REPORT ITU-R M.2027*

Engineering guidance for operators to upgrade shore based facilities to operate the Global Maritime Distress and Safety System in the A1, A2 and A3/A4 sea areas

(2001)

1 Overview

In order to establish a new A2, A3, or A4 sea area it is necessary to gain some knowledge of how the propagation conditions vary. A2 coverage is by groundwave, which is stable, enabling the extent of the service area to be confirmed by measurement before committing capital expenditure, which is recommended by the IMO. A3 and A4 coverage is by skywave which depends upon the condition of the ionosphere which varies with solar activity. Since this follows an 11-year cycle, the extent of the service area cannot be confirmed by performing a new measurement study, and administrations wishing to join the HF shore station network may require methods to verify feasibility and size the equipment required in order to confidently establish a project budget.

The extent of the sea areas A2, A3, and A4 are specified by the IMO in Annex 3 to their resolution A.801(19), and § 3.4.1 of this Report provides charts for rapid assessment of the extent of the A2 sea area using this data, and also guidelines to enable administrations to make their own assessment of potential A3 and A4 coverage using HF prediction software in the context that each shore station is a member of a community of HF stations working together to provide the required grade of service.

– Section 2 defines the functional requirements, and describes the equipment required.

– Section 3 defines single sideband (SSB) carrier/noise ratio and useable signal level, outlines the grades of service, presents performance criteria, reviews the software tools available and provides guidance on determination of receive ranges and transmitter power requirements.

– Section 4 covers site engineering issues: including selection of good receive sites, isolation between sites, protection of watch frequencies, station earthing and lightning protection.

2 The Global Maritime Distress and Safety System (GMDSS)

2.1 Statutory requirements

The GMDSS came into force in February 1992 under the international convention for the Safety of Life at Sea (SOLAS) amended in November 1988 and is intended for setting up a global communications network to support search and rescue activities from land, air and sea for rapid rescue for ships in distress.

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* This Report should be brought to the attention of the International Maritime Organization (IMO).

The GMDSS allows shore based search and rescue (SAR) authorities as well as ships in the immediate vicinity of the ship in distress to be rapidly alerted to the distress incident so that they can assist in coordinated search and rescue operations with a minimum delay.

The GMDSS substantially expands the SAR communications coverage to the global sphere using the VHF, MF and HF bands as well as satellite communication systems using digital selective calling (DSC) which allows a ship in distress to rapidly transmit information on its situation to a shore-based coast station in a simple, secure way. The coast station that has received a distress alert can easily access the ship for SAR communications.

In addition, the GMDSS NAVTEX system provides automatic broadcasting of maritime safety information, navigational and meteorological warnings and SAR information to all ships in a coastal area of up to 500 nautical miles offshore.

Full GMDSS coverage is provided by dividing the oceans of the world into four different areas in which ships are expected to operate:

Area	Definition of sea area	Means of coverage	Typical range
A1	An area within radiotelephone coverage of at least one VHF shore station, in which continuous DSC alerting is available	*Permanent VHF coverage* Within line-of-sight of antenna, extended when ducting persists	*Short range* 15 to 30 nautical miles offshore
A2	An area, excluding sea area A1, within radiotelephone coverage of at least one MF station, in which continuous DSC alerting is available	*Permanent MF coverage* Groundwave propagation over the horizon with some patches fading at night	*Medium range* 100 to 300 nautical miles offshore
A3	An area, excluding sea areas A1 and A2, within which the elevation of an INMARSAT geostationary satellite is 5° or more	*Alternative to INMARSAT* Using skywave propagation on 5 HF bands	*Long range* Mainly between latitude 70° N and latitude 70° S
A4	An area outside sea areas A1, A2, and A3	*Primary HF coverage* Shared between network of participating shore stations by skywave on 5 HF bands	*Long range* Beginning north of 70° N south of 70° S

2.2 Operational requirements

2.2.1 Basic operator functions

Shore-based coast stations providing ships at sea with VHF, MF or HF radiocommunication services for use with the GMDSS have to incorporate the following functions.

Reception of distress alerts. The shore station is required to keep continuous watch for distress alerts transmitted from ships using DSC. The distress alert identifies the ship in distress, its position, the nature of the distress, the type of assistance required and the time of recording of the information.

Transmission of acknowledgement. The shore station which has received a distress alert is required to send back an acknowledgement signal to the ship in distress, to cease any transmission which may interfere with distress traffic, and to continue to watch distress traffic.

Re-transmission of the distress alert. The shore station is required to have the means to re-transmit the received distress alert to all the ships navigating in the vicinity of the ship in distress.

Dissemination of maritime safety information. To support SAR operations, shore-based coast stations are expected to disseminate maritime safety information including navigational and meteorological warnings and other urgency and safety messages. The NAVTEX information is transmitted on 518 kHz by means of narrow-band direct printing (NBDP) telegraphy in forward error correction (FEC) mode.

2.2.2 Functional roles played by shore-based facilities

Although arrangements differ from country to country, shore-based facilities generally comprise radio stations and SAR forces under the supervision of one or more rescue coordination centres (RCC), and rescue missions commonly employ facilities from more than one country, calling for a high degree of international cooperation. Annex 2 of document COM33/2/3 (July 1987) – Input from IMO subcommittee on Life Saving Appliances, Search and Rescue to IMO subcommittee on Radiocommunication concerning SAR communications on Long Ranges in GMDSS, describes how the search and rescue operations are coordinated by the international RCC community with direct assistance from shore-based radio facilities, and lays out some basic guidelines for international cooperation.

The shore station nearest to the reported distress position should acknowledge the alert. Other shore stations receiving the alert should acknowledge if the nearest station does not appear to respond, which may be due to the variability of HF skywave communications. The shore station which acknowledges the alert is then expected to establish and maintain communications with the casualty until relieved by the affiliated RCC which bears responsibility for all subsequent coordination of SAR measures, unless and until responsibility is accepted by another RCC better able to take action.

2.2.3 Initial operator response to a distress alert

The loss of life resulting from any accident or disaster is reduced by the speed of response from the rescue service. The prime directive should therefore be to enable the shore station operator to implement the fastest possible response, summarized as:

– recognizing the nature of the distress and notifying the affiliated RCC;

– establishing initial contact with the distressed vessel or task force;

– accepting responsibility for and initiating transmission of the DSC acknowledgement;

– patching the RCC through by radio to the distressed vessel or task force if required.

The operator response software should be designed to immediately invoke an appropriate human response, minimizing the amount of time which the operator should spend correlating data, deciding what action to take, and performing subsequent actions like dialling telephone numbers and setting up equipment.

The ship's crew-member raising the alert has the option to request the use of NBDP for follow-on communication, mandatory if in A4 waters. The operator workstation should therefore be equipped to double as an NBDP chat-mode terminal.

2.3 Equipment required for distress response

2.3.1 Basic equipment required for short-range communication (A1)

A country with an extended coastline may need a number of VHF base stations for effective radio coverage, as shown in Fig. 1, in which one RCC supervises a number of geographically based subsystems, each with its own operator. As a call may be picked up by more than one base station, each subsystem would use a voting system to decide which base station to use, and these would be linked between sites to decide which operator would be responsible for overlapping calls.

FIGURE 1

Typical system covering a complete coastline

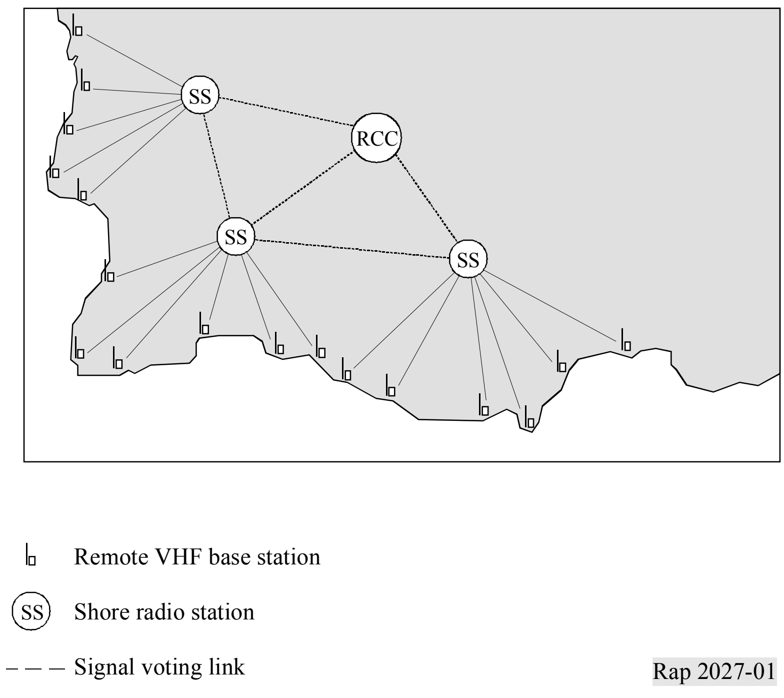


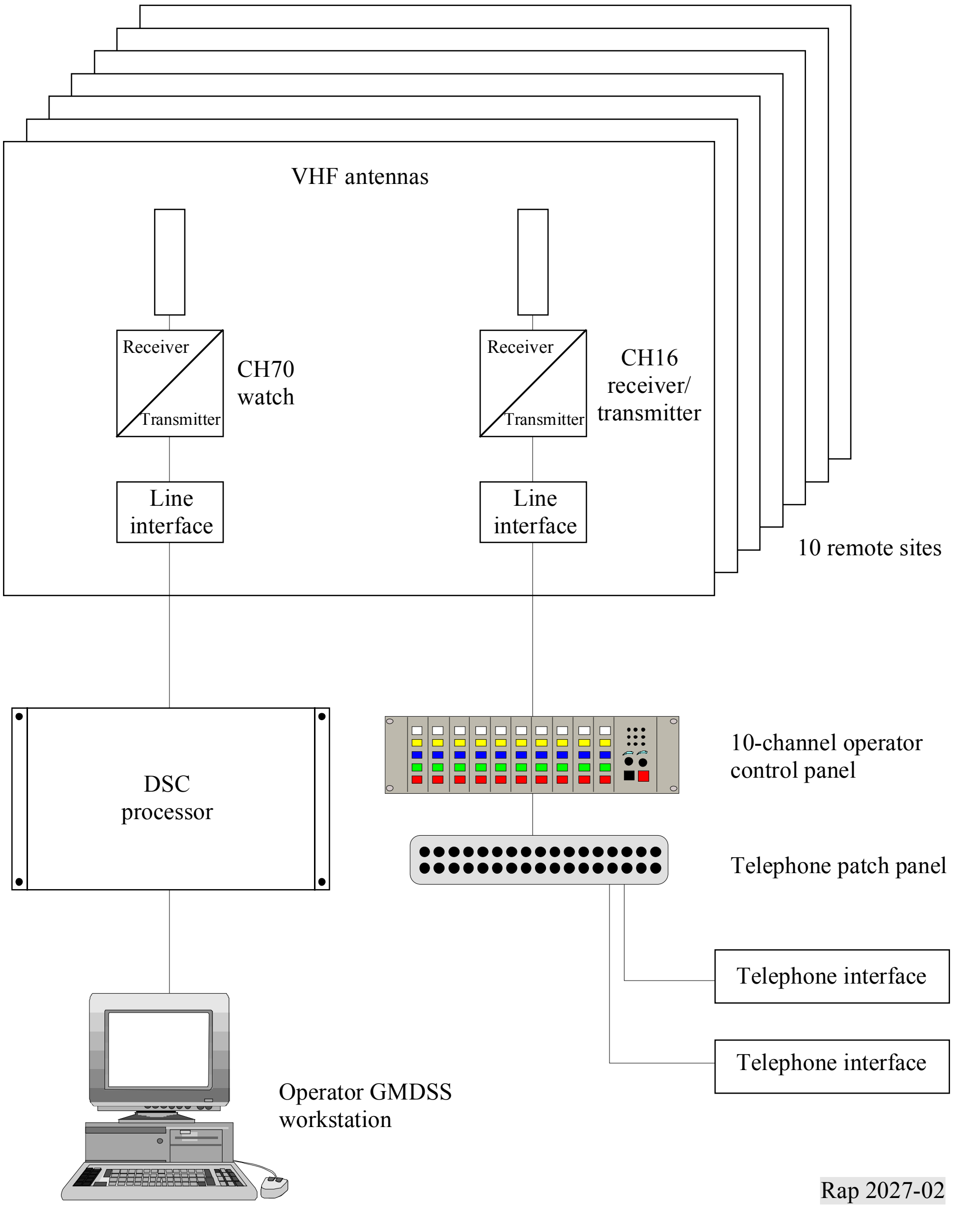
Figure 2 depicts the basic equipment required in each subsystem to provide a response to an A1 distress alert, showing 10 remote VHF base stations under the control of a single DSC processor and operator.

2.3.2 Basic equipment for medium-range communication (A2)

Figure 3 shows the basic equipment required for providing a response to an A2 distress alert, configured to enable the transmission of the distress acknowledgement and provision of manual response using SSB radiotelephony to be accomplished using a single transmitter.

FIGURE 2

Basic GMDSS A1 subsystem

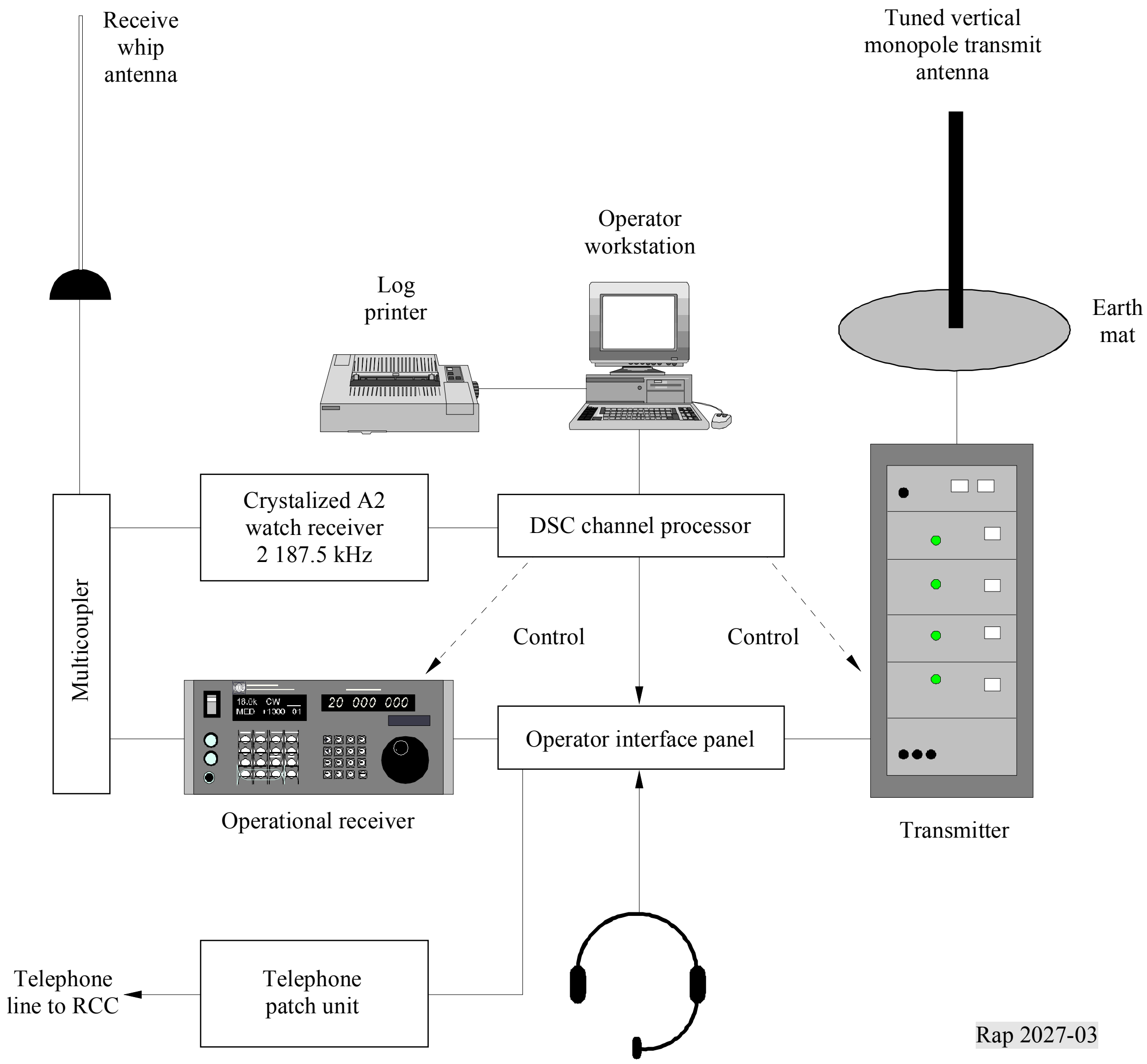


A short whip receive antenna is connected to a crystallized A2 watch receiver and an operational receiver via a multi-coupler. The watch receiver output is connected to DSC processor modem input, the modem audio frequency and PTT outputs being connected to the transmitter via an interface panel to enable the DSC acknowledgement to be routed to the transmitter when required. The interface panel enables the operator to establish a radiotelephony circuit with the ship, and provide the necessary connection to the RCC, and to maintain control of the transmitter and receiver.

