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Radio broadcasting systems; Code of practice for site engineering Very High Frequency (VHF), frequency modulated, sound broadcasting transmitters

ETSI

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Foreword

This ETSI Technical Report (ETR) has been produced under the authority of the Joint Technical Committee (JTC) of the European Broadcasting Union (EBU) and the European Telecommunications Standards Institute (ETSI).

ETRs are informative documents resulting from ETSI studies, relating to the use or the application of ETSs or I-ETSs.

NOTE: This EBU/ETSI Joint Technical Committee (JTC) was established in 1990 to co-ordinate the drafting of European Telecommunications Standards (ETSs) in the specific field of radio, television and data broadcasting.

The EBU is a professional association of broadcasting organisations whose work includes the co-ordination of its Members' activities in the technical, legal, programme-making and programme-exchange domains. The EBU has active members in about 50 Countries in the European Broadcasting area; its headquarters is in Geneva *.

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1 Scope

This ETR provides guidance for engineers concerned with the design, specification, installation, operation and maintenance of radio systems. It is particularly directed towards broadcasting systems working in the VHF band 87,5 MHz to 108 MHz. Such systems can be installed at single-user sites, or at those occupied by many users of both broadcast and other communications systems of widely varying powers.

This ETR examines the objectives of good design and the effects of common deficiencies. It provides recommendations designed to ensure that users avoid interactions which result in mutual interference, spectrum contamination, or danger to personnel, or equipment.

2 References

This ETR incorporates by dated and undated reference, provisions from other publications. These references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this ETR only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

[1] prETS 300 384: "Radio broadcasting systems; Very High Frequency (VHF), frequency modulated,sound broadcasting transmitters".

[2] CCIR Report 258-5 (1990): "Man-made radio noise".

[3] IEC 268-8 (1973) Part 8: "Automatic gain control devices".

[4] CCIR Report 292-6 (1986): "Measurement of programme level in sound broadcasting".

[5] CCIR Recommendation 562: "Subjective assessment of sound quality".

[6] EBU Technical Document 3253-F: "Sound quality assessment material. Recording for subjective tests".

[7] EBU Technical Monograph 3117: "The protection of broadcasting installations against damage by lightning".

[8] IEC 215 (1987): "Safety requirements for radio transmitting equipment".

[9] CCIR Recommendation 412-5 (1990): "Planning standards for FM sound broadcasting at VHF".

[10] CCIR Report 739-1: "Interference due to intermodulation products in the land mobile service between 25 and 1 000 MHz".

[11] CCIR Recommendation 591: "Compatibility between the broadcasting service in the band of about 87 - 108 MHz and the aeronautical services in the band 108 - 136 MHz".

[12] CCIR Report 927: "General considerations relative to harmful interference from the viewpoint of the aeronautical mobile services".

[13] ITU-R Recommendation IS.1009: "Compatibility between the sound - broadcasting service in the band of about 87 - 108 MHz and the aeronautical services in the band 108 - 137 MHz".

3 Abbreviations

For the purposes of this ETR, the following abbreviations apply:

AF	Audio Frequency
AIP	Aeronautical Information Publication
BB	Broadband
COM	VHF Communications
DAB	Digital Audio Broadcast
dBc	dB relative to the carrier
dBd	dB relative to a half-wave dipole
dBi	dB relative to an isotropic radiator
DOC	Designated Operation Coverage
ERP	Effective Radiated Power
FM	Frequency Modulation
GAM	General Assessment Method
hrp	horizontal radiation pattern
HV	High Voltage
IEC	International Electrotechnical Commission
IEE	Institution of Electrical Engineers
IF	Intermediate Frequency
ILS	Instrument Landing Systems
LF	Low Frequency
LEGBAC	Limited Exploratory Group for Broadcast to Aeronautical Compatibility
LV	Low Voltage
NB	Narrowband
MF	Medium Frequency
RCD	Residual Current Device
RDS	Radio Data System
RF	Radio Frequency
SHF	Super High Frequency
S/N	Signal to Noise ratio
UHF	Ultra High Frequency
VHF	Very High Frequency
VOR	VHF Omnidirectional Radio range
vrp	vertical radiation pattern
VSWR	Voltage Standing Wave Ratio

4 Site selection

4.1 Coverage and frequency planning

The choice of site is generally made to fulfil two main criteria. These are that:

a) coverage of the intended area should be as effective as possible; and

b) frequency-planning constraints are complied with.

With respect to coverage, broadcasters and where applicable, regulators, will have a particular area they intend to serve. The broadcaster will wish to maximise the number of people he can reach, for a given set of transmission parameters. The regulator may on the other hand wish specifically to exclude certain localities beyond the area originally intended.

Frequency planning will either be sponsored by a regulatory body, or proposals will be offered to that body by the broadcaster for assessment. In either case there will normally be reference to a national plan to ensure optimum utilisation of the Band II spectrum.

Such utilisation requires a compromise between achieving effective coverage at reasonable cost, and avoiding the radiation of unnecessary energy outside of the intended area. The balance between these two requirements will depend on user demand, and spectrum availability in the area concerned which will be a function of services, present and planned, within a large radius (hundreds of kilometres) of that area. Some of the service area planning standards set out in CCIR Recommendation 412-5 [9] may not match all of these circumstances ideally.

Matching the site to the required coverage for a given frequency assignment may be an iterative process. Approximate site location will normally be decided with some knowledge of the allowed ERP, aerial pattern and height above sea level. This will tend to limit the number of practical options available, but if the chosen site differs sufficiently from the original proposal it may be necessary to adjust the radiation characteristics to suit. For example, it may only be possible to gain access on a mast at a different height to that cleared, and this may dictate an adjustment to Effective Radiated Power (ERP).

4.2 Propagation analysis

Propagation analysis is necessary to decide on the suitability of an actual or proposed site. Given details of the site parameters, any technique should also take account of terrain and clutter, e.g. buildings and trees.

Propagation information may be obtained by several methods:

a) information from site operators based on the performance of existing installations;

b) manual calculations by an experienced propagation engineer based on map information;

c) computer field strength predictions generated by evaluating radio path loss from a database of terrain height and feature data;

d) by radio survey of the measured performance of test transmissions from the proposed site.

To identify the areas of search for radio sites, manual calculations from maps are the most appropriate. These may also be adequate to check the suitability of an existing site when combined with the past experience of other site users.

To decide the location for a new site, computer predictions are strongly advised. These are available from a number of commercial organisations.

> NOTE: Computer predictions are statistical in nature and may be based on differing computer models. They will not always take account of ground clutter and those that do can never be fully up-to-date.

The most reliable information is obtained from test transmissions using identical parameters to those intended for final use. However, it is normally only permissable to transmit at lower ERP levels for test purposes, this should give an accurate indication of the coverage to be expected when transmitting at the full allocated ERP. This test transmission technique may only be available under certain National regulatory systems.

4.3 Compatibility with aeronautical services

Compatibility with aeronautical radio services, navigation (108 MHz to 118 MHz) and communications (118 MHz to 137 MHz), should be considered as the highest priority. Interference mechanisms work in both directions, but it is that to aeronautical services that is, of course, critical. Potential sources are calculated by national frequency management administrations either internally or between nations where more than one country is involved, which is often the case. For further information on compatibility with aeronautical services see Clause 10.

4.4 Compatibility with reception of other broadcasts

Broadcast transmitters often radiate relatively high powers and this may impair reception of other broadcast Frequency Modulation (FM) services in their vicinity, particularly where the wanted service is radiated from a distant transmitter. The impairment usually occurs through one of two mechanisms. The first is receiver overloading, where incoming signals are sufficiently high to drive the receiver into non-linearity thus generating intermodulation products. This may sometimes be alleviated by reducing the received signal, e.g. by re-positioning the aerial. The other is "blocking", where the incident field strength directly injects into the receiver circuitry so as to cause malfunction.

It is, therefore, highly desirable to site powerful transmitters (>200 Watts) away from residential areas. Where this is not possible, multi-tiered aerials should help to ease the problem as should increasing aerial height. Restriction to vertical polarisation only, may also help.

