennas are constructed. In its design, the following considerations are involved:

- The physical length of a half-wave antenna can be calculated by the formula:

$$\text{Length} = k(150/f) \quad \text{m} \quad (1)$$

where:

$f$ : frequency (MHz)

$150/f$ : length of a half-wave in free space

$k$ : correction factor to be taken for the particular length diameter ratio of the conductor used.

Equation (1) is sufficiently accurate for wire antennas at frequencies up to 30 MHz.

- The ohmic resistance of a half-wavelength antenna is generally small enough, compared with the radiation resistance, to be neglected for all practical purposes.
- The radiation resistance of a half-wave antenna is commonly taken to be about 60 to 70  $\Omega$ . The impedance of the antenna also depends upon the diameter of the conductor in relation to the wavelength.
- The radiation from a dipole antenna is not uniform in all directions but varies with angle in respect of the axis of the wire.
- This type of antenna is generally used for short distances.

The dipole antenna is typically one-half wavelength in size, horizontally polarized, narrow bandwidth and easy to install. The dipole antenna has very little azimuth directivity at the high radiation angles, which are required for short-range communication.

The height (in wavelengths) of the antenna above the ground generally determines the elevation angle of radiation. The optimum angle depends on the effective height of the ionosphere and the distance to the other station. Desired take-off angles and best heights for 1F2 are shown in Table 2.

TABLE 2

Distance (km)	Take-off angle (degrees)	Height above ground (wavelength)
200	60-75	0.28
400	45-65	0.33
800	30-45	0.42
1 200	20-35	0.55
1 600	15-25	0.72

Also it is not possible to mount the antenna at the optimum height for all the frequencies. The broadband dipole antenna requires one feed line for all the frequencies and does not need to be retuned when a frequency is changed but to present an acceptable load to the transmitter over the entire frequency range the antenna contains resistive elements which reduce antenna efficiency. These antennas are for short or medium range use with a high angle of radiation.

#### 4.6.2 Antenna specifications

Since we are dealing with HF antennas, our interest is in the 2 to 30 MHz range. Gain is the ratio of the power density radiated by the antenna in a given direction to that radiated by a reference antenna (usually an isotropic source) when both have equal input powers. Directivity is the ratio of the maximum power radiated by an antenna to the average radiated power. Gain and directivity are related in that increased gain is accompanied by greater directivity. This is because the total radiated power remains constant. Thus, an increase in power in some directions results in a decrease in power in other directions. Generally, directivity is considered in terms of vertical (take-off angle) and horizontal (azimuthal beamwidth) angular patterns. The many types of antennas in common use in HF radio provide different combinations of the essential characteristics to meet specific radio link needs.

Table 3 shows many of the important characteristics of HF antennas. The horizontal directivity is important because the antenna can be physically located or directionally turned toward the direction of interest.

TABLE 3

**HF antenna specifications**

Antenna type	Frequency range (MHz) <sup>(1)</sup>	Bandwidth <sup>(2)</sup>	Take-off angle (degrees)	Horizontal beam angle (degrees)	Gain (dBi)	Land area (hectares)	Range <sup>(3)</sup>	Use <sup>(4)</sup>
Dipole	2-30	Narrow	10-90	2-80	2	0.4	S-M	G-N
Inverted V	2-30	Narrow	40-90	OMNI	2	0.4	S	G-N
Inverted L	2-30	Narrow	20-90	80-180	3	0.4	S-M	G-N
Vehicular whip	2-30	Narrow	20-50	OMNI	3	Vehicular	M	M
Vertical quarter-wave	2-30	Narrow	5-40	OMNI	3-5	0.4	M-L	G-N
Quad loop	5-30	Narrow	10-90	80-120	3	0.4	M	G-N
Long wire	3-30	Broad	10-30	10-30	4-10	1.2	M-L	P
V antenna	3-30	Broad	5-30	5-30	4-16	1.6	M-L	P
Yagi	7-30	Narrow	10-35	30-60	7-12	0.4	M-L	G-N
Half rhombic	3-30	Broad	10-40	5-30	5-12	1.2	M-L	P
Vertical LPA	4-30	Broad	5-40	100	6-12	1.2-2	M-L	P
Horizontal LPA	2-30	Broad	10-45	40-75	8-16	0.4-2.4	M-L	P
Rotatable LPA	4-30	Broad	5-50	60-70	8-12	0.4	M-L	G-N-P

LPA: log-periodic antenna

- (1) Frequency range is typical of the antenna type (not of an individual antenna).
- (2) Radiation angles are for comparison purposes. Values represent average range. Actual values depend on ground conductivity, antenna height, and operating frequency.
- (3) S-Short 0-400 km; M-Medium 400-4 000 km; L-Long over 4 000 km.
- (4) G-Ground-to-air; M-Mobile; N-Net station, fixed; P-Point-to-point.