The transmit antenna is a vertically polarized tuned monopole antenna, capable of launching a groundwave for A2 response. The size of transmitter required will depend upon the antenna efficiency, which depends upon the antenna length, and the size of the earth mat, and for output powers below 500 W it would be possible to combine the transmitter and the operational receiver into a single transceiver. More information on antenna efficiency is given in § 4.5.1.3 below.

FIGURE 3

Basic GMDSS MF DSC system



The transmitter and operational receiver can be set to the appropriate mode and frequency by the DSC processor, either directly, or indirectly via the operator workstation.

Additional equipment which may be used, but is not shown, include modems to enable the equipment to be installed on separate sites, and a call logger to enable the radiotelephony messages and DSC signals to be recorded.

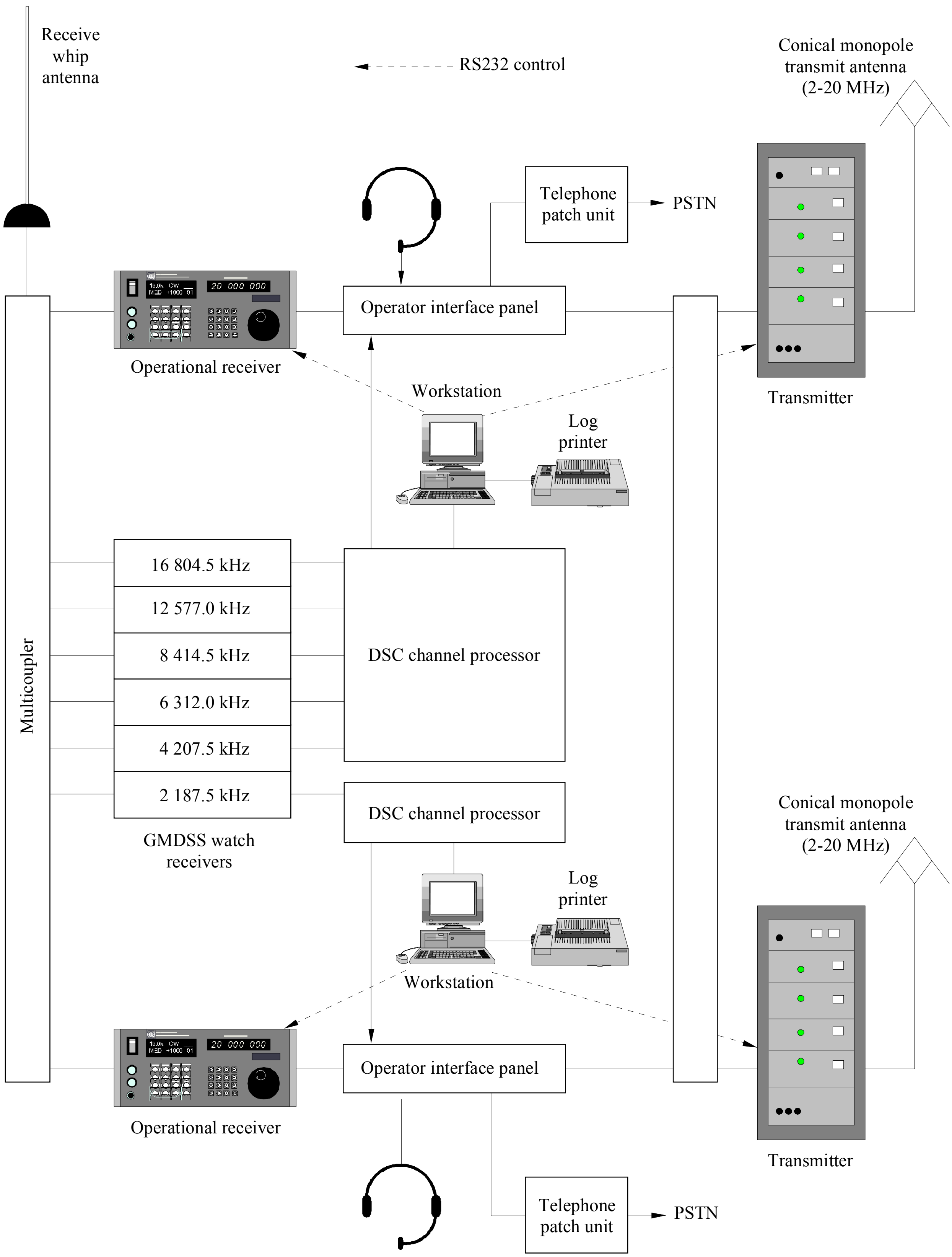
2.3.3 Basic equipment for medium- and long-range communication (A2/A3)

Figure 4 shows the additional equipment required to the basic configuration in Fig. 3 for a second channel providing A3 coverage, comprising watch receivers and DSC modems to cover the five HF bands, operational receiver, transmitter, and transmit antenna.

Both transmitters connect to their own wideband conical monopole antenna suitable for initiating groundwaves for MF A2 coverage, and low angle skywaves for HF A3 coverage, and a transmitter crosspatch ensures that if one transmitter fails the remaining transmitter can be used on either service. Additional redundancy could be provided by doubling the number of watch-keeping receivers, providing two identical subsystems each capable of operating on either A2 or A3.

FIGURE 4

Basic GMDSS MF or HF DSC system



PSTN: public switched telephone network

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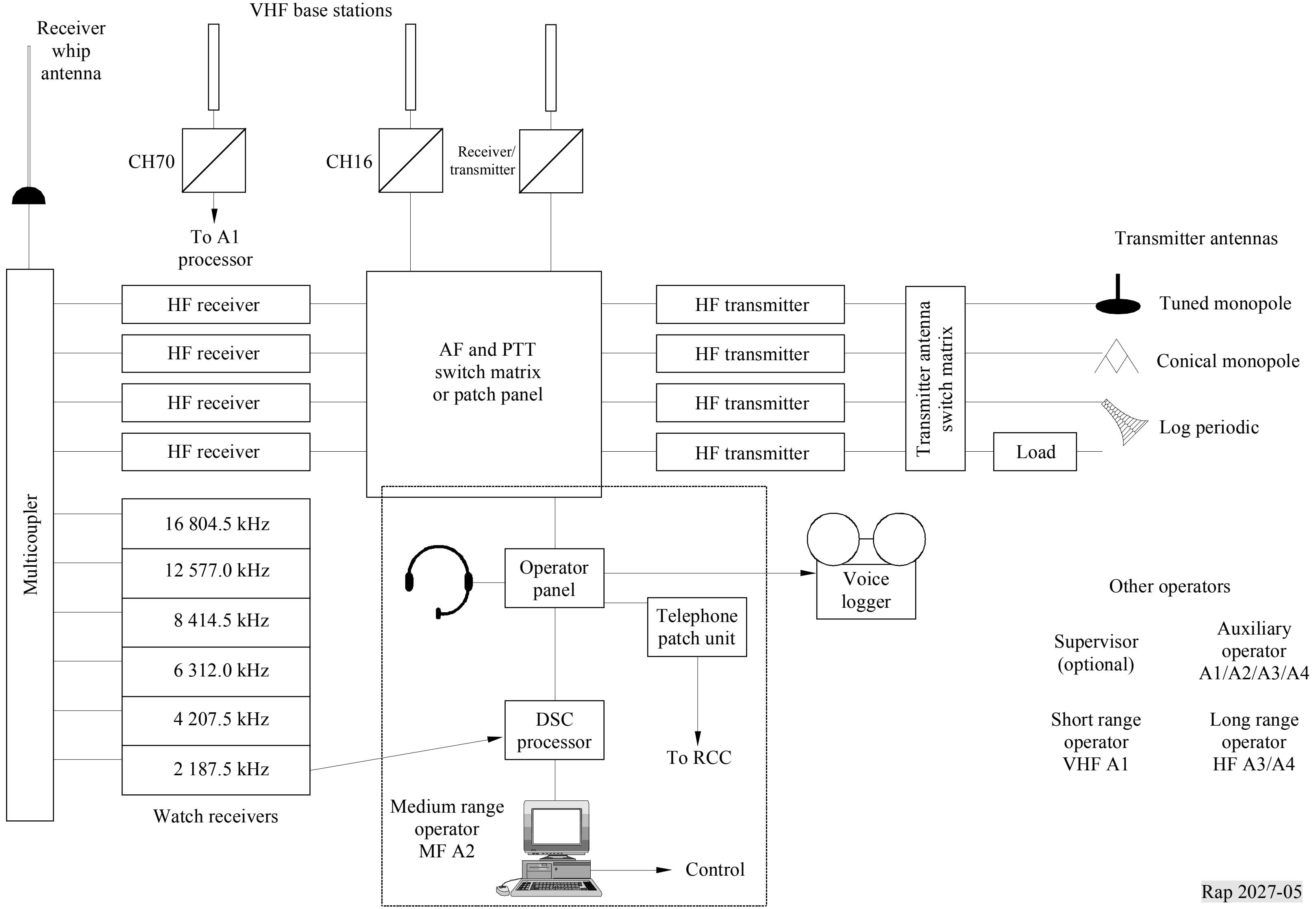
2.3.3.1 Typical system providing full cover on A2, A3, and A4

FIGURE 5

Typical system providing full GMDSS A1, A2, and HF coverage

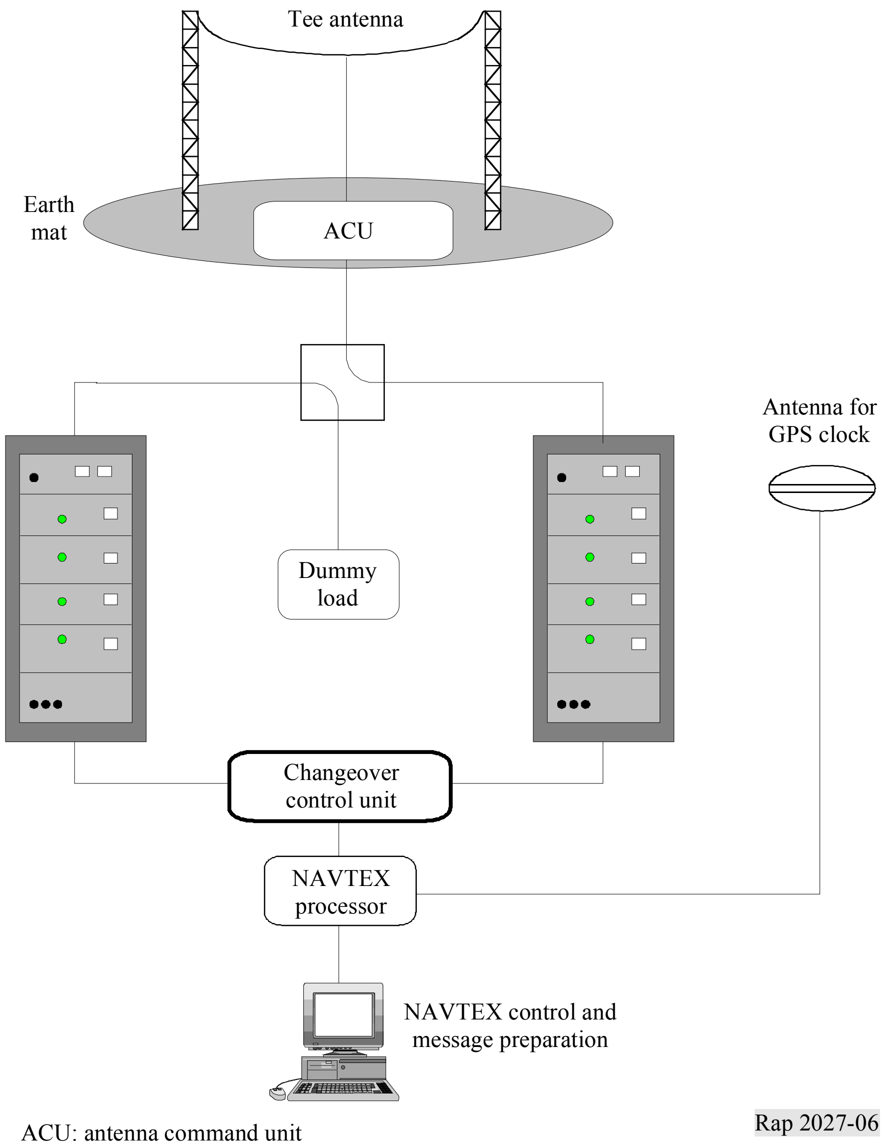


2.3.4 NAVTEX system

The NAVTEX system can store broadcast messages in advance and automatically send them out on a pre-set broadcast timetable. The 518 kHz transmitter is designed to operate in the F1B mode in order to transmit NAVTEX information in the FEC mode through the NBDP system.

FIGURE 6

Basic NAVTEX system



3 System planning

3.1 Planning objectives

Shore-based GMDSS stations have to provide short-range, medium-range and/or long-range services using VHF, MF and HF bands, respectively. Whereas an A1 sea area may require a large number of VHF stations at intervals along the coastline, NAVTEX and A2 sea areas can each be covered from a single shore station, which should be designed to provide a grade of service offering 95% availability for A2, and 90% for NAVTEX broadcasts. The responsibility for covering A3 and A4 sea areas is shared between a number of shore stations working together to provide a joint availability of 90%, i.e. a 90% probability that a call will be picked up by any one shore station.

The range achieved depends upon the transmitted power, the propagation loss, and the ability of the receiver to discriminate between the wanted signal and the unwanted noise or interference. The level of each component in the received signal will drift as the propagation conditions change with time, and therefore arrive at the receive antenna in varying proportions, and the final system design should ensure that the level of the signal will exceed the level of the noise by an adequate amount for an adequate proportion of the time. This proportion is called the availability, and is determined by quantifying the behaviour of the signal and the noise with time.

3.2 Planning criteria

3.2.1 Performance criteria for VHF services

Annex 3 of IMO resolution A.801(19) provides the following formula for calculation of range A:

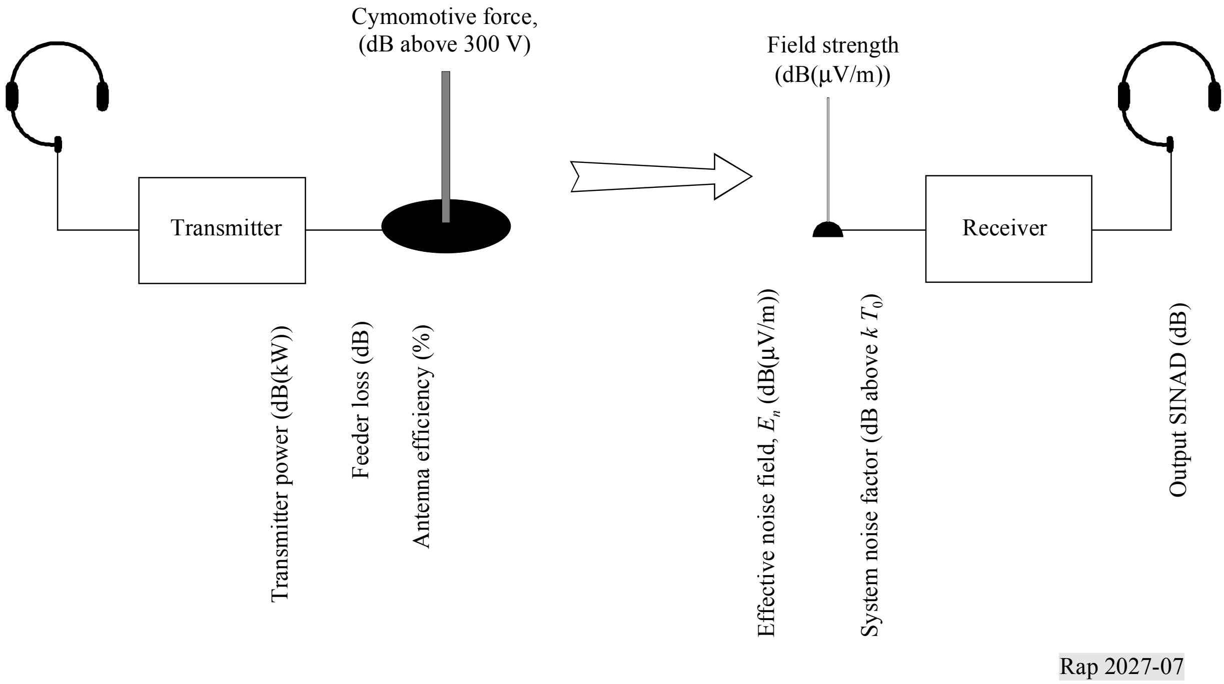
$$A = 2.5 \times \left(\sqrt{H} + \sqrt{h}\right) \qquad \text{nautical miles}$$

where H and h are heights of shore and ship antennas (m) above mean sea level, and h = 4 m.