4.5 Compatibility with other radio site users

It is essential to ensure that broadcast transmissions will not interfere with other radio users at the site in question. Normally this will be avoided through prior, formal consultation with the users concerned. In those cases where incoming signals are to be received for transposing and rebroadcasting, interference to that reception is also a consideration.

4.6 Capacity of existing sites

This should include consideration of accommodation for equipment on the ground, space on the mast for a separate aerial, or capacity to combine with an existing aerial. Aerial combination will only be a solution if the present horizontal and vertical radiation patterns suit the needs of the oncoming service, and will require the addition of combining equipment and possibly extra filters. A separate aerial installation will depend on available wind-loading capacity, and must include consideration of the effect of the mast on the aerial's free-space radiation performance.

4.7 Environmental and planning considerations

Radio sites are prominent features of the landscape, and many building authorities pay particular attention to applications for new sites or for redevelopment of existing ones. Objections may be raised by many organisations, particularly where the site is located in a National park, area of outstanding national beauty or area of high landscape value. Inadequate preparation may result in a refusal that cannot be overturned.

The site should create the minimum impact on the environment. For example:

a) a small relocation may not affect performance but could radically reduce visual obtrusion;

b) antennas may be orientated neatly without sacrificing performance;

c) choice of structure, style, colour and material may be significant;

d) landscaping with trees and shrubs could help.

5 Combiners

5.1 Introduction

Filters and combiners are essential components of many broadcasting antenna systems. They are used for selecting frequencies, suppressing disturbing emissions and noise sidebands, avoiding interference products, combining several channels into one common antenna with low loss and for separating channels. In certain cases, separate antenna diagrams for individual channels may also be generated.

Power handling capacity:

- it should be capable of accepting the required power of each transmitter and transferring it to the antenna with a minimum of loss. It is also advisable to include a safety factor e.g. 1,5 for mean power and voltage;

Input reflection coefficient:

- it should present a reasonably well-matched impedance to each transmitter (i.e. its voltage reflection coefficient should not add significantly to that of the antenna). Typical values for the reflection coefficient at each input port are 5%, within the relevant frequency band, when the output is terminated in a matched load;

Cross-insertion losses:

- it should provide high cross loss between transmitters on different frequencies. The reasons for this are two-fold. The isolation should generally be greater than 30 dB in order to ensure safety and the coupling should be kept low to avoid the creation of intermodulation frequencies which may occur with other services;

- a typical minimum cross-insertion loss is 36 dB, although higher cross-insertion losses may be required as a result of intermodulation products;

Insertion loss:

- the combiner should provide 3 distortion free paths for all input frequencies and their sidebands. This means that the attenuation across an input channel should be reasonably constant. A typical specification would require a maximum insertion loss, between any input port and the antenna output port, assuming matched sources and load of 0,4 dB, at the carrier frequency. Within each channel, the insertion loss across the frequency band, should not vary by more than 0,5 dB.

5.2 Selection of parameters

According to their use as elements of a system, filters are constructed as two-port networks and are matched to the impedance of the other system elements (e.g. transmitter, receiver, antenna or connecting cables) at both the input and the output.

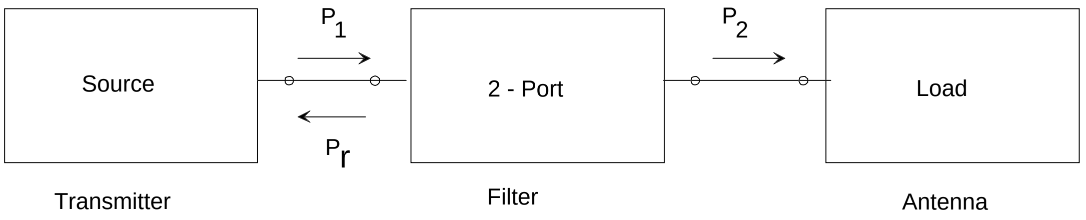


Figure 1: Filter with connections

$P_2 = P_1 - P_r - P_v$ dB

where:

P_1 = Input power;
P_r = Reflected power;
P_v = Power loss through filter;
P_2 = Power transmitted.

5.3 Frequency response

The attenuation (a) usually depends on the frequency (f) used. This relationship is shown graphically by the following diagram of a typical attenuation curve for a filter.

A plot of the attenuation verses frequency shows the typical filter curve. The attenuation is the logarithmic ratio between input power and transmitted power:

$$a = 10 \log_{10} \frac{P_1}{P_2} \text{ dB}$$

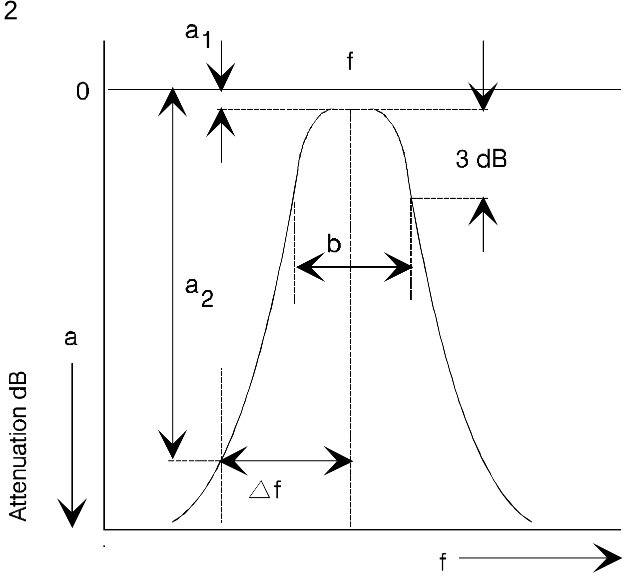


Figure 2: Frequency response of a filter tuned to frequency f_1 with insertion loss a_1, stop band attenuation a_2 at the frequency of $f_1 - \Delta f$ and with bandwidth b at 3 dB

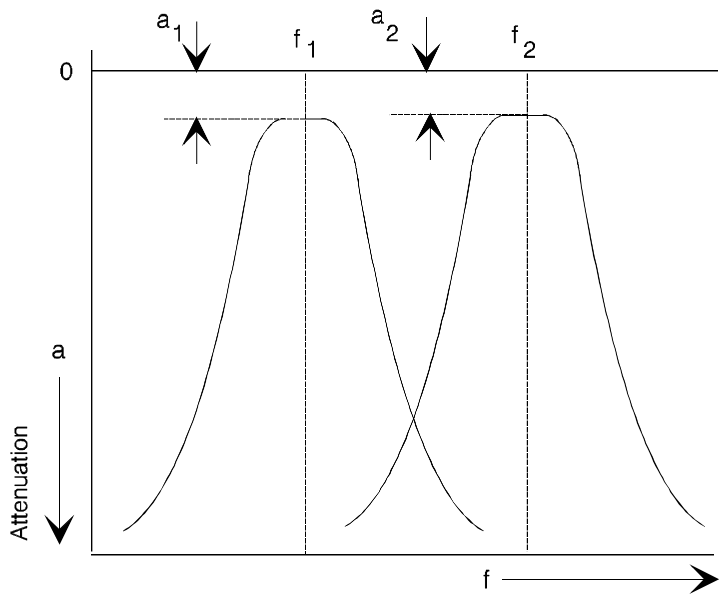


Figure 3: Frequency response of 2-way combiner with insertion losses of a_1 and a_2 at the frequencies f_1 and f_2.