#### 4.6.2.1 Frequency range of operation

The frequency range of operation determines the bandwidth requirement of the antenna. The frequency range of operation is determined based on a computer-operated propagation analysis program to determine the optimum traffic frequencies for the path involved. An assigned frequency near or below the optimum traffic frequency is then used.

#### 4.6.2.2 Bandwidth

The bandwidth is the band over which the communication system can be used without modification to the antenna or its tuning. Antennas can be categorized as narrow-band (e.g. dipole or Yagi) or broadband (log-periodic or vertical half-rhombic).

#### 4.6.2.3 The horizontal range

The horizontal range of radiation angles (beamwidth) required for an antenna is determined by the area to be covered. Multipoint or net operation may require a broad or omnidirectional radiation pattern while point-to-point circuits can use narrow beam, higher gain, and directional antennas.

#### 4.6.2.4 Antenna selection

A significant factor in HF antenna selection is the physical size of the site required for erection of the antenna. An antenna site should be a clear flat area with no trees, building, fences, power lines, or natural terrain obstructions. Large HF arrays require large land areas. Lack of available space may dictate the selection of smaller antennas with less gain.

Antenna selection procedures can be conducted in the following steps:

*Step 1:* Determine the frequency range of operation and select the bandwidth required. If a broadband antenna is required but not otherwise available, two or more narrow-band antennas constructed to the available frequency complement may be selected.

*Step 2:* Determine the required take-off angle for the required path distance.

*Step 3:* Determine the area of coverage required: omnidirectional, bidirectional, or point-to-point coverage.

*Step 4:* Determine the antenna, which possesses the desired properties and produces the highest gain in the desired direction. Check to determine if the chosen antenna can be erected in the available space. If the antenna is to be constructed on site, check to see if the required materials are available. If space and materials are not available, a lower performance antenna may have to be selected.

### 4.7 Equipment performance requirements

#### 4.7.1 Transmitting subsystem

##### *Typical HF transmitters*

HF transmitters are available in many sizes and power ranges. Two power ranges, low power (below 1 000 W) and medium power (1 000 to 10 000 W) have been selected as representative of available equipment. Transmitting power is closely tied to the considerations to be made when considering propagation forecast. Typical medium-power transmitters have the same general electrical characteristics as smaller transmitters. The notable differences are in size, weight, and input power requirements

*Typical characteristics of low-power HF transmitters*

Frequency range: 1.6-30 MHz

Output power: 400 W

Operational modes: CW, USB, LSB, ISB, AM, FSK

Output impedance: 50  $\Omega$  unbalanced

Frequency control: Synthesized frequency generator, integrally or remotely controlled, preset available, tuning automatic with manual override

Cooling: Forced air, filtered

Cooling conditions: 0° to 50° C, 90% relative humidity

Input power: 115/230 V a.c., 50/60 Hz single phase 1 200 W.

*Installation*

Transmitters in this power range are available for installation in standard equipment cabinets. A complete transmitter as described above can be installed in approximately 0.3 m of cabinet space and would weigh about 160 kg. Two such transmitters can readily be installed in a standard 183 cm high equipment cabinet allowing adequate room between units for cooling.

*Operation*

The typical low-power transmitter can be used in either fixed stations or transportable stations. Frequency is set by a synthesized exciter which may be removed from its normal position in the transmitter cabinet and located elsewhere within the station. It also has a capability for a number of preset channels.

**4.7.2 Receiving subsystem**

HF general coverage receivers are of two general categories. Fixed frequency receivers are designed with frequency settings dials or switches and are intended for single frequency operation for hours or days at a time. Variable or tunable receivers are designed for rapid frequency changing and are more suitable for signal search operations. They may have a frequency lock feature to prevent accidental frequency change. There are also some receivers available which cover both the HF and VHF spectrum as part of their general coverage. Characteristics for a typical high quality generic receiver are listed below.