3.2.2 Performance criteria for groundwave services

FIGURE 7

A simple SSB radiotelephony system



The IMO define the range for an A2 shore-based radio station by the ability of the station to hold effective communications with a ship transmitting 60 W into a 25% efficient antenna on SSB radio telephony, for which the essential system elements are shown in Fig. 7. Since this power is much less than the level usually transmitted from the shore station, the first step is to check the sensitivity of the receive site, secondly to determine the amount of power required to return the call, and then to protect the integrity of the DSC distress watch-keeping channels. The IMO recommend a measurement study to provide assurance of the range achieved.

TABLE 1

Performance criteria for groundwave services

Distress channel	Receiver/ transmitter	DSC	ARQ NBDP	NAVTEX
Frequency (kHz)	2 182	2 187.5	2 174.50	490 and 518
Bandwidth (Hz)	3 000	300	300	500
Propagation	Ground wave	Ground wave	Ground wave	Ground wave
Ships power (W)	60	60	60	
Ships antenna efficiency (%)	25	25	25	25
RF full bandwith signal/noise ratio, *S*/*N* (dB)	9	12	18	8
Mean transmitter power below peak (dB)	8	0	0	
Fading margin (dB)	3	Not stated	9	3
IMO reference	res. A.801(19)	res. A.804(19)	Rec. ITU-R F.339	res. A.801(19)
Percentage of time (%)	95[(1)]	Not stated	Not stated	90

ARQ: automatic error correction

(1) This figure is suggested by the Danish Post and Telegraphs administration in their paper “Calculation of GMDSS ranges for selected parts of the world” dated 30 December 1987.

3.2.3 Performance criteria for skywave services

3.2.4 Frequencies used

TABLE 2

Frequencies for GMDSS transmissions

Band (MHz)	NBDP distress	GMDSS distress	Receiver/ transmitter distress
4	4 177.50	4 207.50	4 125
6	6 268	6 312	6 215
8	8 376.50	8 414.50	8 291
12	12 520	12 577	12 290
16	16 985	16 804.50	16 420

TABLE 3

Performance criteria for various HF transmissions

Distress channel	Receiver/ transmitter	DSC	ARQ NBDP
Bandwidth (Hz)	3 000	300	300
Ships power (W)(1)	60	60	60
Ships antenna efficiency	Not stated	Not stated	Not stated
RF full bandwith signal/noise ratio, *S*/*N* (dB)	9	12	12
Mean transmitter power below peak (dB)	8	0	0
Fading margin (dB)	3	Not stated	Not stated
IMO reference	res. A.806(19)	res. A.806(19)	res. A.806(19)

(1) IMO resolution A.806(19) states that higher powers may be required in some areas of the world.

3.3 Planning tools

3.3.1 ITU software

3.3.1.1 NOISEDAT

Recommendation ITU-R P.372 provides a complete method for determination of the levels of radio noise to be expected at any location, in any season, and during any period of the day. The method is based around use of the ITU-R noise maps, which were originally produced for inclusion in HF prediction packages. The basic method included in the Recommendation has been encapsulated in the “NOISEDAT” program, which runs under DOS.

3.3.1.2 GRWAVE

Calculates groundwave field strength curves used in Recommendation ITU-R P.368, and runs under DOS.

3.3.1.3 Recommendation ITU-R P.533

Predicts signal strengths in accordance with Recommendation ITU-R P.533, and runs under DOS.

3.3.1.4 HFANT

This program embraces analytical models of the antennas contained in Recommendation ITU-R BS.705 enabling the gain and radiation patterns for a large number of antennas to be modelled.

3.3.1.5 The ITU International Frequency List CD-ROM

This is available from the ITU in Geneva, and provides an invaluable listing of sites by station type and frequency registration. It is of especial use in determining the locations of other shore stations for frequency planning and coordination purposes.

3.3.2 Institute of Telecommunication Sciences (ITS) of the National Telecommunication and Information Administration (NTIA)/ITS software

The following programs are available from NTIA/ITS in the United States of America for prediction of communications and coverage by HF skywave. They are configured to run under DOS, Windows 3.1, Windows 95, or Windows NT.

Origin of model used	Point-to-point package	Area coverage package	Interference analysis package
Recommendation ITU-R P.533	REC533	RECAREA	–
IONCAP	ICEPAC	ICEAREA	S/I ICEPAC
IONCAP	VOACAP	VOAAREA	S/I VOACAP

Each package contains a useful database of world locations and antennas, and is supported by an extended version of HFANT which enables the library of antenna radiation patterns to be viewed or new ones synthesized in accordance with Recommendation ITU-R BS.705. Area coverage maps are created from an integral world coastline database, over which a wide range of contours can be plotted, including maximum useable frequency (MUF), signal strength, noise power, signal-to-noise ratio, reliability, and required antenna elevation angle. ICEPAC and VOACAP use the same basic model, but ICEPAC has been enhanced to account for geomagnetic activity.

3.3.3 IPS software

IPS is the Australian Department of Administrative Services, who operate a wide range of propagation prediction service. Their “ASAPS” (advanced stand alone prediction system) package is well established, and is a frequency, HF skywave prediction, management and engineering system, and is well known for its “Grafex” frequency predictions. For groundwave predictions they offer their “GWPS” (groundwave prediction system) package which models coverage by groundwave.

3.3.4 Choice of software

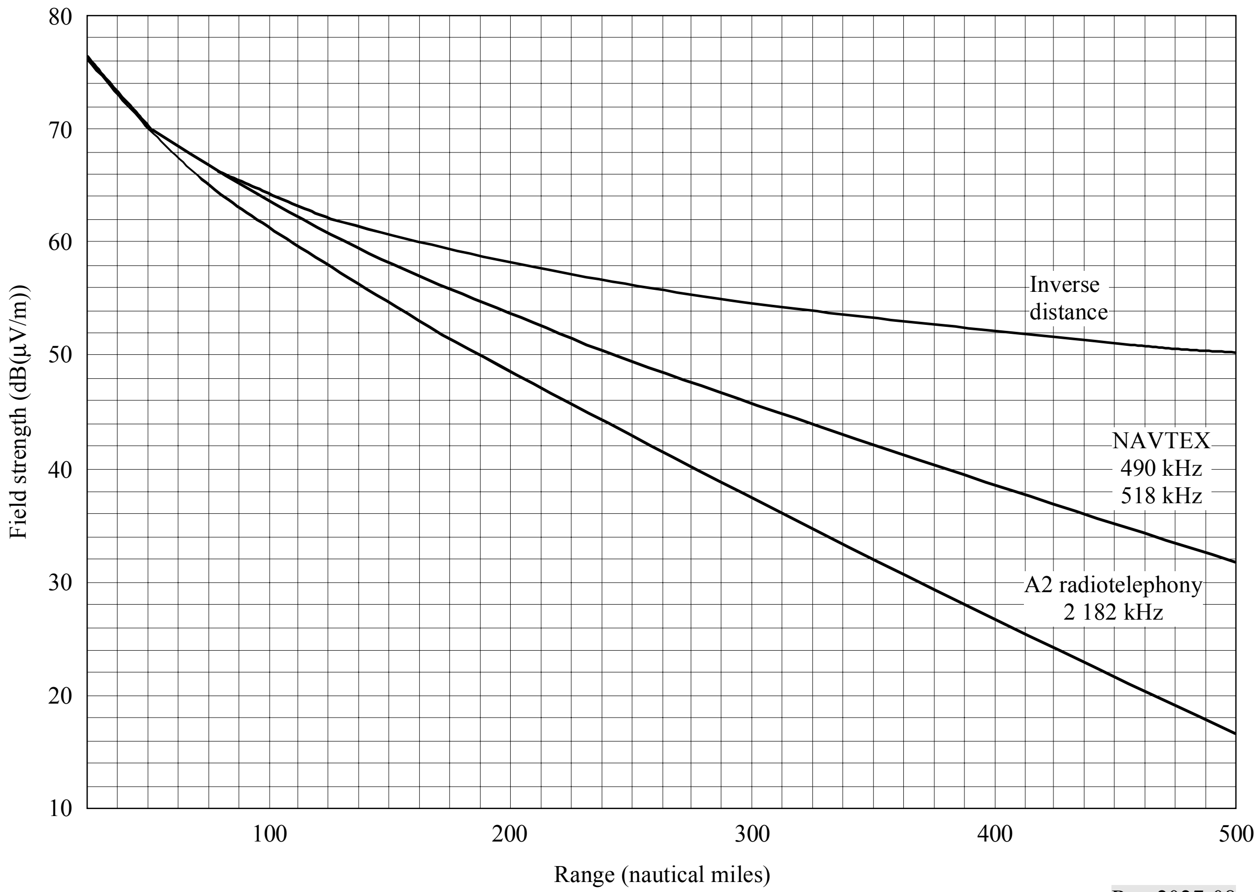
For use in implementing the following guidelines, the ITU program NOISEDAT is recommended for determination of external noise levels for planning the A2 groundwave service, and the NTIA/ITS version of Recommendation ITU-R P.533, RECAREA, and HFANT are recommended for planning the A2 and A3 skywave services. However, administrations may well find that the alternative programs covered above better suit their needs, such as GWPS for modelling within the A2 service area.

3.4 Planning guidelines

3.4.1 Establishing an effective groundwave service area

FIGURE 8

Groundwave propagation curves for A2 and NAVTEX, extracted from Rec. ITU-R P.368



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3.4.1.1 Determination of extent of A2 service area

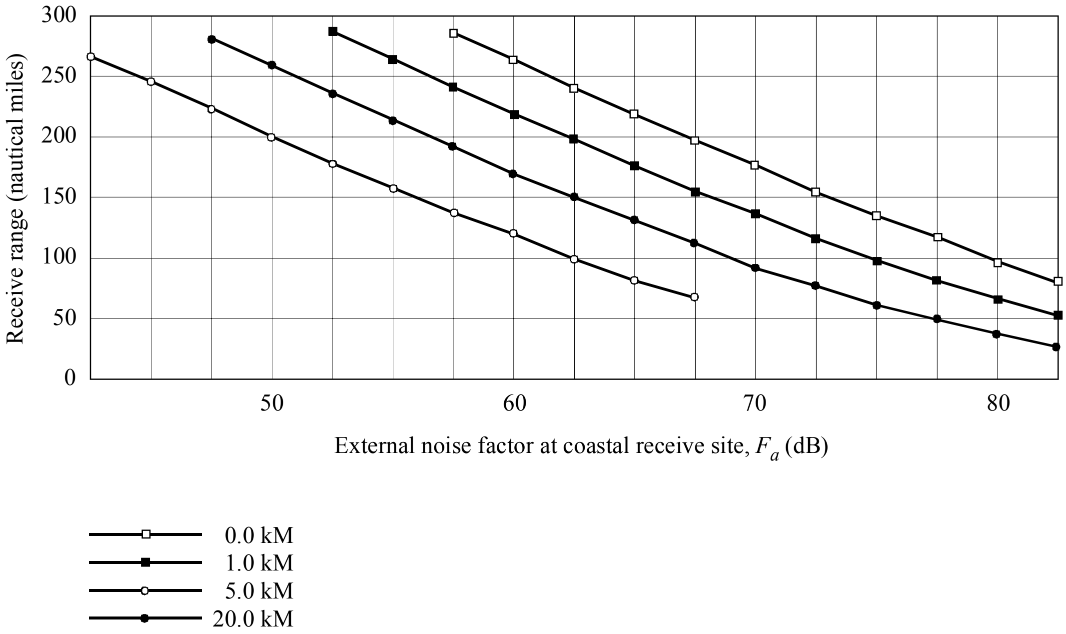
The extent of the A2 service area is determined by the range over which SSB communication is effective at 2 182 kHz between ship and shore. The ship is considered to be fitted with a 60 W transmitter, feeding a short monopole antenna with an efficiency of 25%. The range is fixed by the maximum distance at which the ship can be from the shore station to produce a *S*/*N* of 9 dB in a 3 kHz bandwidth, out of the receive antenna at the shore station which must be equipped with a transmitter of sufficient power to return the same *S*/*N* at the output of the ship's receive antenna. The range in both directions depends upon the sensitivity of the receive antenna, which depends upon the levels of natural and man-made noise present, the quality of the receive antenna installation and earthing, and the ability of the antenna to discriminate between the wanted signal and the unwanted noise. The noise factor of the receive system connected to the receive antenna can be ignored at 2 182 kHz. It is assumed that the shore-based receive antenna can is correctly installed and subject to periodic maintenance, and therefore free from serious corrosion.

3.4.1.2 *Step 1*: Determination of shore-based receive range

The first step is to determine the external noise factor, F_a, at the receive antenna as recommended in Recommendation ITU-R M.1467, using the NOISEDAT program which will print out F_a values in time and season blocks over the year. The IMO minimum range thus achieved can be determined for all seasonal values of F_a using the 15 W curve in Fig. 9.

FIGURE 9

Receive range versus external noise factor, F_a, for various overland distances



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3.4.1.3 Receive range achieved across a headland

Additional values have been included to demonstrate to what extent an A2 sea area can be extended beyond the further shore of a headland or island. A practical limit for the tolerable width of a headland would be 10 to 30 km depending upon the type of ground and the remaining sea area to be covered. On a very quiet site the receive range could be extended by using an array of whips, or a Beverage antenna but to provide a significant improvement such a receive antenna would be expensive and require a long quiet site. In practice, the best solution would be to site an auxiliary receiver and antenna on the far side of the headland linked by a telephone line.

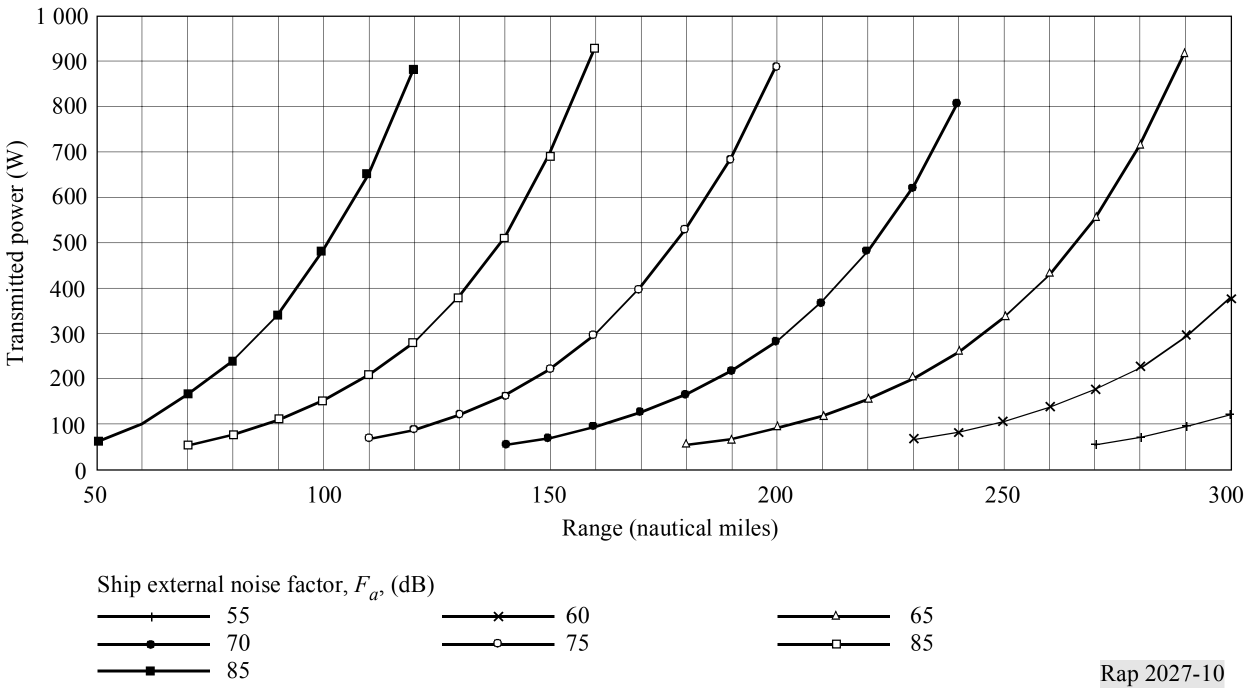
3.4.1.4 *Step 2*: Determination of shore-based transmit power required

Effective two-way SSB radiotelephony requires matched conditions in both directions. Since the transmission loss is the same in both directions the power required to return a call only depends upon the difference in noise levels and transmit antenna efficiency each end. A figure of 10 dB has been included in the calculation of shore-ship power budget to take account of variations in performance of the ships receive antenna and its state of maintenance.