5.4 Matching

As a measurement of how a filter is matched and return loss a_r, which is the logarithmic relationship between the input and reflected power, is displayed.

$$a_r = 10 \log_{10} \frac{P_1}{P_r} \text{ dB}$$

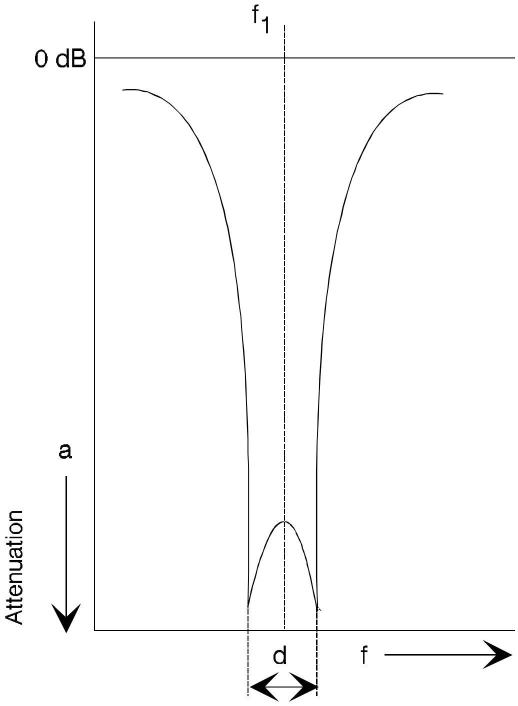


Figure 4: Return loss of a 2-pole bandpass filter tuned to the frequency f_1 and with pass band bandwidth d

The return loss a_r, reflection coefficient r and Voltage Standing Wave Ratio (VSWR) factors are all related according to the following formulas:

$$a_r = -20 \log_{10} |r| \text{ dB}$$

$$s = \frac{1 + |r|}{1 - |r|}$$

5.5 Filters

Where used in broadcasting systems, filters are normally set up as a combination of several λ/4 resonators. The Q factor of the resonators is very important with regard to the electrical data and is influenced by the shape and volume of the filter as well as by the conductivity of the material used.

The selectivity of the filters used for combiners has a decisive influence on the minimum spacing required between the transmitters to be connected into one common antenna. If the frequency spacing is narrow then the filters should similarly be tuned in a very narrow way. But this will cause an increase in the insertion loss (see figure 5) resulting in the filters becoming hot. This problem can be avoided if filters of greater volume are used which have a relatively lower insertion loss.

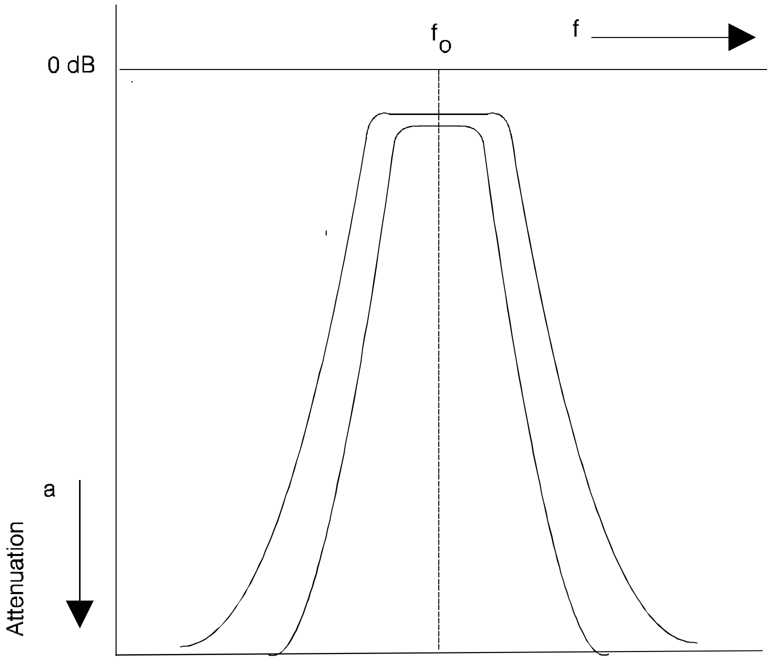


Figure 5: Examples of two different tuning possibilities for a bandpass filter. Narrower tuning will result in higher insertion loss

5.6 Directional couplers

A directional coupler is a reciprocal four-port construction, whereby two of the ports are isolated from each other. For example, the power entering port 1 in figure 6 is split up to ports 2 and 3, whereas port 4 is isolated. The power fed into the other ports is similarly split.

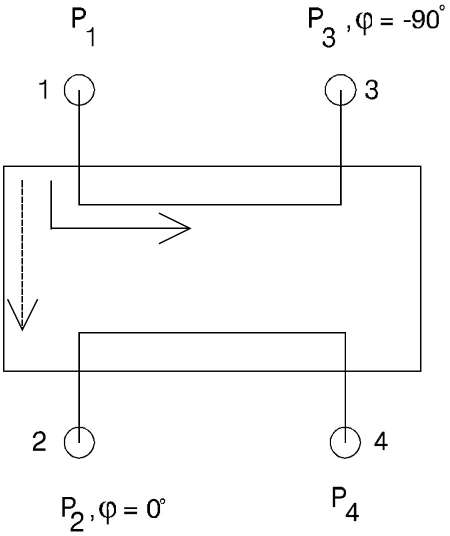


Figure 6: A directional coupler with two coupled lines

If every port is terminated with a reflection-free load, then the following formulas apply:

$$a_k = 10 \log_{10} \frac{P_1}{P_2} \text{ dB}$$

Directivity;

$$a_d = 10 \log_{10} \frac{P_2}{P_4} \text{ dB}$$

If the coupling range of a transmission-line coupler is λ/4 at the centre frequency f_m then the coupling attenuation over a frequency range of $f_1/f_2 = 2$ is almost independent of the frequency. For example, with a 3 dB directional coupler there is a divergence of ± 0,4 dB and phase difference of 90° occurs between the signals at ports 2 and 3, which is also almost independent of the frequency.

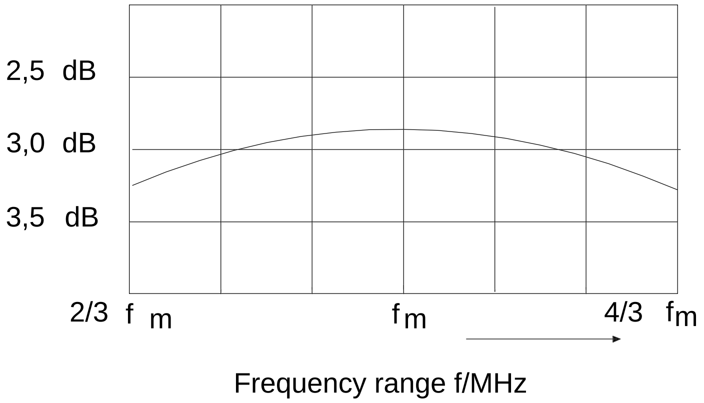


Figure 7: Coupling attenuation for 3 dB transmission-line coupler of $\lambda_m/4$ length

5.7 Combiners

Combiners are a combination of frequency-selecting components (e.g. filters, stretchlines) with nodes and connecting elements (e.g. directional couplers, starpoints). In high quality combiners bandpass filters are used in preference to stop band filters.

5.8 Starpoint combiners

Starpoint combiners for n channels consist of n-bandpass filters with outputs that are connected to a common starpoint. The individual bandpasses are tuned to the respective frequencies. Since the bandpass filters are mismatched outside their pass bands (with inductive coupling the impedance almost approaches a short-circuit) the impedance may be transformed up to very high levels by selecting the appropriate length for the connecting cables between the filters and the starpoint. This means that for every input the transformed impedance's of all the other inputs are very high at the starpoint which produces a very low parallel load at the antenna output