*Single or multiple channel receiver*

Frequency range: 1.6-30 MHz

Frequency stability: 1 part in  $10^6$

Operational modes: CW, USB, LSB, ISB, AM, FSK

Sensitivity: 0.5  $\mu$ V for 10 dB  $(S+N)/N$

Bandwidths: Selectable for 2.1, 3, and 6 kHz

Input impedance: 50  $\Omega$  unbalanced

Temperature range: -30° C to + 50° C, 95% relative humidity

Input power: 115/230 V a.c., 50/60 Hz, single-phase, 125 W

Size: 13 cm high, 48 cm wide, 48 cm deep

Weight: 45 kg.

### 4.7.3 HF transceivers

#### *Typical HF transceivers*

There are many types of transceivers available off-the-shelf. In general, most have power outputs in 100 to 200 W range and are ideally suited for use in small communications sites. A typical transceiver will be entirely solid state, including the final amplifier. Frequency can be changed rapidly, requiring no peaking or tuning. Stability is excellent requiring little or no adjustment between frequency changes. Transceivers are lightweight and entirely self contained, requiring only a microphone or key connected to the input and a suitable antenna connected to the output. The essential characteristics of a typical HF transceiver are as follows:

Frequency range:	1.6-30 MHz
Frequency setting:	Decade switches or continuous tuning by dial with frequency lock
Operational modes:	CW, USB, LSB, ISB, AM, FSK
Power output:	150 W peak envelope power or 100 W average
Output impedance:	50 $\Omega$ unbalanced
Bandwidths:	2.7-3.0 kHz for SSB, 375 Hz for CW
Receiver sensitivity:	0.5 $\mu$ V for 10 dB $(S+N)/N$
Temperature range:	-30° C to +50° C, 95% relative humidity
Input power:	115/230 V a.c., 50/60 Hz, single-phase, 400 W
Size:	18 cm high, 43 cm wide, 43 cm deep
Weight:	50 kg.

#### 4.7.3.1 Ancillary HF components

##### *Ancillary HF components*

A transmitter or receiver usually requires certain peripheral items to constitute a complete operating system. Some of the common items used are described in the following paragraphs.

*Lowpass filters:* Use of low-pass filters at the output of HF transmitters is often required. Since the frequency spectrum above 30 MHz is used by many low-power services susceptible to interference from harmonics of high-powered transmitters, it is necessary to use measures to suppress these spurious emissions as much as possible. Low-pass filters having attenuation of up to 60 dB at frequencies above 32 MHz are available for transmitter powers up to 40000 W. The proper filters are included as an integral part of higher power transmitters.

*Preselectors:* The purpose of a preselector is to minimize receiver overload from nearby transmitters and interference from adjacent RF channels. A preselector is required when the receiver must work in an RF environment that includes high levels of unwanted signals resulting in intermodulation and front-end overload problems. Preselectors are available which will provide protection to the receiver from signals as high as 200 V at frequencies 10% or more removed from the desired frequency.



## 5 Site/field surveys

The primary technical objectives for a good HF radio site are to obtain the maximum  $S/N$  at the receiver site and maximum effective power radiated in the desired direction from the transmitter site. Site topography affects the signal radiated from the transmitting site and signal arrival at the receiver site. The presence of natural and man-made noise detracts from the ability to obtain a good  $S/N$  at receiver sites. Desirable ground constants improve the performance of both transmit and receive antennas. These and other factors which enter into the selection of HF sites often involve compromises and trade-offs between economy, availability, and convenience. This section identifies items to look for in topography relative to terrain features and land-area requirements. Man-made radio frequency noise levels are defined for different areas. Site separation distances from noise sources are given. Earth constants in terms of resistivity and conductivity are discussed. General site requirements of availability, suitability, accessibility, and security are evaluated as to their influence on budget estimate and practicality.

### 5.1 Topography

The technically ideal HF radio site requires a broad expanse of flat, treeless land away from natural and man-made obstacles. Terrain flatness is necessary for uniform ground reflection of the antenna radiation. Obstacles may mask portions of the signal-radiation path at transmit and receive sites.

#### *Site terrain features*

The nature of the terrain in front of an antenna has a significant influence on the vertical radiation pattern. A good antenna site will have a smooth reflection zone and will be free of obstacles that may block the radiation path.