Having established the receive range the transmit power required can be estimated from Fig. 10.

FIGURE 10

Transmit power versus range for various levels of external noise factor on vessel



A more comprehensive formula for the determination of minimum transmitter power required is given in Recommendation ITU-R M.1467.

3.4.1.5 Protection of DSC distress signal

The final step is to ensure that the received DSC watch receiver is not blocked by the adjacent channel SSB signal on 2 182 kHz. This is covered in § 4.3.

3.4.1.6 Comparison of range achieved for DSC and SSB communication

The received distress alert will be well above the threshold set for limit of the SSB service area because the signal bandwidth is less, and also because the transmitted signal power will be closer to peak envelope power than the corresponding SSB transmissions, and the system will be working well above the noise floor for DSC transmissions in both directions providing headroom for the DSC receive and demodulation process.

3.4.1.7 Protection from unwanted intermodulation products

A protection band at least 250 Hz either side of the watch frequency must be kept clear from intermodulation products, and this should be taken into consideration when additional frequencies are selected for operation on the station.

3.4.1.8 Effect of separation between transmit and receive sites

The IMO requires a 24 h watch on the DSC distress frequencies, and makes no provision for outage time when the station may be transmitting on the adjacent distress response channel using SSB radiotelephony. Adequate precautions should therefore be taken to ensure that the watch receivers are not unduly effected by adjacent channel radiotelephony transmissions, and this is especially difficult where the transmit and receive equipment are co-located, and this is dealt with in § 4.3.4.1.

However, this headroom will also result in the ability to receive distress signals well beyond the range limit set for SSB communications, and administrations should be aware that the systems will be capable of receiving and acknowledging distress alerts beyond the range available for follow through communications using SSB.

3.4.1.9 How to minimize degradation of the A2 signal at night

By day the ionospheric D layer is strong and absorbs any skywave signals generated by the A2 transmit antennas. This layer disappears at night, enabling the higher layers in the ionosphere to return high levels of skywave, causing co-channel interference at distant receivers, and fading wherever it reaches earth at the correct level and phase to mix destructively with the groundwave signal. Interference can only be avoided by ensuring that transmit powers are controlled, if necessary using a suitable two-mast array, and a directional receive antenna such as a loop, or an Adcock. The effect of fading can be reduced by increasing the transmit power to provide a fading margin, at the expense of interference. However, the extent of the fade-free groundwave service area can be maximized by ensuring good ground under the transmit antenna, and by using a specially designed tuned mast radiator approximately 5/8λ high (75 m) at the shore-based transmit site.

3.4.1.10 Determination of the range achieved using NAVTEX operation

The range achieved by a given NAVTEX transmitter depends upon the efficiency of the transmit antenna, and the external noise factor on board the ship, as shown in Fig. 11. The antenna efficiency depends upon the quality of the earthing system provided, and once the required cymomotive force (c.m.f.) has been determined, it should be measured as described in Recommendation ITU-R M.1467, and the efficiency determined.

IMO resolution A.801(19) specifies 90% availability and so the upper decile value for F_a should be calculated using the statistical data produced by NOISEDAT.

The impact of earth system designs on antenna efficiency is covered in § 4.5.1.3.

3.4.2 Establishing an effective skywave service area

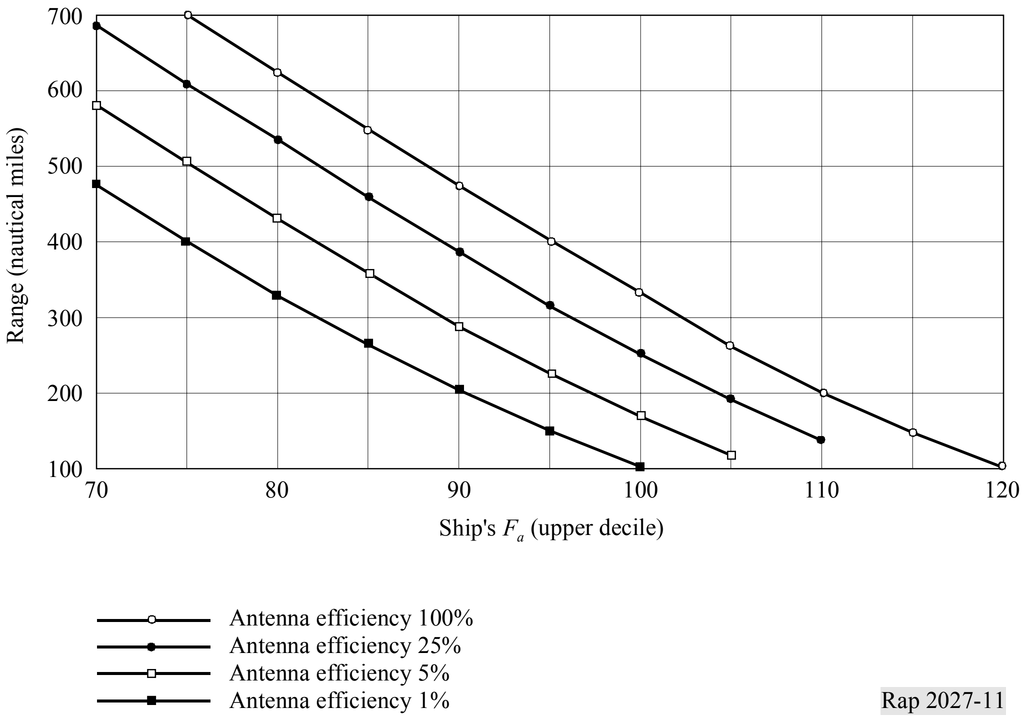
3.4.2.1 Determination of the extent of the A3 and A4 service areas

The A3 and A4 ocean regions stretch much further from the shore station than the A2 sea area, and propagation is by skywave which is dependent upon the strength of the ionosphere, and so shore stations need to provide more powerful transmission and more sensitive reception than for A2 to achieve effective two-way communications. In the A4 region there is no INMARSAT coverage, and as the frequency shift keying (FSK) signal used for both DSC and NBDP has a greater range than for SSB follow-on communication is carried out primarily using NBDP.

FIGURE 11

NAVTEX range for 1 kW transmitter, versus ship's F_a

(For 5 kW transmitter, reduce F_a by 7 dB)



IMO resolution A.801(19) states that responsibility for coverage of each A3 and A4 sea area should be shared between at least two shore-based radio stations situated around the area to be covered, and a study made by the US Coastguard in 1985 revealed that although the probability of any particular shore station receiving an alert is moderate the probability of the alert being received by at least one HF coast station among a number of stations may be 90% or more.

In order to establish an A3 or A4 service area it is necessary to gain some knowledge of how the conditions are likely to vary. Since the condition of the ionosphere varies with solar activity, which follows an 11-year cycle, the extent of the service area can not be confirmed by performing a new measurement study, and analytical methods are required to verify feasibility, and establish a project budget with confidence.

The methods described below are typical, and intended to serve as introductory guidance. When using ICEAREA, judgement is required to select appropriate sunspot numbers and to account for multipath effects. In addition the planner has to be aware of phenomena specific to the area of interest. For instance at high latitudes, skywave signals can be attenuated by auroral and polar cap absorption, and can be blacked out for minutes or on rare occasions for hours by the latter, and judgement is required to provide ICEAREA with a suitable value for the magnetic Q index. At low latitudes propagation can be seriously degraded by gradients and rapid diurnal changes in the F2 layer, which can be offset by sharing coverage between shore stations.

3.4.2.2 *Step 1*: Verification of shore station sensitivity

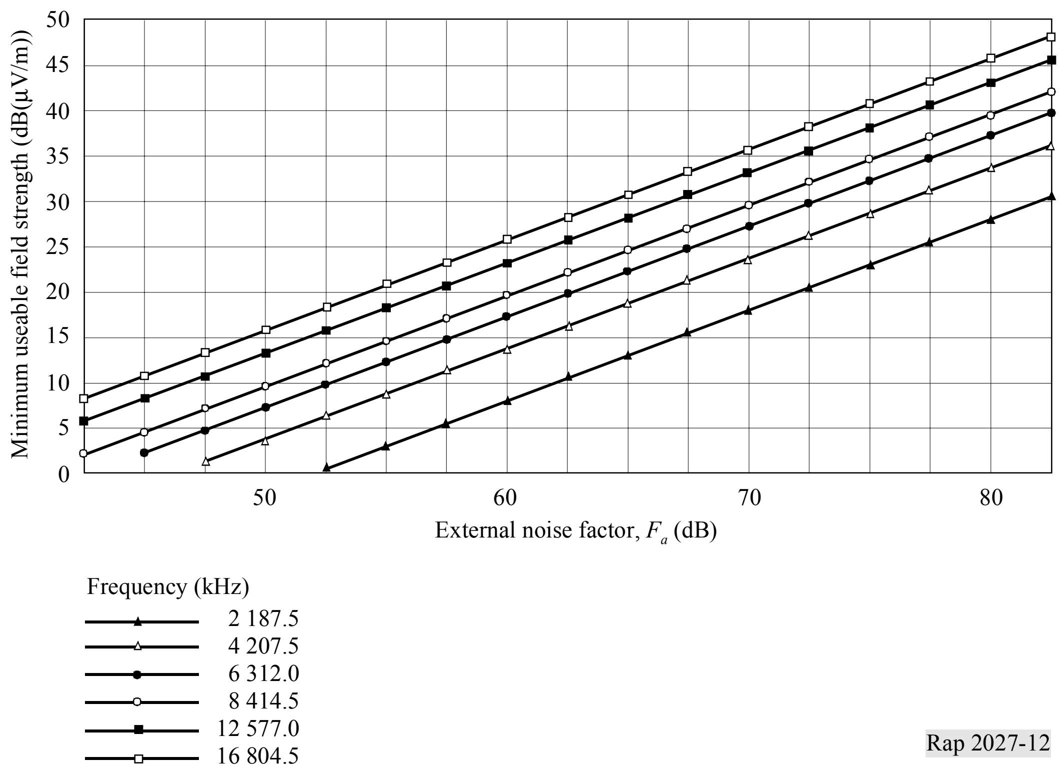
The first step in the design of a skywave service area is to verify that the receive site is sufficiently quiet. Run NOISEDAT to determine the maximum and minimum seasonal values of F_a to expect at the shore station. Inspect the noise maps given in Recommendation ITU-R P.372 and select a noisy location towards the limit of the service area and run REC533 to predict the performance of the ship-to-shore path, for different values of sunspot number on each DSC frequency. As input data, use the performance criteria stated in Table 3 above, and assume that the ship is transmitting 15 W into a short monopole antenna, selecting the Recommendation ITU-R P.533 receive whip as the receive antenna to start with.

Compare the predicted median field strength values with the figures shown in Fig. 12. If there is a shortfall revise the extent of the area covered in the light of the range established for the F_a at the receive site, and try an alternative receive antenna such as a rhombic or log periodic. In practice modelling packages tend to be optimistic, often failing to provide correct discrimination between wanted and unwanted signals having different angles of arrival.

Final determination of coverage of the sea area concerned should be carried out in coordination with the other shore stations assigned to share the coverage responsibility.

FIGURE 12

Minimum useable DSC field strength versus F_a on the DSC distress frequencies



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3.4.2.3 *Step 2*: Verification of ocean area for effective two-way HF communications

Having rationalized the receive range against the sensitivity of the receive site, run NOISEDAT to determine the external noise factor to expect on board the ship, and run REC533 again assuming that the shore station is running 10 kW transmitter power into an isotropic transmit antenna. The predicted field strength at the ship should be at least 10 dB above the figure shown in Fig. 12 to provide a contingency to cater for the ship's receive antenna, as discussed in § 3.4.1.4. Repeat Steps 1 and 2 for other sites in the expected ocean area until two-way communication has been confirmed over a satisfactory ocean area.

3.4.2.4 *Step 3*: Establishment of a radiation profile from the transmit site

Having verified that the expected sea area can be covered, the next step is to sketch the area to be covered onto a map. Draw a line from the transmit site right through the middle, measure the antenna heading and estimate the width of the main beam required. Next examine the data produced in Step 2 above, and identify the maximum and minimum ray angles listed. Run HFANT, and select an antenna such as a horizontal log periodic from the antenna library with a beam shape which provides the best fit. Note that the format used for the antenna radiation pattern data files in the NTIA/ITS version of HFANT is now well established, and on request, some manufacturers will provide suitable radiation patterns for their antennas on disk.

Use the same antenna and heading with ICEAREA. Enter the same basic system performance parameters that were used for running Recommendation ITU-R P.533 above, and assume a transmitter power of 1 kW. A contour map showing ray elevation angle can be used to confirm the antenna selection, and a contour map showing required antenna gain/transmitter power will provide an indication of required transmitter power (dB(kW)).

3.4.2.5 *Step 4*: Determination of overall service probability

Service probability contours can be generated by running ICEAREA in batch mode. From the input file prepared for Step 3, prepare a set of 8 input files corresponding to each of four seasons at high and low sunspot numbers, using the filename convention specified in the program instructions. ICEAREA will generate 64 result files, each one recording coverage performance data on the best DSC channel for a particular time, season, and sunspot number. ICEAREA can then be run in combine mode to generate a single file, corresponding to median, upper decile or lower decile performance from which contour maps can be generated depicting for instance MUF, signal strength, C/N, and service probability.

3.4.2.6 Use of the reciprocity theorem

This states that any radio path is reversible, and can be used to enable the capture area of the receive site to be plotted using ICEAREA. It is valid if the skynoise levels are constant over the service area, and to retain any effects of path asymmetry the antenna locations are not reversed. Steps 3 and 4 can be re-run entering the ship's power (15 W) and shore receive antenna at the transmit end, and the external noise factor at the shore station receive site with a whip antenna at the receive end. Contour plots can then be generated showing shore station receive *C*/*N* and service probability.

3.4.2.7 *Step 5*: Protection of the DSC distress signal

Adequate isolation is required between the transmit and receive antennas, so draw a second line from the transmit site on the bearing determined by the receive site, and refer to § 4.3.

4 Site engineering

4.1 Engineering GMDSS systems

4.1.1 A practical approach

At most frequencies the propagation of a radio wave between any two points is subject to the condition and state of the medium between them. Similarly the operation of the transmitters and the antennas used is subject to their immediate electromagnetic environment. In order to provide a universal plan for a system such as GMDSS it is necessary to provide generalized models which are simple enough to be managed using the data and facilities available, and difficulties can be encountered in the engineering of real systems, some examples of which are:

– Capture of data for a noise model is difficult over sea areas, placing limitations on accurate prediction of noise over the sea, especially in the tropics where electrical storms are commonplace.

– It is difficult to apply a universal noise model appropriate to all circumstances.

– Recommendation ITU-R P.372 only accounts for radiated noise, noise performance of a roof-mounted receive system can be degraded both by loss in antenna output due to its elevation, and by noise induced directly into the antenna and earthing system from fluorescent lights, lift machinery, high voltage busbar coronas, and thyristor controllers, all in use in the building underneath the antenna.

Also, many existing shore stations have been subject to continuous development over a long period, and extreme difficulties can be encountered adding more equipment to an existing site, which may already be overcrowded, or become badly sited due to ongoing development of the user's system, or growth in urban development in the neighbourhood, such as the appearance of a new overhead powerline or motorway alongside what was once a quiet receive site.

4.2 Factors affecting the choice of a new receive site

4.2.1 The nature of external noise

External noise decreases with increase of frequency. The F_a defined in Recommendation ITU-R P.372 accounts for three types of noise: skynoise, man-made noise, and galactic noise. The noise level encountered on the quietest possible site, at the quietest time of year, is referred to as the quasi-minimum noise (QMN), the major component of which would be:

– atmospheric noise below 700 Hz;

– man-made noise between 700 Hz and 4 MHz;

– galactic noise above 4 MHz.

In practice sites this quiet are rare, and most sites will be dominated by atmospheric or man-made noise. Recommendation ITU-R P.372 defines five environmental categories to account for levels of man-made noise reproduced in Table 4.

TABLE 4

Environmental categories used in Recommendation ITU-R P.372

Location	**dBW at 3 MHz**	**dB above kT_0 at 1 MHz**
Business	–140.4	76.80
Residential	–144.7	72.50
Rural	–150.0	67.20
Quiet rural	–164.0	53.60
Galactic	–163.0	52.00

The sensitivity required for new a receive site would depend upon the receive range required for the shore station, as shown in Fig. 9 for the A2 sea area. The sensitivity required to receive distant ships at the ranges required to provide coverage of sea areas A3 and A4 is much greater than this, and due account has to be taken of skynoise, and possibly galactic noise.