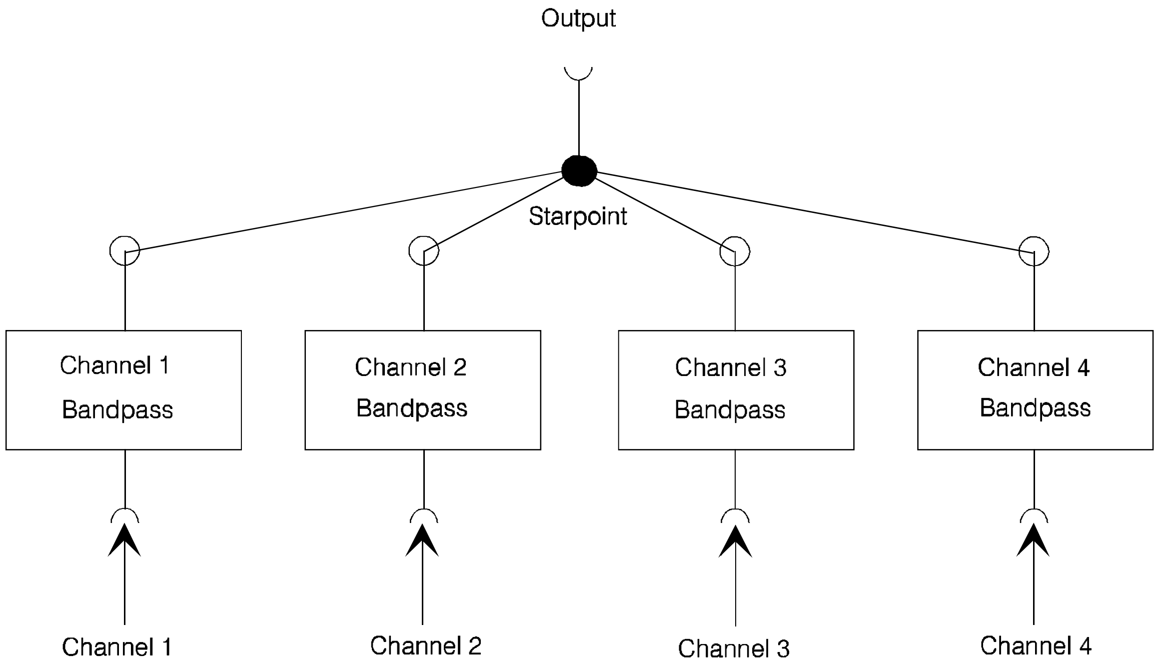


Figure 8: Starpoint combiner for 4 channels

5.9 Directional filters

Directional filters are a combination of filters and 3 dB couplers. One module consists of two bandpass filters, two 3 dB couplers and a load (see figure 9). One input is Narrowband (NB), corresponding to the bandpass curve of the bandpass filter. The other input is Broadband (BB), corresponding to the operating range of the 3 dB coupler.

Compared to other types of combiners that may be produced at less expense, directional filters offer a number of useful advantages:

- simple set-up of multiple combiners through cascading several modules;
- very high isolation between the narrowband inputs of a cascade;
- broadband matching at all inputs;
- easy extension of existing combiners by adding new modules.

5.10 Function of module

The signal fed into the Narrowband (NB) input is split into two halves by the 3 dB coupler (see figure 9 (1)), both of which pass through one of the bandpass filters to the 3 dB coupler (see figure 9 (2)) and are then added in equal phase at its output due to the 3 dB coupler's function. At the Broadband (BB) input the two partial signals are anti-phase and therefore practically no signal appears at this port. The BB input is isolated from the NB input by the directional coupler, but this also depends on the bandpass filters being identically tuned.

The frequency of a signal fed into the BB input lies within the stop band of the bandpass filters. The signal is split into two halves by the 3 dB coupler (2) and reflected completely by the bandpass filters and proceeds to the output after co-phase addition. The narrowband input is isolated from the broadband input by the directional coupler, as described above, but there is additional isolation due to the stop band attenuation of the bandpass filters.

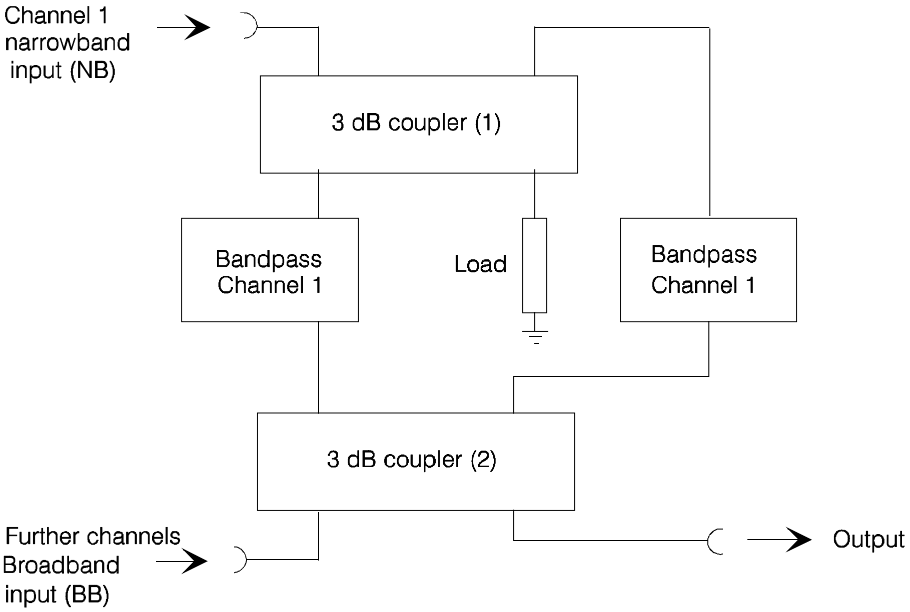


Figure 9: Diagram of a directional filter

5.11 Cascading of modules

Multiple combiners are easily set up by using several modules with the output of each module feeding the broadband input of the next module. The number of channels possible in a given frequency band is limited only by the minimum spacing between the signals. But practical limitation may also arise because the insertion loss for each additional module increases by 0,05 dB to 0,1 dB and may assume intolerable values. The power rating of the 3 dB coupler at the output also can limit the number of channels in practice.

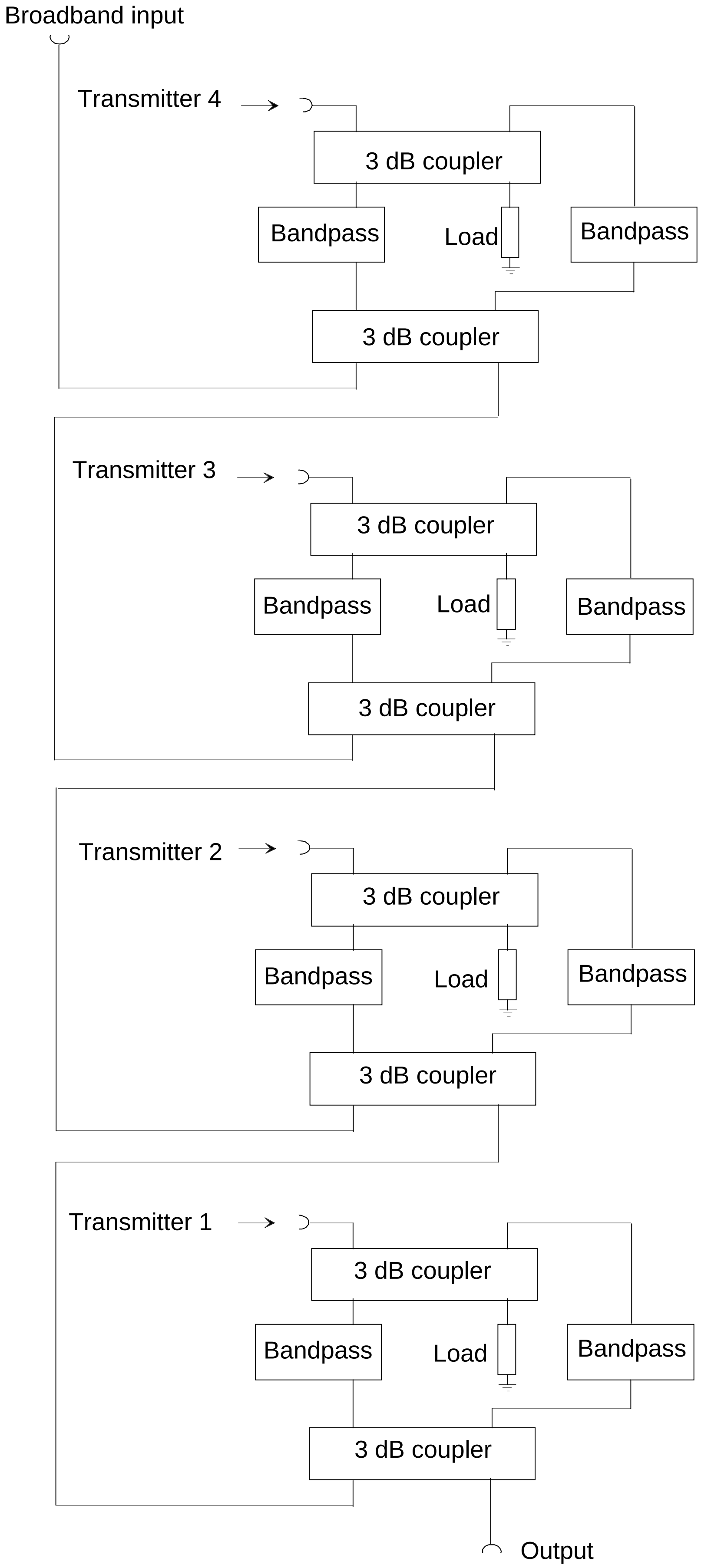
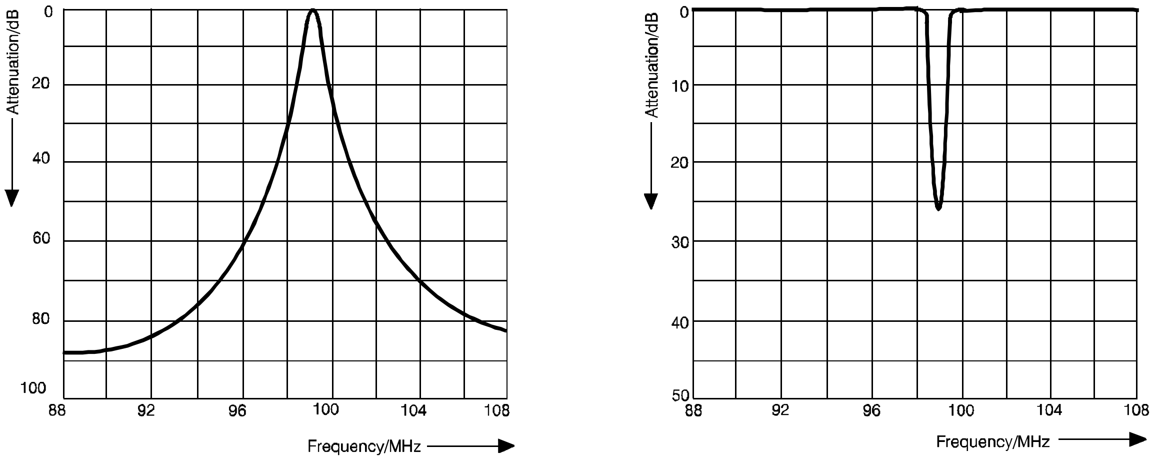