- *Reflection zone:* The reflection zone is the area directly in front of the antenna that is required for the reflection of the ground-reflected component of the sky wave signal. The surface of the reflection zone should not have any abrupt changes in elevation greater than 10% of the antenna height nor a slope greater than 10% in any direction. Surface irregularities in the area should be limited to 0.1 wavelength in height at the highest operating frequency. The reflection zone at fixed sites and wherever else practicable should be cleared of all trees and brush. A low ground cover of grass, clover, or similar growth should be maintained for erosion control.
- *Obstacles:* In the direction of propagation, any substantial obstruction (such as a terrain mass, man-made structures, and trees) should subtend a vertical angle less than one-half of the angle between the horizontal and the lower 3 dB point of the required take-off angle. At potential HF sites where obstructions are likely to be encountered, a manually plotted site azimuth-elevation profile should be made. Elevation profile records are also useful for future planning in the event of expansion. Such a profile may be drawn by using a transit and a compass with azimuth readings corrected for the local magnetic variation. Normally, plotting the elevation in 10° increments of azimuth will be satisfactory.

### *Land area requirements*

The area required for an HF site depends upon the size and number of antennas, the spacing between antennas, the clearance required for ground reflection, and the clearance required to avoid mutual coupling. In addition to known initial plans, space should usually be set aside for unspecified future antenna field expansion. Sites may vary from a minimum of a few acres for a small site to up to 60 acres for a medium-sized site.

## **5.2 Radio transmitting station site choice**

Two essential technical factors may influence the site choice for the installation of a radio transmitting station:

- availability of an expanse of flat land, clear from natural and artificial encumbrances over the whole horizon, for the antenna installation;
- possibility of easy utilization of the existing main networks for the transmitter power supply.

## **5.3 Radio receiving station site choice**

A good quality reception and ease of operating can be attained with a site having the following:

- considerable ground space, possibly a square surface, both for allowing an optimal installation of directional antennas at a suitable distance (for diversity reception 200-300 m) and for obtaining a minimum beam as a safety guarantee against mechanical encumbrances and neighbourhood electrical interferences;
- level ground configuration, so as to install an antenna array having a regular electric behaviour;
- a clear, unobstructed view of the horizon around the antenna, for an elevation angle of less than 40°;
- man-made noise negligible with respect to atmospheric noise;
- no buildings, high voltage lines or other radio electric interference sources nearby;
- possibility of easy utilization of existing main networks for receiver power supply.

### **5.3.1 Environmental RF noise receiving station site**

For reliable reception of weak signals from distant stations, the receiving antennas must be located in an electromagnetically quiet area relatively free from man-made noise. At HF, there are three major sources of RF noise: galactic, atmospheric, and man-made. The latter is of chief concern since it is the only source over which some control can be exercised. At many locations the noise from power lines dominates in the lower part of the HF band. Ignition noise from motor vehicles tends to predominate over power-line noise in the upper part of the HF band. Any strong, nearby source can be dominant in controlling the noise environment.

### *Site separation*

Radio transmitters located within several miles of a receiving station may create serious interference due to harmonics or co-channel operation. In addition, intermodulation products may be generated in receivers due to intense radio energy fields from nearby transmitters even when operated on widely separated frequencies. Radio receiver and transmitter sites must be isolated from each other, from other radio facilities, and from heavily travelled highways, cities, and industrial areas. Exceptions are sometimes required for small sites where antennas may be as close as 300 m from each other. Transmitters with less than about 1 kW of transmitting power can be collocated with receivers if special attention is given to frequency selection. The use of RF filters may be necessary at collocated sites.

### **5.3.2 Earth constants**

Resistivity and conductivity of the earth and the relative dielectric constant at the HF site should be considered during site selection. The resistivity of the earth affects the quality of the earth electrode grounding system. Good conductivity of the earth increases the range of groundwave propagation and lowers the take-off angle of sky wave signals, thereby increasing their range. Ground conductivity is difficult to measure accurately. However, it may be estimated by the nature of the terrain.

### **5.3.3 General site requirements**

In addition to the technical factors, other important features of a general nature should be considered when selecting HF sites, are availability, suitability, accessibility and security:

#### *Availability*

Land which meets the flatness criteria of an HF site is generally prime construction land or agricultural land. When this land is acquired, the acreage required even in small sites, can be very expensive. In fact, land acquisition may be the single greatest expense in the project. Therefore, the site selector should always consider the use of existing facilities. The least expensive siting of an HF installation is to use and expand an existing HF site.