4.2.2 Minimizing man-made noise

Receiving systems should be placed as far away from sources of man-made noise as necessary to achieve the required sensitivity. The effective ranges of different sources of man-made noise are given by Armel Picquenard in his book "Radiowave Propagation" (p. 178), and are reproduced in Table 5.

TABLE 5

Effective ranges of sources of man-made noise

Noise source	**Effective range**
Electric motor	200 m
High voltage power lines, when raining	1-10 km
Motorcars	500 m
Aircraft	1 km

It follows that an ideal site would be located 1-5 km from any low voltage unscreened power lines, small aerodromes and highways, 5-10 km from major airports, motorways, electric railways, or open-wire overhead power lines, (more for open electrical power switching stations). If the receive antennas are placed any closer then the *S*/*N* will be degraded, and in this respect active whips are most resilient to magnetic fields, produced by electric motors, and loop antennas are most resilient to local electric fields, produced by the insulators on powerlines. In addition, the station should not be situated in the main transmit beam of any airport radar beacons, or short-wave broadcast radio stations, or in the vicinity of any radiocommunications facilities, or MF radio stations.

4.2.3 Minimizing susceptibility to skynoise

In order to provide the sensitivity required to achieve the required receive range it will first be necessary to select a suitably quiet site, and then, for A4 at least, to design a receive system sufficiently sensitive to resolve the low signal levels received from distant ships against the residual noise background. This is achieved by increasing the directivity of the receive antenna.

The noise generated by electrostatic discharges from electric storms is referred to as atmospheric noise, which can propagate for thousands of kilometres by skywave before dissipating. The main sources of such noise are in the tropics. If the remote ship is located away from the main source of atmospheric noise then a directional antenna can be used to discriminate between the directions of arrival of the wanted signal and the unwanted noise. On the other hand, if the ship is located in the centre of a tropical storm, nothing can be done to separate the signal from the noise. The main choices of antenna for this are a log periodic, a rhombic, or an array of loops or whips. Below 4 MHz log periodic and rhombic antennas may become un-economic compared to an array of active whips or loops. An array of whips can be manually steered to null-out unwanted signals, and work well at low frequencies. Arrays of loops can be tailored to provide a high directivity.

Another source of natural noise is the galaxy, and levels are strongest in the brightest patches of stars visible to the eye on a clear night, especially when looking towards the centre of the galaxy. These patches have a relative motion around the Earth as does the Sun, and will act as a noise source when they pass across the main beam of a receive antenna. This effect would be limited to higher frequencies where galactic noise dominates, and high gain antennas are more economic.

4.3 Protection of DSC watch frequencies

4.3.1 Impact of close spacing between DSC and SSB frequencies on system performance

A received distress alert will be well above the threshold set for limit of the SSB service area because the signal bandwidth is less, and also because the transmitted signal power will be closer to peak envelope power than the corresponding SSB transmissions, and the system will be working well above the noise floor for DSC transmissions in both directions providing headroom for the DSC receive and demodulation process. The resulting DSC signal level reaching the shore station will depend upon the declared A2 range for the shore station, and in turn depend upon the F_a sensitivity shown in Fig. 9. The distress alert frequency is very close to the frequency required for SSB communications, as shown below.

TABLE 6

GMDSS distress frequencies

Band	DSC watch frequency (kHz)	SSB frequency (kHz)	Frequency separation (%)
A2	2 187.50	2 182	0.25
4 MHz	4 207.50	4 125	1.96
6 MHz	6 312.00	6 215	1.54
8 MHz	8 414.50	8 291	1.47
12 MHz	12 577.00	12 290	2.28
16 MHz	16 804.50	16 420	2.29

If the separation between transmit and receive sites is more than a few wavelengths the most likely propagation mode will be groundwave, either because the transmit antenna is vertically polarized, or because of inadvertent output from a horizontally polarized HF antenna, as can be produced by antennas employing dipoles with drooping elements. If the receive antenna has a considerable gain in the vertical direction then propagation by near vertical incidence skywave (NVIS) may give rise to interference. This would be the case if the receive antenna were a loop, wideband dipole, log periodic, or a helically wound antenna in high-angle mode.

4.3.2 Performance criteria for protection of A2 watch frequency

The IMO specify that the distress channels should be watched 24 h per day. The system should be designed so that the watch function is not desensitized by noise or interference. It is essential therefore that all transmit channels assigned for use on the transmitting station are selected so that no intermodulation products are allowed to fall within the frequency bands of the watch channels.

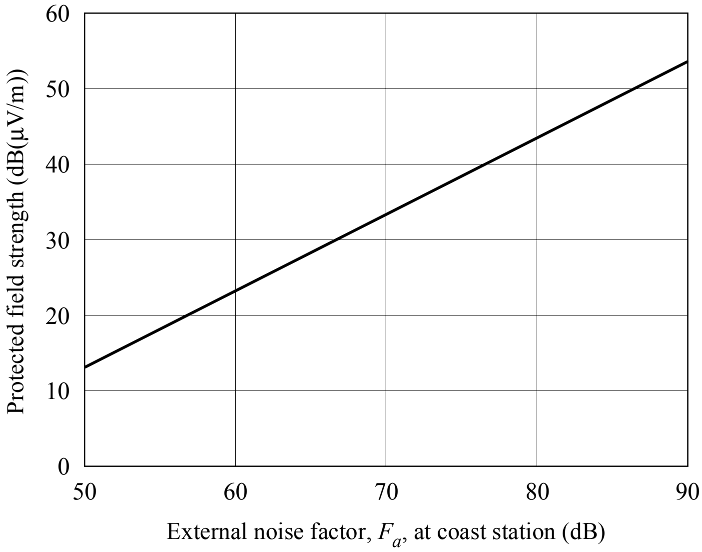
For very close channel separations the watch process can be threatened by energy in upper sideband of the adjacent SSB transmission falling within the receiver passband, where the wanted signal could be swamped by blocking or reciprocal mixing. Where channel separation is large enough to remove the threat of reciprocal mixing, a further, but lesser threat to the watch process may be sideband noise from the transmitter falling in the receiver passband.

The resulting DSC signal level reaching the shore station will depend upon the declared A2 range for the shore station, and in turn depend upon the F_a sensitivity.

The level to be protected would be the level reaching the shore station after suffering a 3 dB fading loss, and is shown in Fig. 13.

FIGURE 13

Protected DSC field strength at receive site



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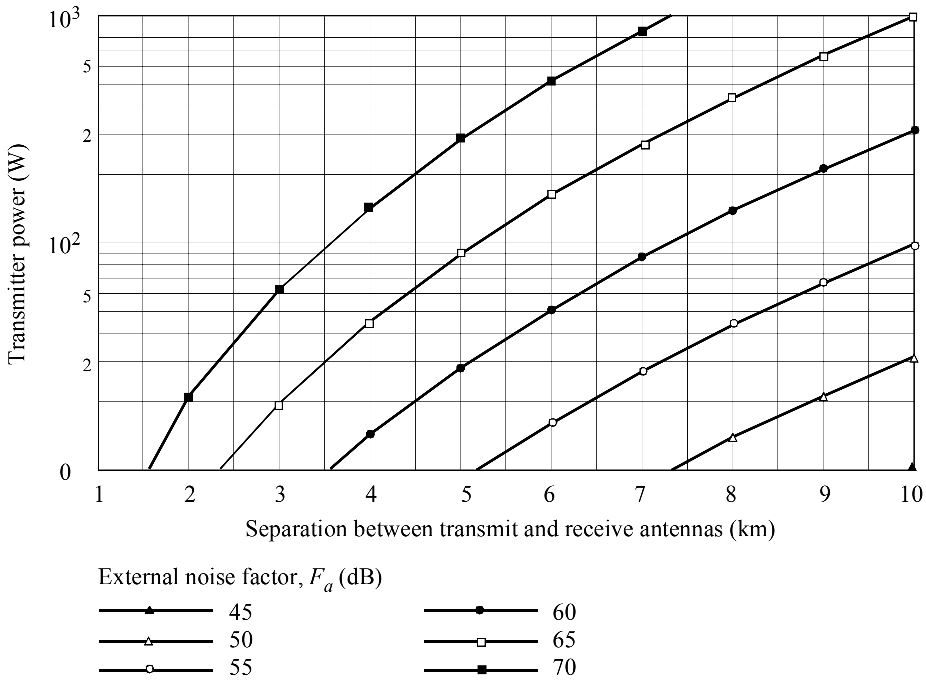
4.3.3 Impact of site separation on system performance

FIGURE 14

Transmitter power versus antenna separation for 50 dB adjacent channel isolation



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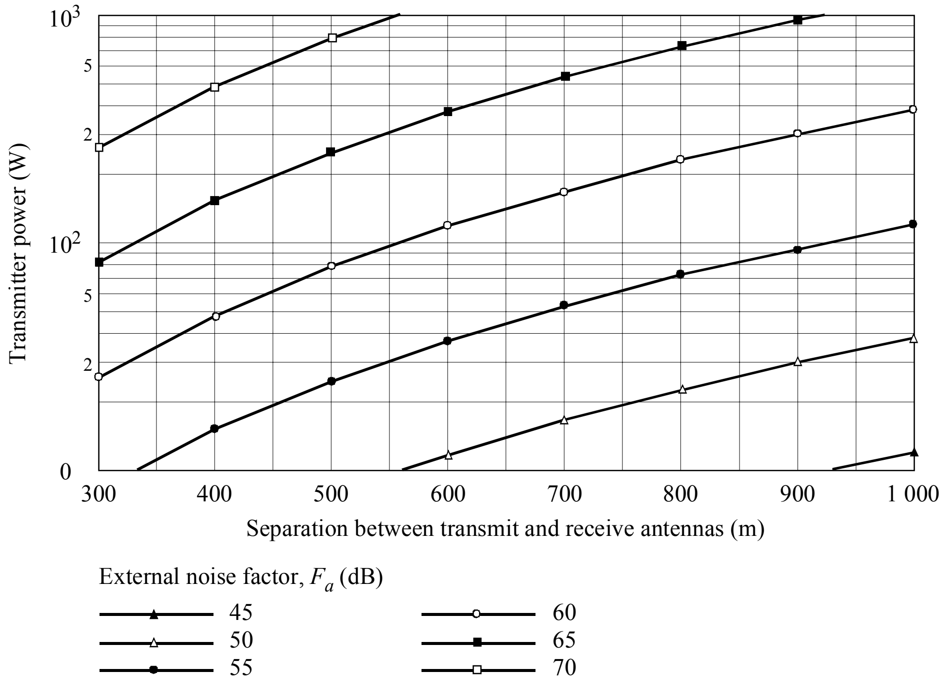
4.3.4 Cases requiring special attention

4.3.4.1 Co-site operation

Figure 15 shows the effect of reducing the separation between the transmit and receive antenna below 1 km to 300 m, the minimum value computed using GRWAVE. By way of example, if a station close to the shoreline had a maximum annual median, F_a, of 65 dB then from Fig. 9 the range achieved would be just under 200 nautical miles. If the adjacent channel isolation were 80 dB, then for an effective monopole radiated power (e.m.r.p.) of 200 W the antenna separation should be not less than 450 m.

FIGURE 15

Transmitter power versus antenna separation for 80 dB adjacent channel isolation



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Under such circumstances a long feeder would be required to attain the separation required. As the frequency increases there is a considerable reduction in external noise and increase in feeder loss. At 2 MHz the F_a is very much greater than the system noise factor, and for a system noise factor of 15 dB up to 10 dB of feeder loss would be tolerable on a well designed and maintained system, and so a cost effective way to avoid the cost of a very long low loss co-axial cable would be to use a separate antenna for A2.

To summarize, the basic guidelines for co-site operation are:

– keep the system simple;

– keep the transmitter powers low;

– use a dedicated A2 receive antenna with adequate spacing from the transmit antenna;

– use high performance watch receivers, offering 80 dB adjacent channel isolation.

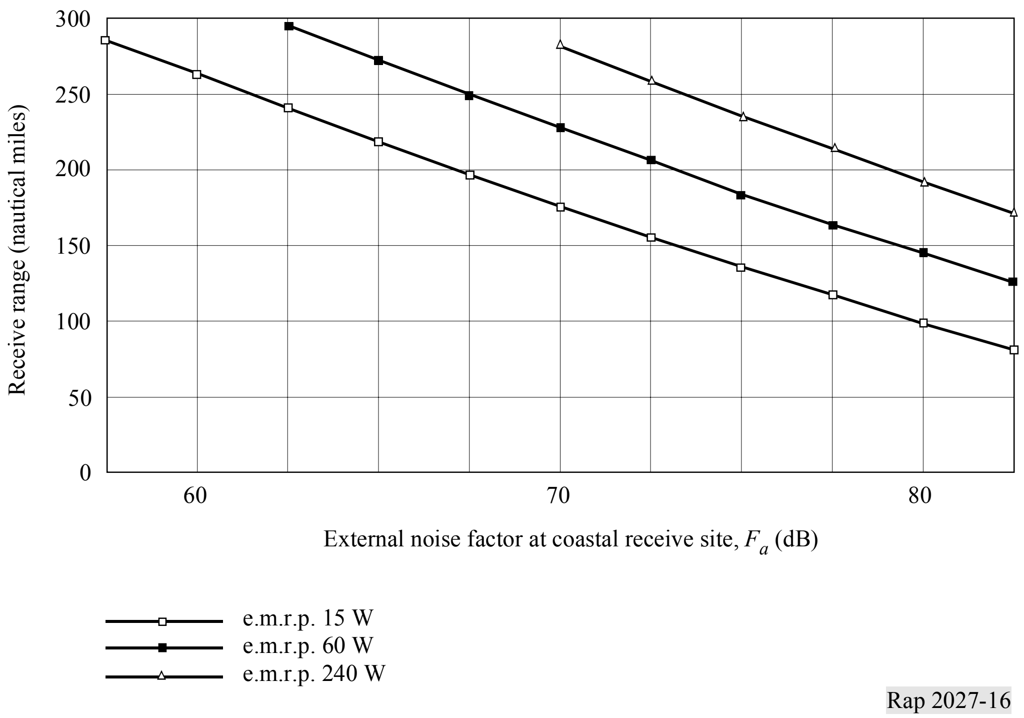
If the spacing between transmit and receive antennas is reduced any further the effect of direct electromagnetic coupling between them, has to be taken into account, and every case would require separate consideration.

4.3.4.2 Impact of commercial operation

Calculations for commercial operation are based on Recommendation ITU-R F.339 for an RF *S*/*N* ratio of 66 dB in 1 Hz bandwidth for J3E under stable conditions, equivalent to 32 dB in 3 000 Hz bandwidth. Figure 16 shows receive range, versus shore station F_a for various values of ships radiated power. These were prepared for distress grade communication and so 12 dB should be added to the F_a to obtain the equivalent range for "good commercial" grade of service.

FIGURE 16

Distress receive range versus F_a for various transmitted ships powers



More power will be required for commercial operation than for distress in order to match increase in performance. Since the transmission loss is the same in both directions, then the required e.m.r.p. required at the shore station to return a call should only depend upon difference between noise levels each end plus a 10 dB contingency to overcome degradation of the ship's receive antenna (see § 3.4.1.4), and if the F_a on the ship exceeds that at the shore-based receive site by 5 dB, then the shore station e.m.r.p. should be 15 dB above that on the ship. If the antenna efficiencies at the shore station is 70% then the transmitter output should be increased by another 1.5 dB.

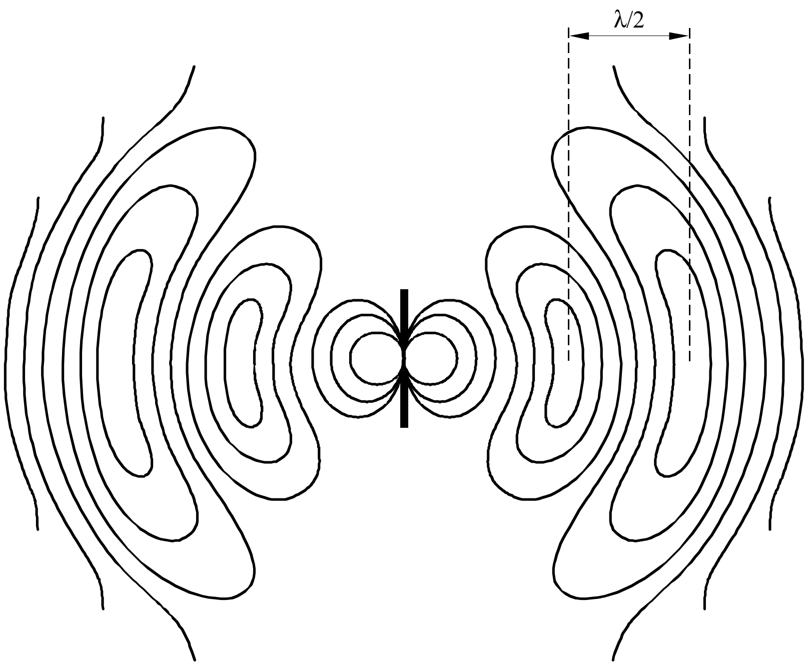
4.4 Transmit antenna selection guide

4.4.1 Principles of operation

The function of a transmit antenna is to generate an electromagnetic wave which couples a signal into a remote receive antenna. In order to radiate an electromagnetic wave, a length of wire must conduct a current at the required frequency, and must therefore be provided with the correct electromagnetic conditions in the immediate environment. In the dipole this is achieved by providing two conductors and the circuit is made complete via the capacitive coupling between them. Figure 17 depicts a stream of electromagnetic waves leaving a vertical dipole in free space.