Figure 10: Diagram of a directional filter combiner with four modules

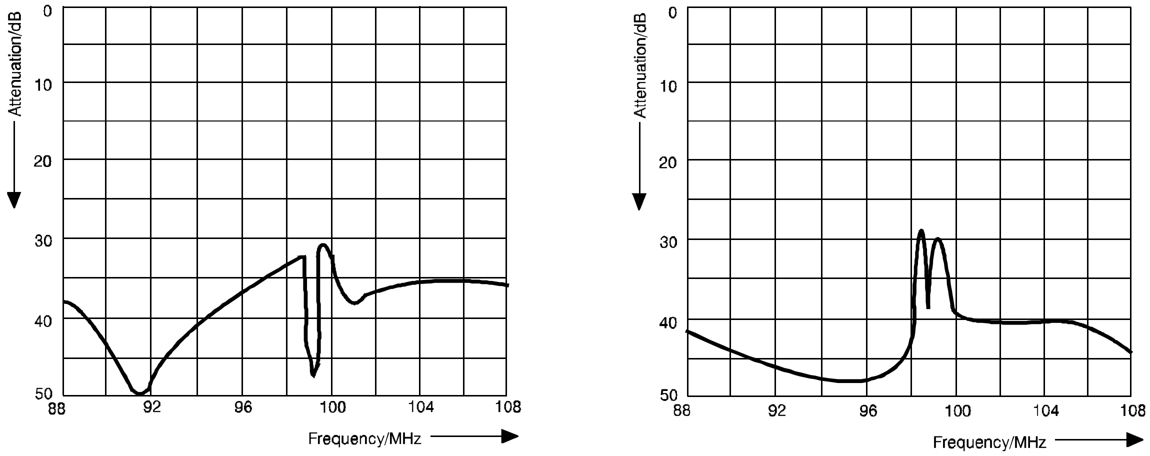
Examples of measured curves for a directional filter module,

(with narrowband input tuned to 99 MHz)



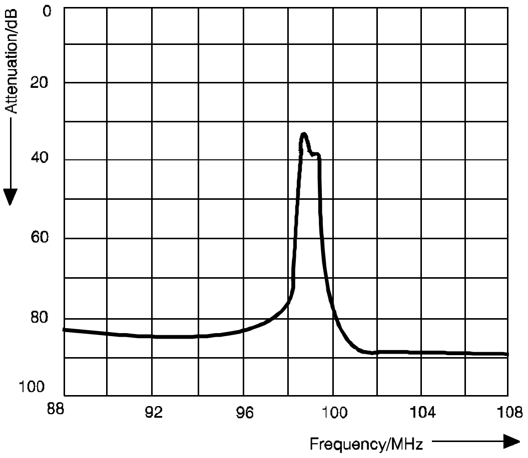
Attenuation between narrowband input and output

Attenuation between broadband input and output



Return loss at narrowband input

Return loss at broadband input



Isolation between narrowband and broadband input

Figure 11: Examples of measured curves for a directional filter module (with narrowband input tuned to 99 MHz)

5.12 Multiplexers

Multiplexers consist of one or more directional filter modules and a starpoint combiner. The output of the starpoint combiner is connected to the broadband input of the directional filter. It is advantageous to feed the channels with the greatest possible frequency spacing into the starpoint combiner since this produces the greatest isolation.

Figure 12 shows an example of a triple combiner with a favourable distribution of channels at the inputs ($f_1 < f_2 < f_3$).

The isolation of the narrowband inputs from the inputs of the starpoint combiner is determined by the directional couplers and additional by the stop band attenuation of the bandpasses.

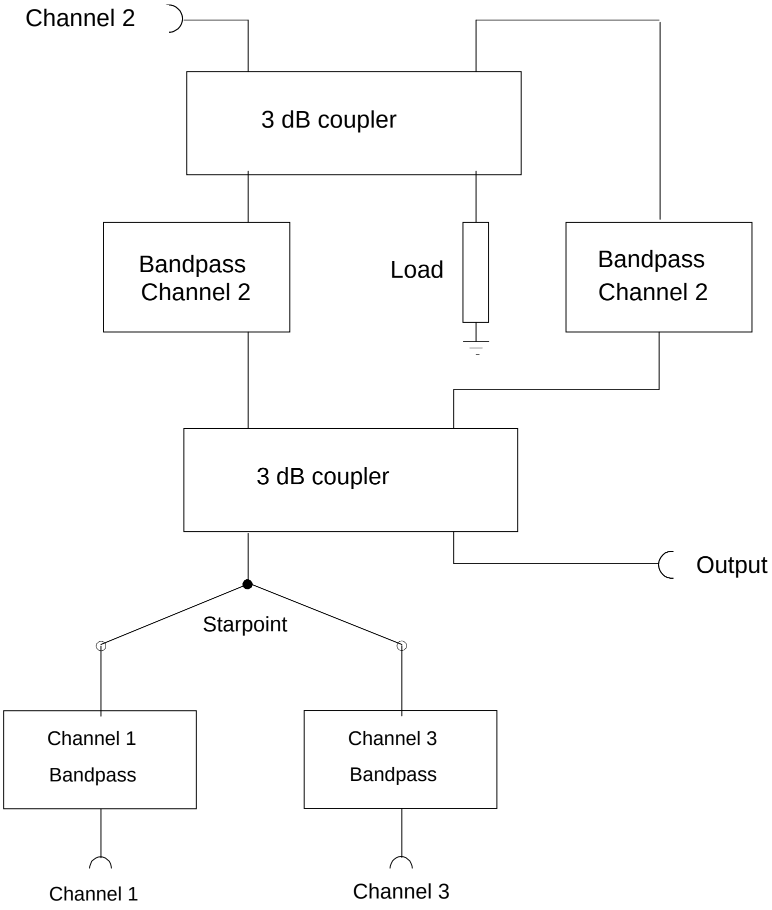


Figure 12: Multiplexer with 3 inputs

5.13 Stretchline combiners

Where there is greater frequency spacing a particularly simple form of directional filter combiner may be used, namely a stretchline combiner as shown in figure 13. This consists of two 3 dB couplers, a stretchline and a load. Decoupling is achieved through the directional coupler. The combiner cannot be tuned but it may be re-configured for other channels simply by changing the stretchline. Function principle: The two signals fed into the 3 dB coupler (1) are each split into half and one half signal each is then routed through the stretchline. The length of the stretchline should be chosen in such a way that the partial power flows will add up at the output and no power flows into the load. These conditions are fulfilled if the stretchline has a length of $n\lambda_2$ for f_2 and $(n+½)\lambda_1$ for f_1.