#### *Suitability*

The general suitability of a potential site is dependent upon the magnitude of construction required for site development, implementation, and maintenance of facilities. The existence and capacity of nearby utilities such as electrical power, water, gas, and sewage disposal are important factors in site selection. Information relating to geological conditions such as soil and drainage data, wind and weather data (including icing conditions), and seismic activity should be gathered and considered. Soil and drainage data should be available from the supporting facility engineer. Wind and weather data are available from area weather stations, while records on seismic activity are usually available from the geological survey or from a nearby university geophysics department.

### *Accessibility*

Access to HF sites should be supported by the existence of adjacent roads and highways leading to the site. Conditions such as slopes, constrictions, curves, overhead and side clearances, surfacing, turnouts, and weight limitations on bridges and culverts should allow transportation of equipment during installation as well as during support operation and maintenance after installation. The facility engineer should be consulted about existing road conditions or for new road construction.

### *Security*

HF radio site selection should consider provision for fences, area lighting, guard and alarm systems and proximity to other facilities.

#### **5.3.4 Site survey procedures**

Site surveys are conducted for the purpose of determining the technical and general suitability of land for an HF transmitting or receiving site. Each survey will have unique requirements for the number and size of transmitters, number of receivers, and the land and topography requirements for antennas. The process of selection of a site for a radio transmitting or receiving facility involves three distinct steps:

*Step 1:* Entails map studies, ownership studies, logistics studies, and long range planning to select several tentative candidate areas.

*Step 2:* Consists of teams who conduct preliminary site surveys to gather general site information of all the likely candidate areas. From the general site information, the list of candidate sites is then reduced to a potential few.

*Step 3* Involves survey teams who visit one or more of the final sites selected. The teams will gather detailed information which will be analysed to determine the adequacy of the site or sites. From this information, a decision is made as to the best site to use for the facility.

More information can be found in the ITU-R Handbook on Spectrum monitoring.

#### **5.3.5 Construction plans**

There is no standard configuration for the layout of HF radio sites. This is due to the wide variations in the makeup of HF radio stations. Some factors and considerations in HF station layout and development are contained in this section. When developing fixed small- and medium-sized HF systems, the selection of buildings, land, and related physical plant is usually limited to the modification of existing facilities. The development of HF radiocommunications systems within existing buildings and antenna layout on the existing land becomes a task of adapting the new system to available facilities. Antenna field layout specifications are governed by the area available to provide reflection zones and the clearances required to avoid mutual coupling between antennas. Other factors involve separation for purposes of diversity reception and consideration of interconnections between antennas and equipment. Typical site layouts, which may serve as a point of departure to the site layout designer, are depicted in this section. The early establishment of the sequence of installation is the key to the orderly development of transportable HF communications.

### 5.3.6 HF antenna layout

One of the most important factors in the successful performance of HF radiocommunications is the correct positioning of antennas to provide maximum performance. An HF antenna layout requires a practical balance between choosing good sites, taking advantage of natural terrain features, separating noise sources, and taking into consideration the requirements for logistic support and accessibility. HF antenna layout within a selected site involves three determinations: the requirements relating to the reflection zone area, the mutual separation clearances, and the physical layout of related facilities.

#### *Reflection zone areas*

The reflection zone is the area required in front of an antenna for the formation of the ground reflection lobe. The main lobe of an HF transmitting or receiving antenna is formed by the interaction of the direct radiation and the reflection from the ground plane. The ideal reflection zone has the following characteristics:

- it is perfectly smooth, unobstructed ground or water;
- it is of sufficient size as determined by the operating frequency and take-off angle, and
- it is an elliptically shaped area with the major axis in the direction of the radiation pattern of the antenna.

#### *Mutual coupling*

Mutual coupling is the effect of one antenna on another antenna when both antennas are located in the same general area. Mutual coupling occurs:

- when the radiation pattern of one antenna passes through another antenna;
- when antennas interact by being too close; or
- when an antenna couples to a metal object or structure.

Mutual coupling may alter the radiation pattern of the antenna, may cause high reflection losses, may change the resonant frequency, or may introduce interference in other systems. Mutual coupling may be calculated as a function of the distance of separation, frequency of operation, and antenna gain.

#### *Other antenna siting considerations*

In addition to separation distances to avoid mutual coupling, space diversity antennas must be separated to perform properly. Receive antennas operating in space diversity mode should be separated from each other by a minimum of 300 m and, where space permits, by five wavelengths at their lowest operating frequency. Space diversity antennas should be located for both lateral and forward separation. Other considerations are:

- requirements for a spare antenna;
- room for future expansion;
- short and direct transmission-line runs;
- orderly arrangement of the transmission line;
- building entrance;

- equipment location with the building;
- separation between transmission lines;
- clearance of service roads and obstructions from in front of antennas.