FIGURE 17

Release of successive wavefronts from a vertical dipole in free space



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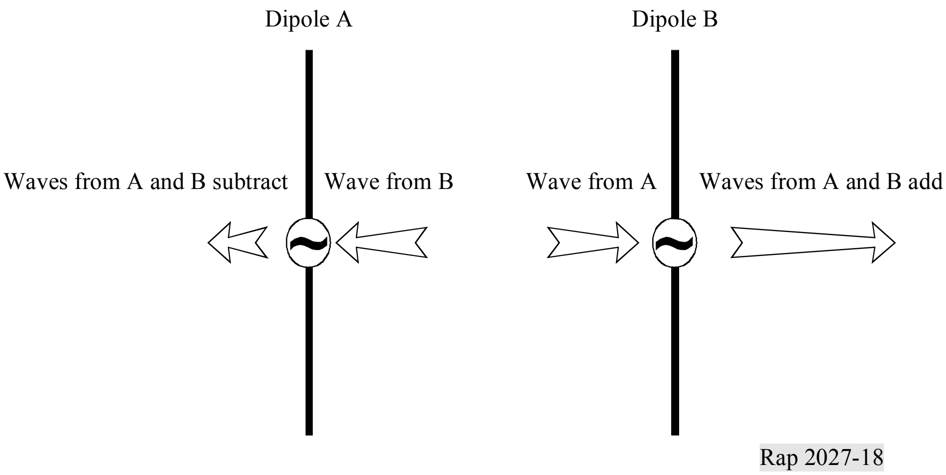
Elements may be grouped to control the above process so that more power is radiated in one direction, as shown in Fig. 18.

FIGURE 18

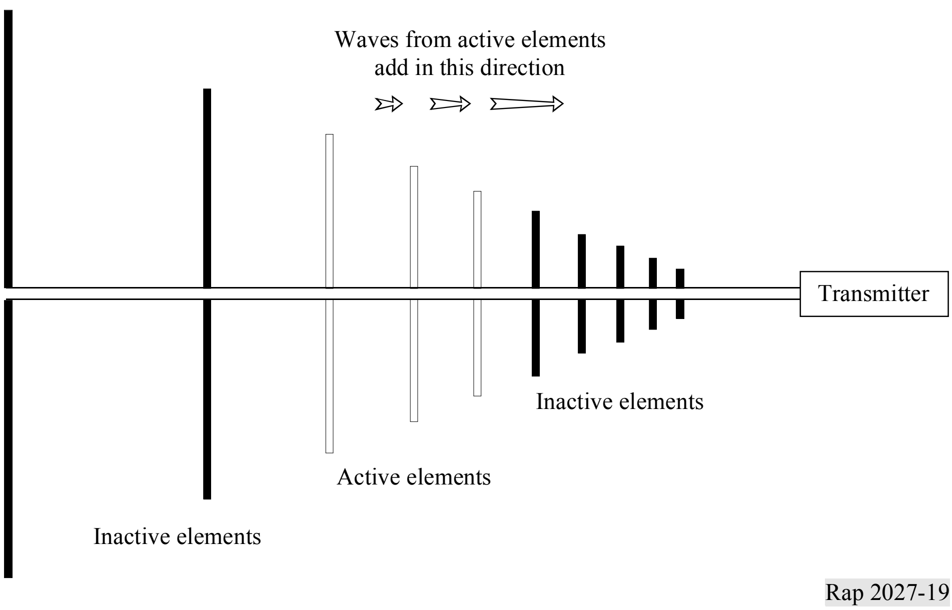
Grouping of elements to achieve directive gain



At HF a number of elements can be situated in line, and spaced logarithmically such that a subset will become active at any frequency, whilst the others remain ineffective, as shown in Fig. 19.

FIGURE 19

Log-periodic antenna



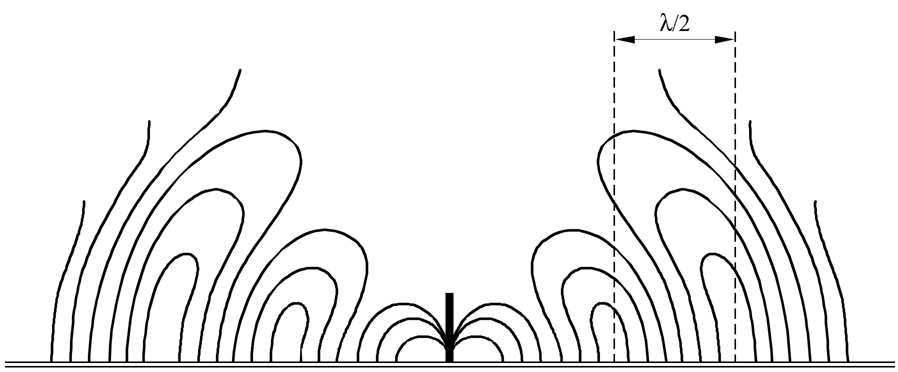
4.4.2 Groundwave antennas

4.4.2.1 Requirement

At frequencies below about 5 MHz energy absorbed by the ground enables a vertically polarized wave to reach a receive antenna over the horizon by hugging the surface of the ground. This is referred to as groundwave propagation, and for this to occur the transmit antenna must excite appropriate current flow in the antenna foreground which is best achieved using a grounded antenna. Figure 20 shows the effect of converting a vertical dipole into a monopole by replacing the lower element by a perfectly conducting plane.

FIGURE 20

Release of successive wavefronts from a monopole on perfect ground



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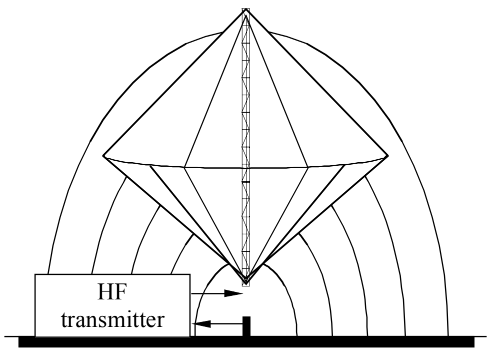
A monopole will generally be resonant at one frequency, but can be used at lower frequencies if tuned using a matching network, or at higher frequencies if fitted with a wire cage as shown in Fig. 21, in which case the local field and hence input match is sustained over a wide range of frequencies.

FIGURE 21

Local field from conical antenna over perfect ground



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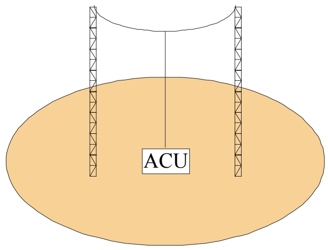
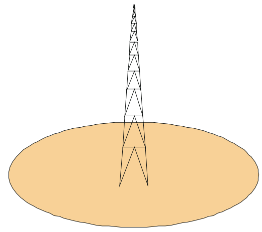
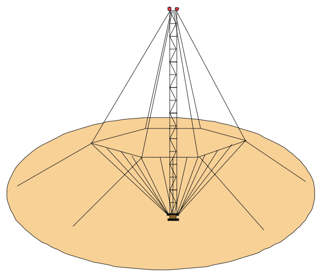
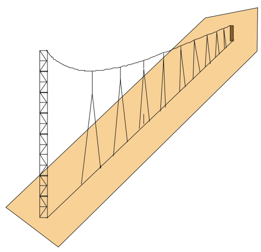
4.4.2.2 Vertical antennas in use for GMDSS

Application	Description	Configuration
NAVTEX *Omnidirectional*	*MF Tee antenna* capable of channelized operation from 415 to 535 kHz. Capable of operation from 1 to 5 kW. Requires ground-screen. Efficiency depends upon effective height of antenna and quality of earth system. Requires an antenna coupling unit (ACU), set to the required channel by the transmitter via a screened control circuit	 Rap 2027-21a
GMDSS A2 only *Omnidirectional*	*Tuned monopole antenna* or beacon antenna, with an average power rating of 1 kW, and a voltage standing wave ratio (VSWR) < 2:1 into 50 Ω from 2 174.5 to 2 189.5 kHz using an antenna tuning unit. Requires a groundscreen. Efficiency depends upon antenna height and quality of earth system	 Rap 2027-21b
GMDSS A2, and A3 *Omnidirectional*	*Conical monopole antenna* with an average power rating of 1 to 10 kW, and a VSWR < 2:1 over the frequency band 2 to 18 MHz. Requires a groundscreen. Efficiency depends upon antenna height and quality of earth system. VSWR depends upon size of curtain	 Rap 2027-21c
GMDSS A2, A3, A4 *Directional*	*Log periodic monopole antenna* with an average power rating of 1 to 10 kW, and a VSWR < 2:1 over the frequency band 2 to 18 MHz. Requires a groundscreen	 Rap 2027-21d

4.4.3 Skywave antennas

4.4.3.1 Requirement

If the frequency is too high or the distance too long for groundwave the only path available between antennas will be through the ionosphere, where all the energy in the wave will be absorbed and re-radiated by free electrons in ionized layers of the atmosphere. This is referred to as skywave propagation, for which the transmit antenna must first generate a wave which excites the free electrons in the ionosphere into motion such that the re-radiated energy is capable of efficient reception with an appropriate receive antenna.

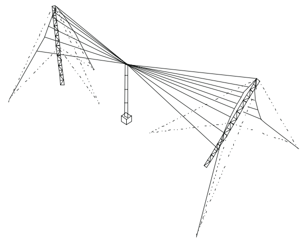
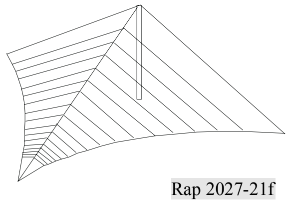
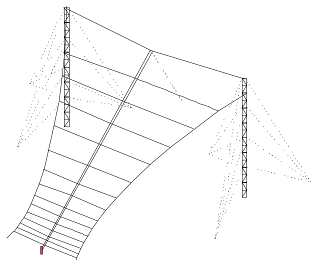
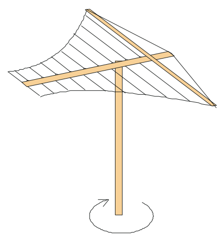
All radio waves passing through the ionosphere are attenuated by absorption which varies inversely with frequency, whilst those too high in frequency for their angle of incidence pass straight through. It follows that long circuits benefit from high frequency waves glancing at low angles from the ionized layers, whilst shorter circuits can exploit lower frequencies at much higher angles of incidence. The low frequency limit is set by ionospheric absorption occurring at lower altitudes where the ionosphere is too weak to cause reflection. However, the levels of ionization at different altitudes do not rise and fall together and conditions exist when the absorption at low altitudes falls whilst the ionization at higher altitudes is maintained, and propagation becomes possible at vertical incidence. This effect is exploited in tropical regions where heavy daily changes occur in ionization levels.

It follows that a transmit antenna needs to radiate sufficient power at the best frequency, with the correct polarization, and at the correct angle of elevation, and it is important therefore to select the antenna best suited to its application.

The antennas described in § 4.4.2 above for groundwave propagation can also be used for skywave propagation down to extremely low angles of elevation, but produce little or no radiation at high angles, and horizontal antennas are generally used when groundwave propagation or radiation at extremely low angles is not required. Suitable antennas are generally dipole or log periodic designs, budget versions being available using a single mast, with high performance models employing two masts.

Whilst horizontal antennas do not require an earth mat, the low angle performance does depend upon the ground conductivity and the antenna height, and raising the height of a horizontal antenna above the ground will increase gain at low angles of elevation.

4.4.3.2 Horizontal antennas in use

Application	Description	Configuration
GMDSS A3 *Omnidirectional*	*Horizontal wideband dipole* with a gain of 7.5 dBi and an average power rating of 1 to 10 kW, and a VSWR of less than 2:1 over the frequency band 4 to 28 MHz. Suitable for operation over short and medium ranges, and for vertical incidence propagation	 Rap 2027-21e
GMDSS A3 *Directional*	*Horizontal log periodic antenna* with a gain of 8 dBi and an average power rating of 1 to 10 kW, and a VSWR of less than 2:1 over the frequency band 4 to 28 MHz. Suitable for operation over short and medium ranges	 Rap 2027-21f
GMDSS A3 and A4 *Directional*	*High performance horizontal log periodic antenna* with gain of up to 11.5 dBi, and an average power rating of 1 to 10 kW, and a VSWR of less than 2:1 over the frequency band 4 to 28 MHz. Gain can be increased by stacking two curtains on raised supports. Low angle gain can be increased at high frequencies by raising apex off ground on poles, making the antenna suitable for operation over very long ranges	 Rap 2027-21g
SAR coordination in sea areas A3 and A4 *Steerable*	*Rotatable log periodic antenna*, horizontally polarized with gain of up to 10 dBi, with an average power rating of 1 to 10 kW, and a VSWR of less than 2:1 over the frequency band 4 to 28 MHz. Can be designed for operation over medium and long ranges, steerable in any direction, but response time may be insufficient for immediate response to distress alerts	 Rap 2027-21h

4.5 Provision of a good station earth

4.5.1 The need for an efficient earthing system

A good earthing system satisfies three main requirements on a station of this type:

– to permit sufficient earth-fault current to flow to trip main circuit breakers;

– to protect against damage caused by a lightning strike;

– to permit satisfactory operation of grounded antennas.

4.5.1.1 Safe operation of circuit breakers

A station of this type would usually employ circuit breakers on the incoming mains supply to disconnect the station in the event of connection of one phase of the power supply to earth under fault conditions. By way of example for a line voltage of 380 V, an earth resistance of 4.4 Ω would be required to enable an earth fault to trip the incoming circuit breakers at 50 A. If the incoming current is likely to exceed this level, then a lower value of earth resistance would be required.

4.5.1.2 Protection against damage caused by a lightning strike

Two main precautions are recommended, which are described in § 4.6; a low value of earth impedance to minimize the risk to equipment connected to external systems by reducing the voltage rise in the local earth system during a strike and an earth ring around the building to minimize the step potential inside the building, and reduce the risk to life.

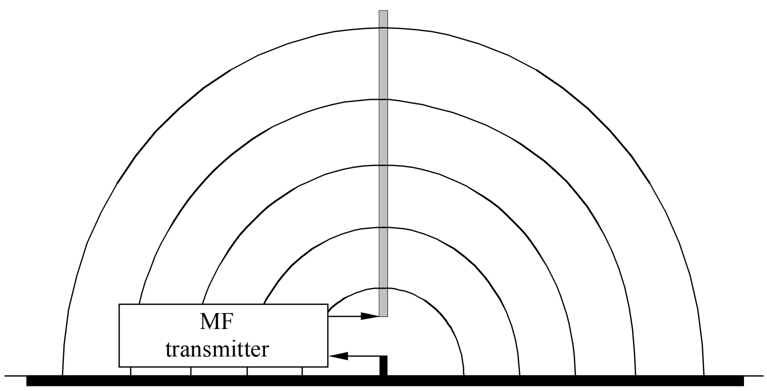
4.5.1.3 Satisfactory operation of grounded antennas

The types of earth required by a transmitter for RF and to satisfy power safety purposes are quite different. The earth required for power safety should present a low resistance at low frequencies, and due to inductance and skin effect an efficient power earth is not necessarily efficient at RF. Similarly an earth mat under an antenna should provide it with the capacitance required for efficient performance, but need not be in contact with the ground to do so, and is not necessarily suitable for power safety. The earth required for use on a transmitting station should be designed to satisfy both requirements, and it is therefore normal practice to provide a buried earth mat for integration into the station earth system.

Figure 22 shows the local field for a monopole antenna over a perfectly conducting plane. In such an antenna the maximum gain would occur in the horizontal direction.