Annex F compares the parameters of the typical combiners as used by broadcasters.

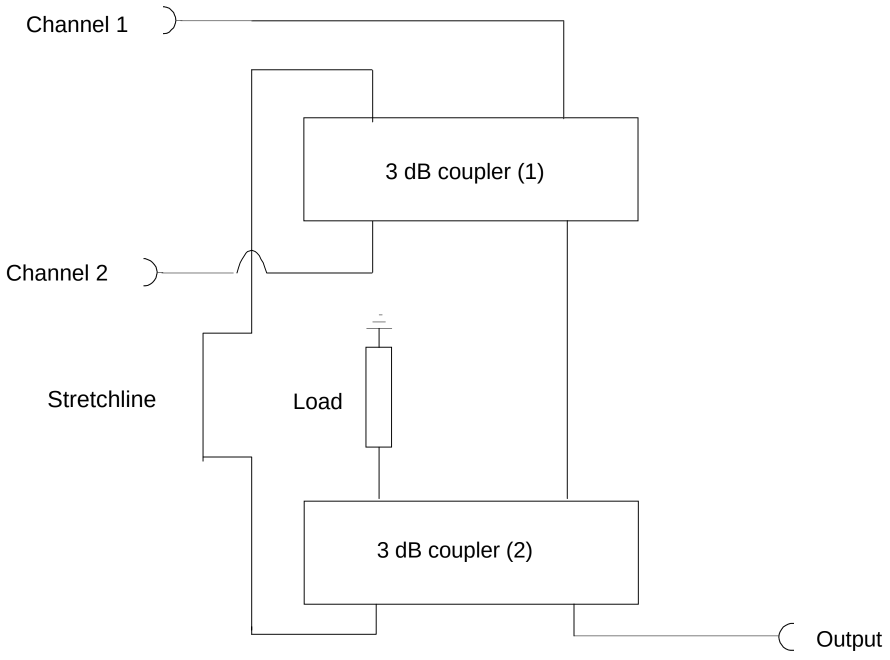


Figure 13: Stretchline combiner for two channels

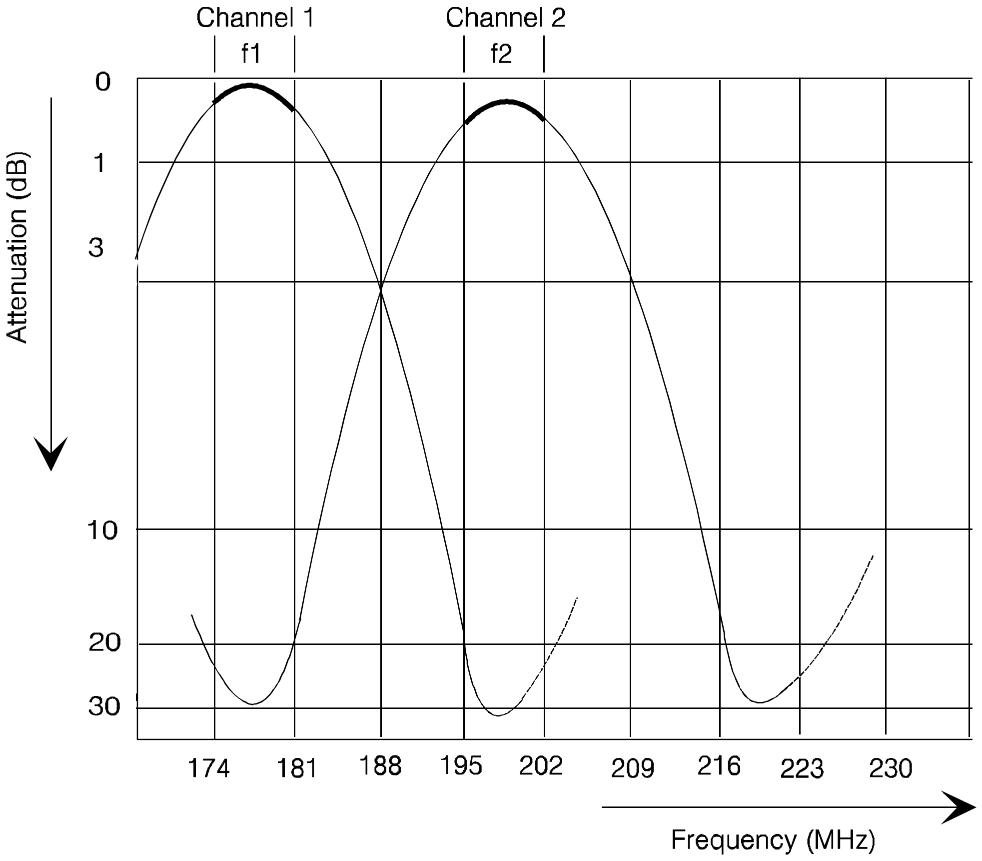


Figure 14: Frequency response of a stretchline combiner for two channels in Band III

6 Antennas and feeders

6.1 Choice of transmitting antenna type

The principle which governs the choice and siting of transmitting antennas is that only the minimum necessary ERP should be radiated in each desired direction. Consideration of this should be made in both the azimuthal and the vertical planes. Even where an omnidirectional horizontal radiation pattern (hrp), is required, generally the same will not be true of the vertical radiation pattern (vrp).

Typical high power, Very High Frequency (VHF) broadcast antennas consist of several tiers of dipoles, or crossed dipoles, arranged around a lattice steel mast. The outside of the mast may be screened with metal bars or mesh. This increases the forward radiated power from the antenna, and helps to protect climbers inside the mast. The antenna may be divided into two halves, vertically, and fed by separate main feeders, to protect the service in the event of a fault. Individual elements are fed by smaller branch feeders.

Low power VHF antennas generally comprise a number of dipoles or 4-element log periodic arrays arranged around a mast or tower.

6.2 Transmitting antenna system specification

The following parameters should be considered when procuring or selecting antennas:

Gain:

- specified either in dB relative to an isotropic radiator (dBi) or dB relative to a half-wave dipole (dBd).

VSWR:

- the maximum value compatible with the system being considered. For a transmission line to deliver power efficiently to a load, it is necessary for the system to be matched, i.e. for the load to behave as a pure resistance, equal in value to the characteristic impedance of the line. Impedance discontinuities cause Radio Frequency (RF) power to be reflected back from the discontinuity, towards the input of the line;

- reflections upset the uniform distribution of RF voltage and current on the line. Standing waves are established which cause voltage and current maxima and minima to exist at intervals along the length of line. In severe cases, these standing waves, may cause the failure of system components, or a transmitter shutdown;

- Voltage Standing Wave Ratio (VSWR), return loss and voltage reflection coefficient are all parameters which are used to describe the match.

Polarization:

- this may be horizontal, vertical, mixed or circular.

Radiation pattern:

- a convenient method of specifying the required pattern is to define a template showing the horizontal and vertical field components necessary. This may include details of the maximum permissible ERP in some directions, and the minimum permissible ERP in other directions. Also included may be arcs over which the ERP should not vary by more than a specified value.