### 5.3.7 Typical fixed site layout

The physical size and layout of an HF facility are dictated by the communications traffic that the facility is expected to handle. Simple HF antennas often require space of less than one acre, however, a single large fixed HF antenna may require up to 15 acres. A small transmitting facility could consist of a single transmitter using a rotatable log-periodic or Yagi antenna for transmission on different azimuths. A similar receiver site separated some distance for isolation could also contain remote control facilities for the transmitter. A single-circuit facility may have a transmitter and receiver collocated and may use the same antenna in simplex mode. A medium sized facility could consist of several fixed antenna systems serving an equal number of transmitters and receivers at separate sites up to 16 km apart.

Generator power installations of 100 kW output power or less may be integrated into the operations building complex, but ideally are installed in a separate building near the operations building. Power building should be of well-bonded metal construction with fuel storage facilities. Fuel storage may be in aboveground tanks near the power building, but ideally should be buried and located with a trench at least 10 m from the power building.

### 5.3.8 System test and evaluation plans

An important part of any installation is to perform a system test and to evaluate the installation in a performing environment. As the system analysis and design phase progresses, thought should be given to how the system will be tested and evaluate after installation. One of the important steps that the system engineer should generate is a system test and evaluation plan that will be carried out as soon as installation and operation has begun. In cases where a network is involved, the network manager should be involved and the network design plan should be considered an integral part of final system test. Areas that should be included in a system test plan might be:

- system performance;
- network performance;
- data and message throughput;
- power considerations;
- physical and network security.

## 6 System test

As the third phase of installation of the HF radio system, the system test and evaluation plan must be implemented. Possible areas that should be examined might include:

### *System performance:*

- operating all equipment, which includes adjusting transmitter power, reading meters, rotating antennas, etc.;
- equipment functioning properly;
- transmitters, and receivers operating within specifications;
- antenna performance;
- are we reaching all the stations we wish;
- are radiation patterns as expected;
- environmental noise as expected.

### *Network performance:*

- proper network connectivities;
- reasonable congestion;
- proper network capabilities;
- reasonable number of system faults;
- proper software installation;
- network routing tables being filled properly;
- linking protection scramblers functioning properly.

### *Data and message throughput:*

- linking properly with all stations;
- priority message handling adequate;
- data message throughput adequate.

### *Power considerations:*

- adequate power for all operations, including emergency conditions;
- clean power with only minor noise and fluctuations.

### *Review site security plan:*

- physical security adequate on all parameters;
- no hazardous conditions left from construction or implementation;
- network security is functioning.

## 7 Conclusion

HF radio design process is not difficult if the proper up-front planning is done and the project manager understands just what is to be accomplished. To summarize the major steps:

**7.1** From definition and analysis of the requirements should be detailed in a preliminary system design and feasibility study. This plan outlines requirements for frequencies, personnel, support, local issues, communication type, reliability, real estate, environmental impact, milestone dates, etc. Also included should be a detailed estimate of all known aspects of the design. Individual steps to be accomplished in the system design are listed in Table 4.

TABLE 4  
Step-by-step system design procedures

Step No.	Task to be accomplished
1	Prepare system block diagram
2	Tentatively select sites for HF equipment
3	Determine final site locations from field survey data
4	Determine total required system gain
5	Develop a detailed block diagram for each facility
6	Research possible equipment sources military inventory and commercial
7	Write specifications for equipment not in the inventory
8	Develop equipment subsystem application drawings for each facility
9	Complete installation package (specifications and drawings)
10	Prepare acceptance test procedures for each equipment, subsystem, and the total system

**7.2** A system analysis and design is then completed, to identify the details of the network topology, operational parameters, propagation forecast, equipment selection, performance issues, site surveys, and construction plans. Also included in the system design is the writing of a plan for system test and evaluation.

**7.3** The third phase is the system test and evaluation phase where details of system are checked for proper performance.

The system designer and network manager must fully cooperate to ensure that all details of the system design and network design are properly coordinated and completed.

With careful management, the HF radio system can be a valuable asset to the communication needs of the typical user. HF propagation has many valuable attributes and a few weaknesses. By proper planning, many of these weaknesses can be overcome.