FIGURE 22

Local field characteristic for a monopole on perfect ground



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The ground plane is never perfect, and in practice the conductivity has to be improved by burying a copper mat under the surface of the ground, the amount required depending upon the ground conductivity, which in turn depends upon the ground condition and moisture content. This gives rise to two important effects which directly impact antenna efficiency:

– Instead of reaching a maximum along the ground, the gain reaches a peak a few degrees above the ground and then tucks in to a lower value along the ground, resulting in loss of groundwave output.

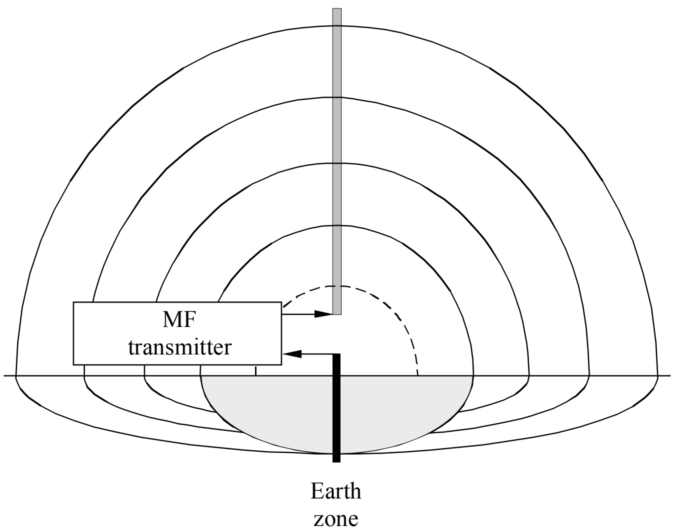
– The earth resistance increases slightly, causing power to be lost into the ground.

The earth mat usually takes the form of wires radiating out from a small ring around the base of the antenna. As the number and length of wires decreases the ground loss and earth resistance will increase, and in practice the antenna efficiency will be limited by the amount of space available for the earth mat.

Figure 23 shows the effect of reducing the copper earth mat to a minimum. The earth will occupy a zone around the earth conductors which does not constitute part of the radiating antenna resulting in a high series earth resistance, and very severe reduction in efficiency.

FIGURE 23

Effect of reducing the ground mat to a bare minimum



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4.5.1.4 Impact of earth design on antenna efficiency

Antenna efficiencies for two tee antennas are given below, assuming a range of site conditions and earth mat sizes.

			Overall efficiency	
Ground conditions	**RF earth resistance (assumed) (Ω)**	**Ground loss (dB)**	**T antenna 30 m long 15 m high (%)**	**T antenna 75 m long 45 m high (%)**
Wet ground, 120 radials, 240 m long	0.5	0	44	90
Medium ground, 36 radials, 90 m long	5	1.5	5	31
Dry ground, 16 radials, 60 m long	12	2	2	16

4.5.2 Practice

4.5.2.1 Station earth

Where earth conditions are poor, or risk of a severe lightning strike is high, it is accepted practice to provide continuous earth rings surrounding each building or group of buildings and where necessary a system of radials around them, with interconnected rings around multiple buildings. The rings would usually be made from copper strip not less than 25 mm × 2.5 mm buried 1 m deep, and each radial would consist of copper strip not less than 20 mm × 2 mm or copper strip. All joints should be lapped, double bolted and soldered. All connections between the earth system and station equipment should be kept as short as possible, the main connection for technical equipment being where the bond from the antenna earthing system enters the building

Earths supplied by separate parties should be separately and independently bonded to the station earth except where connections to external supplies call for special measures.

The bond between the mast earth and the station should be not less than 35 mm × 2 mm copper strip. If a gantry is provided, the bond should pass under the feeder gantry at or below ground level and should be firmly bonded to any intermediate gantry support structures. It should be bonded to the earth ring and continue into the building. It should be adequately protected against mechanical damage (e.g. motor vehicles, pneumatic drills etc.). It should not be longer than the feeder run on the gantry.

On stations employing grounded antennas and internal antenna tuning units the buried earth radials should be connected to the earth ring at one end at regular intervals, and extend outwards in all directions required for radiation. As a guide, on sites with average ground, (conductivity 3 to 10 mS/m) the length of each radial would not usually be less than the height of the antenna itself.

On stations employing grounded antennas and external antenna tuning units, the buried counter-poise radials should extend outwards from the antenna drive point and extend outwards in all directions.

Where buried radials have to be cut short at the edge of a building, they should be connected to the earth ring. Where the earth resistivity is abnormally high, or the building area is large it will be necessary to replace the missing sections of earth mat by installing a Faraday screen on the roof of any buildings contained in the ring. This screen should be connected down the walls of the building at regular intervals.

4.5.2.2 Earth requirements on very dry sites

On very dry sites it may be necessary to use radials at least a quarter wavelength long. This results in good radiation in the direction of the radials, but for efficient NAVTEX broadcasts the radials would need to be at least 150 m in length, requiring a large site.

If the ground is dry but a reasonable water table exists within a few metres, then it may be necessary to make connections to it by driving a number of earth rods into the ground close to the antenna, and at the ends of a few radial wires. If the water table is deep it may be necessary to gain access to it by drilling a borehole to enable a copper electrode to be buried in bentonite clay. If the water table is covered by soft ground it may be possible to drill the borehole manually using an auger, otherwise the drilling process would have to be mechanically assisted.

If the ground is bone dry and there is no water table then copper alone may not suffice, and it would be necessary to dig a large pit, line it with bentonite clay to retain moisture, fill it with iron waste, and connect it to a source of waste water.

4.5.2.3 VHF, UHF and microwave antennas

Where VHF, UHF and microwave antennas are used, any feeder ascending a mast should be connected to the mast steel at the highest and lowest points and should be bonded to the station earth outside the building using the shortest possible connections. There should be a good earth path down the stays and all rigging components should be suitably by-passed, and the mast lighting supply should be adequately protected.

On MF and HF sites, all groundwork should be bonded together, and all mast radiators should be fitted with a spark gap, and static discharge mechanism.

4.5.2.4 MF and HF antenna and feeder systems

On a transmitting station considerable spacing is required between the antennas in order to provide the required isolation, and this can lead to large antenna farms, and very long lengths of buried feeder. In some areas there will be a high probability of a lightning strike hitting an antenna, or going to ground between them. A point on the ground between the antennas struck by lightning will be raised to a very high potential. This would result in a steep potential gradient along the ground away from the point struck, accompanied by an outward flow of current sufficient to induce a secondary current along any feeder buried in the underlying subsoil. Earthing points should be provided either end of each feeder to conduct this current safely to ground.

Where the feeders enter the main building this can be accomplished by bonding the feeder outer conductors to the earth ring. On a large receive station employing several receive antennas and a multi-coupler the feeders should enter the building at one point and be terminated on a panel bonded to the main station earth ring, providing an effective location to fit gas discharge devices to provide primary protection to the inputs to the receive multi-couplers.

Main feeders usually connect to the antenna by means of a balun transformer or matching equipment, where an earth should be provided to absorb any current resulting from a strike to the curtain or, on some designs, the support structures, and this earth should be shared by the outer conductor of the feeder. Any discharge current flowing into this earth should raise the potential of the connection point causing a small residual current to flow along the outer of the feeder connected to it which would be absorbed by the common earth at the transmitter building.

4.5.2.5 The building

The roof should be fitted with lightning conductors and vertical spikes in accordance with local practice. Each lightning conductor should be continuous over the building and be connected to the earth ring at both ends.

If an external lightning conductor passes behind a piece of internal equipment, it should be interconnected by means of a short connection through the wall (or ceiling). Otherwise it is possible for a flash to go through the wall. (Because building materials are bad conductors, the air behind the equipment could heat up so quickly that its rapid expansion could blow the equipment off the wall.)

4.5.2.6 External supplies

When a supply, e.g. mains, telephone or control signal is brought in from a source which uses a separate earth, adequate measures must be taken to protect the inter connecting feed and to isolate the cables or lines concerned to ensure that lightning current is always taken safely to earth without causing remote damage. Opto-isolators may be used to isolate telephone and data lines, the earth on the supply side being bonded back to an earth which is totally separate from the station earth.

An isolation transformer for the incoming mains supply. The primary/secondary insulation should be able to withstand the elevated potential caused by a strike to the system either side. The secondary neutral should be connected to station earth, and the primary neutral should be earthed separately in accordance with local regulations. The secondary neutral should be connected to station earth, and the primary neutral should be earthed separately in accordance with local regulations. The current flow during a strike would usually be 20 kA (low risk) to 200 kA (high risk). If the transformer is designed to withstand a potential of 20 kV between primary and secondary windings, then for sites of low risk the required value for station earth resistance would be 1 Ω. On a high risk site the required value for earth resistance would be 0.1 Ω.

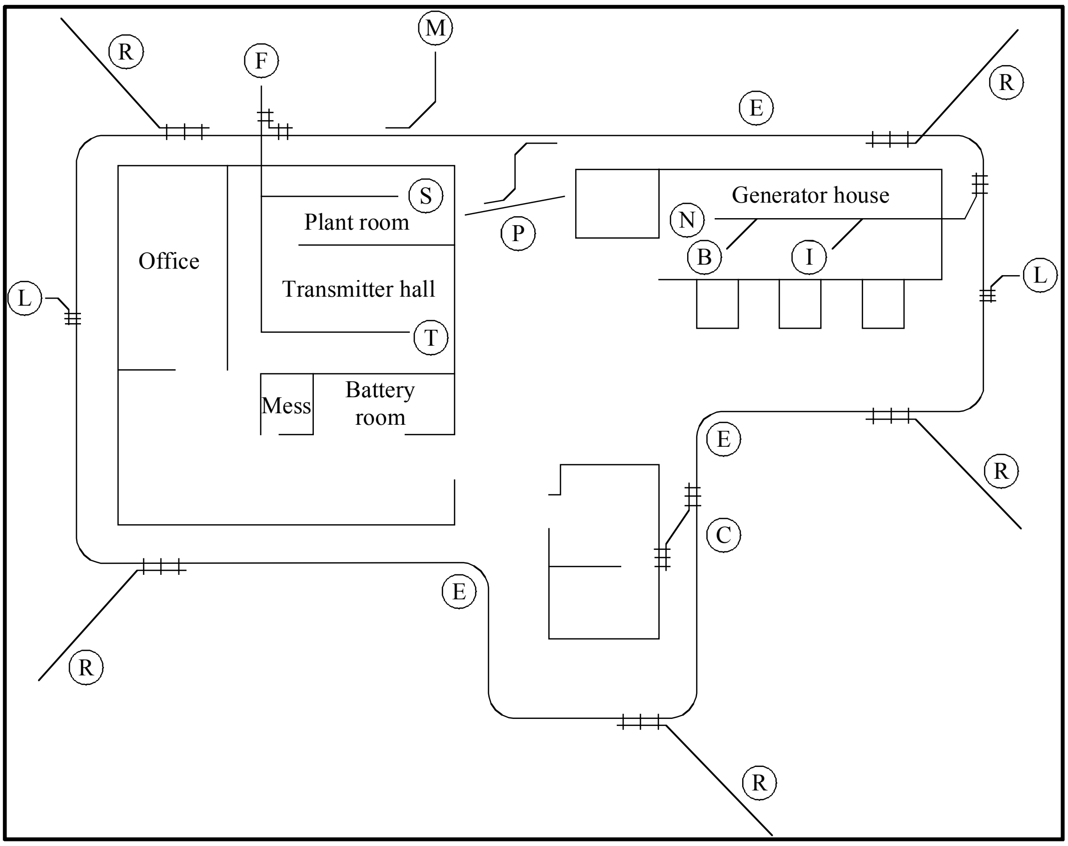
4.5.2.7 Value of earth resistance required

The earth resistance required for lightning protection will usually depend upon local regulations, but in cases where the station is completely independent, i.e. it is using microwave links for signal feeds and telephones, and derives power from local generators, then 5 Ω is commonly accepted as a value for earth resistance.

The value of earth resistance required on grounded antennas depends upon the number and configuration of antennas in use. On sites employing one transmitter with a grounded antenna, an RF earth resistance up to 5 Ω would usually be sufficient to provide adequate protection against lightning. Electrically short antennas such as small Tees and short whips may require an earth resistance of 2 Ω or less to maintain efficiency. On sites employing more than one grounded antenna, but too small to separate their earth zones an even lower value may be needed to minimize coupling effects, depending upon frequency separation.

4.5.3 Implementation of typical station system

FIGURE 24



E Main earth ring
R Earth radials, either earth tape up to 150 m long, or counterpoise radials
P Strip above cable pipe or buried feeder
S Switchboard and power distribution earth
T Technical earth
F Feeder entry earth
B Powerhouse busbar
I Power supply authority earth
N Local neutral connection (in accordance with local regulations)
C Connection to civil hardware
L Connection to air termination on roof
M Connection to external mast earth

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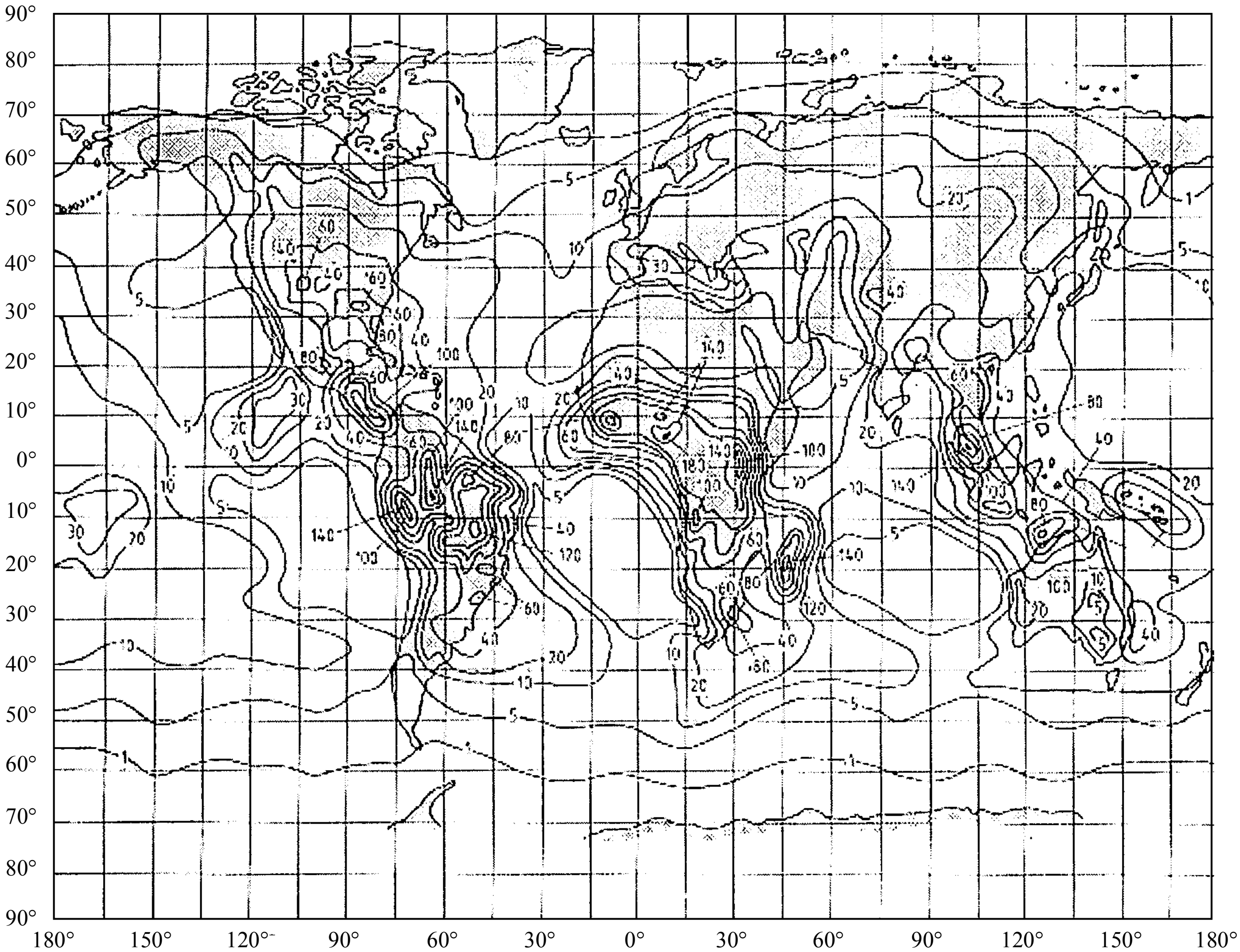
4.6 Lightning protection

FIGURE 25

Map showing thunderstorm days per year



Note 1 – This map is based on information from the World Meteorological Organization (WMO) records for 1955.