  NOTE: Any null filling required, may be achieved by phase perturbation to the individual element inputs.

Input power:

- the radiating elements, transformers, distribution and main feeders of the antenna system should be capable of continuously and simultaneously handling the required power. This should include a suitable safety factor (e.g. 1,5) for both mean power and peak volts at an appropriately high ambient temperature;

- the required safety factors should be met after due allowance for standing waves in the feeder system, but systems offering higher safety factors in the distribution system, with a view to limiting the extent of damage which might result from an open or short-circuited feeder are to be preferred.

Bandwidth:

- the frequency bandwidth over which the antenna is to be used and over which all the parameters specified should be met.

Feeders and connectors:

- it is necessary to ensure that there is adequate screening between adjacent cables and feeders and minimal coupling between items of equipment;

- the direct and shortest route is always the best for minimum radiation and minimum insertion loss. However, it is important that transmitter cables and receiver cables should be installed as far apart as possible. It is advisable that when they cross, they should cross at right angles;

- where feeders undergo bends, it is important to ensure that no "ovality", "necking" or other objectionable deformations occur;

- all feeders should be clearly and permanently marked at both ends so that easy identification of their length and position in the system may be made;

- in the antenna aperture, all distribution feeders should be of the non-braided outer type;

- the fixing of feeders in the antenna aperture by toothed clamps is inadvisable as damage to the structure may result;

- it is recommended that high quality connectors be used. For example standard International Electrotechnical Commission (IEC) or DIN connectors;

- it is advisable that all flanges and bolts be treated with protective paste and waterproofed with polyisobutylene (PIB) self-amalgamating tape;

- if air spaced feeders are used, the antenna system should be pressurised by a dehydrator and air distribution system;

- in cases where the mast is exposed and there is a possibility of moisture gathering at the outer jacket of the copper case of the incoming cables, it is wise to remove the outer insulating jacket at a point well inside the equipment room where it may be inspected for traces of moisture.

6.3 Receiving antenna systems

The receivers on a relay site should be protected from the output of co-sited transmitters because a receiver may be overloaded, resulting in mixing products which may fall within the pass band of the IF. The transmitters will also radiate wideband phase noise which will fall within the pass band of the receivers. Both of these effects degrade the Signal/Noise (S/N) ratio of the wanted signal.

Design of the antenna system can reduce these problems by maximising the path loss between the transmit and receive antennas.

Positioning of the antennas has the greatest effect. Care should be taken to avoid mounting the antennas in each others beamwidth. If possible the antennas should be orientated so their polarization's do not couple. In practice the receive antennas polarization should be finely adjusted to take local reflections into account.

The use of high gain antennas may be advantageous as the beamwidth becomes narrower. However, sidelobes outside the main lobe become unpredictable as the antenna gain is increased. Coupling of sidelobes becomes difficult to avoid as their number increases and their angular spacing decreases.

The receiving antenna's primary purpose is to provide an adequate signal level for the receiver. The gain and height above the ground should be chosen with regard to the wanted field strength in the area.

The antenna's gain may also be used to discriminate against unwanted transmissions on similar frequencies but different bearings. For example, a half-wave horizontal dipole can achieve 30 dB discrimination between transmitters which are spaced 90 degrees apart with reference to the receive site.

Multiple antennas may be used to increase the receive level by increasing the effective aerial aperture. More useful is the ability to reject unwanted transmissions on bearings which would normally lie within the beamwidth of a single antenna.

The two (or more) antennas are positioned so they receive the wanted signal in phase by aligning them on bearing for the wanted transmitter. The horizontal spacing is then set so the unwanted signal arrives with a 180 degree phase difference between the antennas. When the signals of both antennas are added the wanted signal will sum whilst the unwanted signal will cancel. This system may be used successfully with single unwanted frequencies but is less effective when several unwanted frequencies are to be rejected.

7 Interference generated on site

7.1 Modulation related effects (out of band emissions)

The determination of protection ratios, as specified in CCIR Recommendation 412 [9], are based on the following assumptions:

a) the maximum deviation of ± 75 kHz should not be exceeded;

b) the average power of the complete multiplex signal (including pilot tone and additional signals) integrated over any interval of 60 seconds is not higher than the power of a multiplex signal containing a single sinusoidal tone which causes a peak deviation of ± 19 kHz.

7.1.1 Overdeviation

Frequency deviation beyond ± 75 kHz, known as "overdeviation", will jeopardise protection ratios and increase the likelihood that service areas of other broadcasters, either co-sited or from sites many kilometres away, will be infringed. (Research has indicated that 1 dB of overdeviation may require the addition of 3 dB to protection ratios). On site, this is of particular concern in the planning and implementation of re-broadcasting links.

A definition of overdeviation is not easily achieved, nor is a repeatable method of measurement, particularly during live programming and where test equipment's of different integration times are used. It is possible to look at the overall RF spectrum occupancy; this is not a direct method of indicating frequency deviation, but it can give a good representation and is relatively easy to measure, provided agreement is reached as to which limits to use.

Regulatory techniques based on modulation analysis vary between different organisations but are broadly summarised below:

a) ± 75 kHz not to be exceeded under any circumstances. This is easy to regulate, but will mean that non-processed audio material will achieve only a low level of average deviation;

b) a higher overall limit is defined. This is also easy to regulate, but is undesirable as it will lead to significant impairment of protection ratios if programming is highly compressed;

c) ± 75 kHz not to be exceeded other than for excursions of a pre-determined minimum time. This should achieve a fair compromise between a) and b) above, but does require a more complicated test technique.

7.1.2 The effect of multiplex signal power

It is possible, even without overdeviation, to cause protection ratios to be infringed. The power contained within the multiplex signal envelope, or its "modulation density", resulting from the degree of audio processing, should also be considered. CCIR Recommendation 412 [9] quoted at subclause 7.1, paragraph b) above, defines the level of multiplex power upon which protection ratios have been derived.

7.1.3 Broadband noise and spurious products

Greatly increased use of RF spectrum by FM broadcast stations, land mobile services, aeronautical stations, etc. creates more and more compatibility problems between these different users.

The FM broadcasting transmitter does not just create its wanted signal, but also a higher noise floor and also spurious products near the carrier.

These unwanted signals may disturb:

- aeronautical services, immediately above band II;
- neighbouring FM-frequencies and Digital Audio Broadcasting (if FM broadcasting has to share with Digital Audio Broadcasting (DAB)), within band II;
- land mobile services, immediately below band II.

Modulation and RF circuitry of FM broadcast transmitters are sources of broadband noise and spurious effects. In order to minimise the effect of such signals, their sources should be understood.

Basic calculations for signals of very small modulation:

$$S/N_{RF} = 20 \log \{A_{(fc\pm fx)}/A_c\}$$

$$A_{(fc\pm fx)} = A_c \times I_1(m)$$

$$m = \Delta f/f_x$$

$$\Delta f = \Delta f_{ref} \times A_{mf}/A_{ref}$$

$$\Delta f = \Delta f_{ref} \times S/N_{MPX}$$

$$A_{(fc\,\pm\,fx)} = A_c \times S/N_{MPX} \times 0{,}5 \times \Delta f_{ref}/f_x$$

$$S/N_{RF} = S/N_{MPX} \times 0{,}5 \times \Delta f_{ref}/f_x$$

$$S/N_{RF} = S/N_{MPX} - 6\text{dB} + 20 \log \Delta f_{ref}/f_x$$

where:

I_1 is the amplitude of the first modulation component;
m is the modulation index;
m is 0,5 for small modulation signals (Bessel formula);
Δf is the deviation;
Δf_{ref} is the reference deviation (e.g. 40 kHz);
f_x is the frequency of the disturbing modulating signal;
A_{mf} is the amplitude of the modulating signal;
A_{ref} is the amplitude of the reference modulating signal (e.g. 1,55 V);
A_c is the amplitude of the unmodulated carrier.