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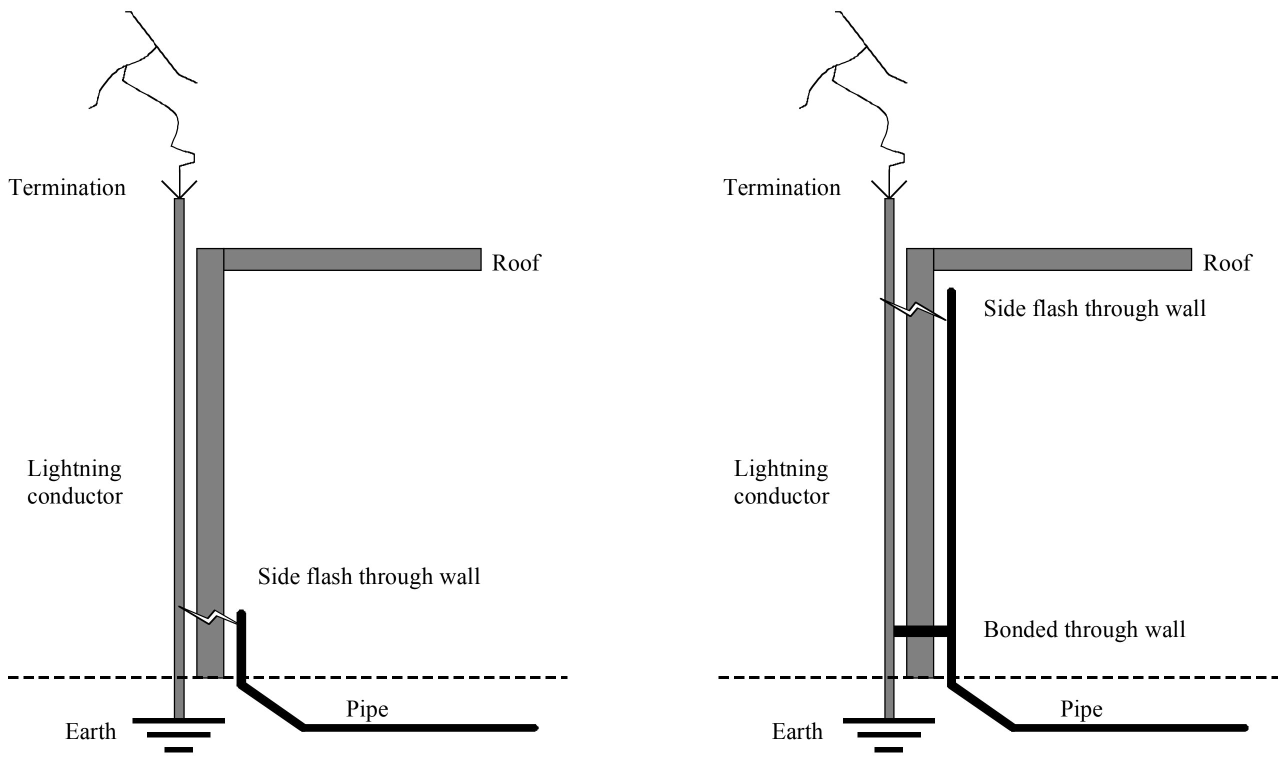
4.6.1 Introduction

Lightning results from clouds charging up like a capacitor, and then discharging to earth, or a neighbouring cloud. An electrical charge grows within a cloud due to peculiar behaviour of the water droplets.* As the charge grows, so does the voltage between the cloud and its immediate environment and a multi-branched stepped leader stroke is formed.* Sometimes the air breaks down around structures on the ground and another dart leader is created which shoots upwards. When the two meet, a conducting path of hot ionized gas is created which allows the total charge in the cloud to flow to earth causing one or more strokes of lightning. Once a discharge path has been established, the total energy stored up in the cloud must be dissipated. If part of this path is a bad

* GOLDE, R.H. – Lightning Protection (p. 9 and 11).

conductor, large quantities of energy will be liberated. For example, in South Africa, one strike smashed a path through rock to earth and produced an explosion equivalent to 250 kg of TNT which released 70 t of rock!* It is important to ensure that the current path taken by lightning through the protection system has as low an impedance as possible. Usually a strike to a conductor which connects to a good earth will leave no trace. Although the current may typically reach 100 kA*, the total energy dissipated in a good conductor may never be sufficient to raise its temperature by more than a few degrees. Under normal conditions, about 95% of the energy goes into producing the acoustic shock wave, a small amount is radiated as light and RF and the remainder should be dissipated as heat in the ground. The map shown in Fig. 25 provides an indication of the number of thunderstorm days per year to expect in any part of the world, and is based upon WMO records for 1955.

4.6.2 Side flashes



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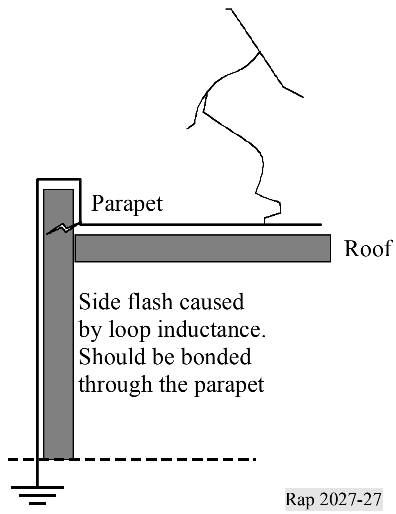
* GOLDE, R.H. – Lightning Protection (p. 17 and 55).

Consider what happens when lightning strikes a conductor fitted to a building. Up to 100 kA may build up and die away during a few microseconds causing a magnetic field to grow and collapse very rapidly around the conductor. This magnetic field will surround the conductor wherever it goes, right down into the ground. Self-induction will cause a high potential to build up on the conductor which will increase with height and will tend to flash over to anything else that may provide an alternative path to earth. Even at ground level, it may flash over to a nearby water or gas pipe. This type of flashover is called a side flash*.

As the current passes through the earth resistance, it will raise the potential of the entire system connected to it. If another part of the system is earthed separately, the lightning current may try to flow to it, destroying anything in its path, so it is essential to bond all the separate earths together, including service pipes, at ground level.

If a unit is mounted on an inside wall behind a lightning conductor, a side flash may try to go through the wall. At the least, this would cause rapid heating of the air in the path of the flash. As this air expands, it could blow the unit off the wall. At worst, the material of the wall could blow apart. (This type of damage is worst where the flash goes between pieces of reinforcing material which have not been bonded together.)



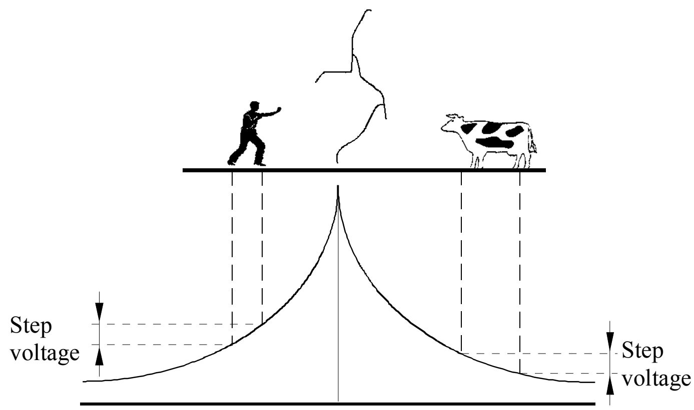
The lightning conductor must go in a straight line to its earth. If a bend or loop is introduced, the magnetic field enclosed will be even greater. This may cause a flash to go between two different parts of the same conductor, making it look as though the current were taking the shortest path to earth. This can occur if a conductor is routed around a parapet, when the resulting flashover may cause severe damage to the concrete or brickwork*.

Other places vulnerable to side flashes are the mast supplies. Except for mast radiators, all feeders must be connected to the mast or tower, both at the top and at the point where they leave the mast at the gantry. All antennas, both for transmitting and receiving, must provide a DC short circuit between the inner and outer of the feeder to reduce the risk of a flashover occurring. On a receiving aerial, severe damage can be caused to the input stage of the receiver. Although no figures are available regarding failure of mast lighting supplies, there is clearly an acute danger of a flashover occurring between the armouring (which will be raised to mast potential) and the line and neutral conductors (which will be at ground level potentials). Further investigation is required to determine whether special measures are necessary.

* GOLDE, R.H. – Lightning Protection (p. 57/84 and 78).

4.6.3 Ground potential

The lightning strike may raise the earth system and its close surroundings to a potential several tens of thousands of volts above that of the ground some short distance away*. For a short period of time, a potential gradient will exist along the ground. This produces a hazard to personnel and livestock because a person can suffer a fatal shock due to the potential difference between his feet. This can be avoided by surrounding the inhabited area by a copper ring earth buried 1 m deep. This ring may be utilized as part of the earth system and radials added to it if necessary. However, this cannot replace the mast earth which must always be installed to take the bulk of the lightning current when the mast is struck.



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4.6.4 Earth ringing

When a pulse of energy is injected into a tuned circuit, it will ring. If different pieces of equipment connect to different parts of the earth system, earth loops will be set up. These can all act like interconnected tuned circuits. When lightning strikes a conductor connected to the earth system, circulating RF currents may be caused to flow. The earth system should be designed to minimize this effect by ensuring that all the technical equipment is brought back to a single earth point in each main area and ultimately to a single station earth. An alternative system in use utilizes a copper damp proof course as a main part of the earth system allowing more than one earth connection to be made but keeping them as short as possible.

The effect of earth ringing is made worse when an earth connection is omitted, e.g. between mast earth and station earth. This brings the feeder into a large earth loop which would be capable of storing sufficient energy to destroy the input stage of a receiver or the output stage of a transmitter. The latter should be protected by ensuring that co-axial output equipment provides a DC path to earth. In an MF transmitter, this may be the only way to connect the aerial or mast to earth for safety.

4.6.5 Third party connections

A transmitting station sited on a remote peak may be totally disconnected from all normal services such as mains power, water, and telephone system. It will derive power from a diesel generator, signals will arrive by microwave link and communications will be by radio telephone. All these services will share the station earth, allowing adequate protection to be installed at low cost. When the transmitting station is installed near a town, the mains supply will come from a nearby substation, the telephone will connect to the local exchange and additional signals may come by

* GOLDE, R.H. – Lightning Protection (p. 86).

landline from a weather centre, or satellite receiving station. It is the responsibility of the authorities concerned to lay down practice which depends upon local conditions, but this practice can be summarized in general terms:

4.6.5.1 Isolation

Where necessary, an incoming line or feeder should terminate in a device which isolates it from the station earth. For example, the mains transformer should have a primary neutral earth on the high voltage side which goes to a completely independent earth, all parts of which should be sited or insulated to avoid danger to personnel. The transformer secondary neutral will be connected to station earth and so the insulation in the transformer must withstand the potential which could exist between the two earth systems. If all the lightning current goes down the station earth then this voltage will depend upon the quantity of current and the quality of the earth. Research has shown that 20% of lightning strikes reach a maximum current flow of 50 kA. If the station earth is 1 Ω, then the transformer primary/secondary insulation must be 50 kV. If the transformer will only withstand 25 kV, then the station earth must be improved to 0.5 Ω. This standard is adopted by one broadcasting authority [EBU, 1961a].

4.6.5.2 Protection [EBU, 1961b]

The incoming line (power or telephone) should be fitted with lightning arrestors. These should sense when the voltage on the line reaches the maximum tolerance level and then flash over. This maximum voltage will depend on:

– The maximum input voltage of the terminal equipment, for example, the primary/secondary isolation of the mains transformer (25 kV in the above example).

– The breakdown characteristic of the line insulation or the insulators on which it is mounted.

A further measure which can be taken is to install a lightning conductor above the service line. If this is an open wire feeder mounted on poles, the conductor should pass from pole to pole above the main conductors, should connect to the pole steelwork and connect to an earth in the ground at the pole base.

If the service (mains, programme or telephone) comes in via a cable buried in the ground, then a conductor should be buried above the main cable. This is especially important on mountain sides where there is a strong likelihood of the cable attracting a strike through the ground. The cable would be at a depth of 1 m and the earth line about 10 cm above it. The earth line should be connected to the isolated side of the isolation equipment at each end.

4.6.6 Fuel tanks*

These should be installed and earthed to eliminate the risk of an explosion due to a side flash or other breakdown. Particular attention should be paid to the wiring of the metering circuits. All metal parts outside the building must be bonded back to station earth.

* GOLDE, R.H. – Lightning Protection (p. 131).

Oil is not a good electrical conductor. Oil stored in large tanks has been known to receive a large charge when some other part of the system has been struck. An explosion followed some time later when the charged section of oil was able to discharge itself to nearby steelwork creating a spark. Large oil tanks should be carefully designed, especially if made of fibreglass. They should be equipped with a suitable internal structure to provide a safe earth to the oil itself.

4.6.7 Further developments in protection

4.6.7.1 Finial spike*

This is a simple spike fitting, mounted at the highest part of a building or mast. It is said to provide a zone of protection. Within this zone, it is more likely for the lightning to strike the spike than anything else. The higher it is mounted, the greater is the zone of protection. Its operation is simple. When lightning is likely to strike, the finial spike provides a convenient point around which the air can break down to create a positive dart leader which will strike out to meet the negative dart leader coming down from the cloud. The finial spike is the oldest form of protection used. It connects to the lightning conductor which should take a direct path across the roof and down to a good earth.

4.6.7.2 Dissipators and inhibitors

These are a development of the simple finial spike and versions are available for mounting on the roof or for mounting on the top of a mast. They have a number of spikes or points on the end which cause the air to ionize. The negative charge flows to earth and the positive ions flow outwards in a stream. Sometimes this effect causes a glow to be seen like a corona discharge (Hermestine glow). When this happens naturally it is known as St Elmo's Fire and can be seen around trees or other prominent features.

The discharge mode depends upon the geometry of the hardware. This provides a means of controlling the breakdown of the surrounding air. By correct design, a mode of activity can be chosen which will prevent the growth of positive leaders and greatly reduce the chance of a lightning strike.

Positive ions can flow outwards, laying a blanket of positive charge around the building and mast, thus protecting quite a large area. It has been claimed that this action can be enhanced by the use of radioactivity. This has two effects. It will provide ionization even when there is no local thunderstorm and it will eliminate some of the ionic activity which precedes a strike. Versions using radium sulphate are available for mounting on a roof [EBU, 1965] or mast.

Another type uses a gold tipped spike connected to the inner of a co-axial cable earthed at the base of the mast. The cable outer is connected to a number of gold plated ionising sources utilizing americium 241 isotope which continuously emits electrons (8.33×10^{12} per s). The manufacturer claims that this gives the unit "the ability to launch a streamer earlier in time than from points subject to natural ionization", and is effective within a radius of 250 m. This unit operates by attracting a lightning strike and conducting it safely to earth. The danger from side flashes is eliminated as long as no other part of the structure is struck.

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* GOLDE, R.H. – Lightning Protection (p. 32).

4.6.7.3 Thunderstorm detectors*

Charge dissipators designed for mounting on masts usually consist of a large open disc containing a myriad of tiny spikes. The resulting current flow can be detected by a sensitive current amplifier to sound an alarm or to automatically take executive switching action. In one system in use in the USA, a switching pulse is fed to the generator mains fail equipment, the generator is brought into use and the incoming line is completely isolated. This procedure reduces the risk of destroying the main transformer.

4.6.7.4 Use of a Faraday cage

When conditions are really poor and human life is at risk, a Faraday cage may have to be installed. Copper straps are fitted externally around the building and secured to the earth ring at each end. Each of these straps becomes part of the lightning conductor system and finial spikes may be added to the system around a copper damp proof course which would become part of the station earthing system.

4.6.8 Other types of strike

Not all strikes originate in the cloud. Some start at the ground and begin as a positive leader. They always need a mast or similar structure to start from. They are usually positive strikes but it has been known for negative lightning to originate from the ground** and for positive lightning to start from a cloud [JFI, 1967a].

It is not known what factors cause the high field strengths necessary to create upward dart leaders [JFI, 1967b]. Some people suggest that they are secondary, that they are not actually brought into existence until lightning has struck somewhere else. The clearest picture is gained by considering a charged cloud drifting over a town. The cloud base will act like one half of a capacitor, the other half will be a patch of ground as small as a football pitch or as large as a whole town or valley. As the cloud drifts over, every prominent feature, such as trees, chimney pots, roof gutters, etc. will begin to bristle with electrical life. Every point is a potential target. There may be hundreds of upward streamers that could become positive dart leaders, the tip of the negative downward leader will be at full cloud potential. As it approaches the ground, it will increase the tendency for these possible upward darts to actually be made. The result is, as its traditional name suggests, fork lightning.

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* Broadcast Engineering.

** GOLDE, R.H. – Lightning Protection (p. 14).