EXAMPLE: 300 kHz disturbing signal in the multiplexer (MPX).
fx = 300 kHz.
Δf_{ref} = 75 kHz.
Assuming S/N_{MPX} = - 70 dB relative to the nominal audio input level.
The level of spurious RF signals may be evaluated at the output of the FM broadcast transmitter frequency offset of 300 kHz.
S/N_{RF} at 300 kHz = (- 70 dB - 6 dB - 12) dB = - 88 dBc.

Compatibility with aeronautical services. Instrument Landing System (ILS)

In order to fulfil aeronautical requirements, the following assumptions are made (all values as seen at the antenna socket of the aeronautical receiver):

aero-receiver frequency f_{aero} = 108,1 MHz;
minimum input signal level on f_{aero} = - 86 dBm;
protection ratio = 14 dB (for interfering components falling into the receiver input bandwidth).

This figure was measured with noise. The reference noise power ratio of - 46 dBc/Hz was calculated to the appropriate receiver input bandwidth.

Acceptable noise power density is calculated using the following formula:

P_{NMAX} = Minimum input signal on f_{aero} - protection ratio + noise power ratio;

P_{NMAX} = - 86 dBm - 14 dB - 46 dBc/Hz;

= - 146 dBm/Hz.

Assuming that the FM broadcast transmitter operates on a frequency of 106,1 MHz to protect the aeronautical receiver against desensitisation, the power at the receiver antenna socket on a frequency of 106,1 MHz should not exceed 5 dBm.

The resulting S/N_{RF} of the FM broadcast transmitter at 2 MHz offset from the carrier is:

S/N_{RF} minimum at ± 2 MHz = - 146 dBm/Hz - 5 dBm = - 151 dBc/Hz.

Compatibility with land mobile services

An FM broadcast transmitter is planned to be installed at a shared site with relays for land mobile radio. The following example shows the assessment required to ensure compatibility.

receiver characteristics:

frequency range:	68 MHz to 76 MHz;
minimum input signal:	- 4 dBμV (0,6 μV).

which results (at 50Ω) to:

power minimum at 50Ω = - 111 dBm;
input bandwidth = 15 kHz;
calculation factor: Noise power dBm/15 kHz/Noise power density dBm/Hz = 42 dB.

Measurements at receivers to find maximum allowable disturbing signals gave the following results (at S/N audio minimum = 20 dB rms weighted according to CCITT Recommendation P.53:

a) Interfering signal: Broadband noise;

with S/N_{RF} = 9 dBc/15 kHz;
the S/N audio = 20 dB is fulfilled.

Maximum acceptable interfering signal at the input of the receiver:

PRD_{max} = - 111 dBm - 9 dB - 42 dB;
PRD_{max} = - 162 dBm/Hz.

b) Interfering signal: Modulated discrete signal ($f$mod = 1 kHz, deviation = 5 kHz, Δf carrier for most interference):

with S/N_{RF} = 16 dBc;
the S/N audio = 20 dB is fulfilled;
PRD_{max} = - 111 dBm - 16 dB;
PRD_{max} = - 127 dBm.

The power difference between the output of the VHF FM broadcast transmitter and the input of the land mobile service receiver is given by the de-coupling between the two antennas.

A typical de-coupling between broadcast and land mobile antennas is 40 dB. The maximum acceptable interference power on the frequencies of the land mobile services at the output of the broadcast transmitter with:

a) Broadband noise;

P_{TD}max = - 162 dBm/Hz +40 dB;
P_{TD}max = - 122 dBm/Hz.

b) For a discrete interfering signal (spurious product);

P_{TD}max = - 127 dBm +40 dB;
P_{TD}max = - 87 dBm.

If more than one disturbing signal falls into the receiver input bandwidth, then the power of all these disturbing signals should be added.

This power sum must comply with the above requirements.

Spectrum at the output of the FM broadcast transmitter

In cases where compatibility problems are expected, it is advisable to apply stringent restrictions to broadband noise and spurious product levels at the output of the transmitter. The noise spectrum of different types of broadcast transmitters were measured as follows:

- to obtain required dynamic range of the spectrum analyser a special notch filter was used to suppress the carrier; the filter loss characteristics were compensated in all plots:

- furthermore, the used RF bandwidth for the measurements has to be chosen carefully; in the case of noise, the result may be normalised to 1 Hz by the used bandwidth (in this case 10 kHz).

In the case of discrete spurious products within the spectrum of the FM transmitter (e.g. spectral lines due to the synthesizer), the used bandwidth is of great importance and the bandwidth of the interfered system has to be taken into account; otherwise, if the chosen measurement bandwidth is too high, discrete products with interference potential might be masked by the noise.

It is, therefore, recommended, to use a RF bandwidth for measurements of discrete spurious produces, which is approximately. 10 times smaller than the bandwidth of the interfered system (e.g. 1 kHz).

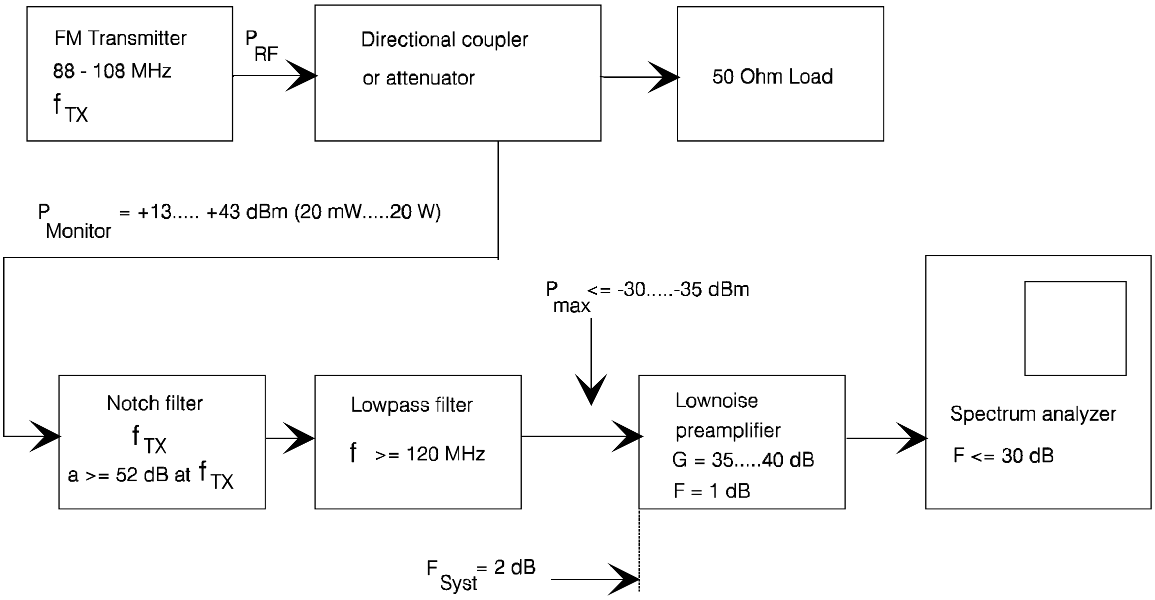


Figure 15: Test equipment to measure the FM transmitter noise power density in the frequency range f_{TX} ± 25 MHz

The following plots show the output spectrum of FM broadcast-transmitters without modulation and without output-filters. The output-load was 50 Ω broadband.

Conclusion (result of the spectrum-measurements)

The spectrum-measurements show, that the required protection of the aeronautical services as well as of the land mobile services may not be guaranteed without additional suppression of the FM broadcast transmitter noise density.

It is highly recommended to install additional filters for frequency offsets $\Delta f > \pm 2$ MHz.

Furthermore, it has been found, that at frequency offsets $\Delta f \pm 2$ MHz solid state transmitters create much more noise than valve transmitters.

In spectrum-critical situations where there is a requirement for high power transmitters it is recommended that valve transmitters should be installed.

EXAMPLE: Figure 16 Broadband noise spectrum at the transmitter output, ± 25 MHz.
Transmitter type: 20 W, synthesized, fully transistorized.
Load impedance = 50 Ω, broadband.
Measuring the absolute noise power spectral density in dBm/Hz.
Noise power ratio [dBc/Hz] = P_{RF}[dBm] - P_{NOISE}[dBm/Hz].

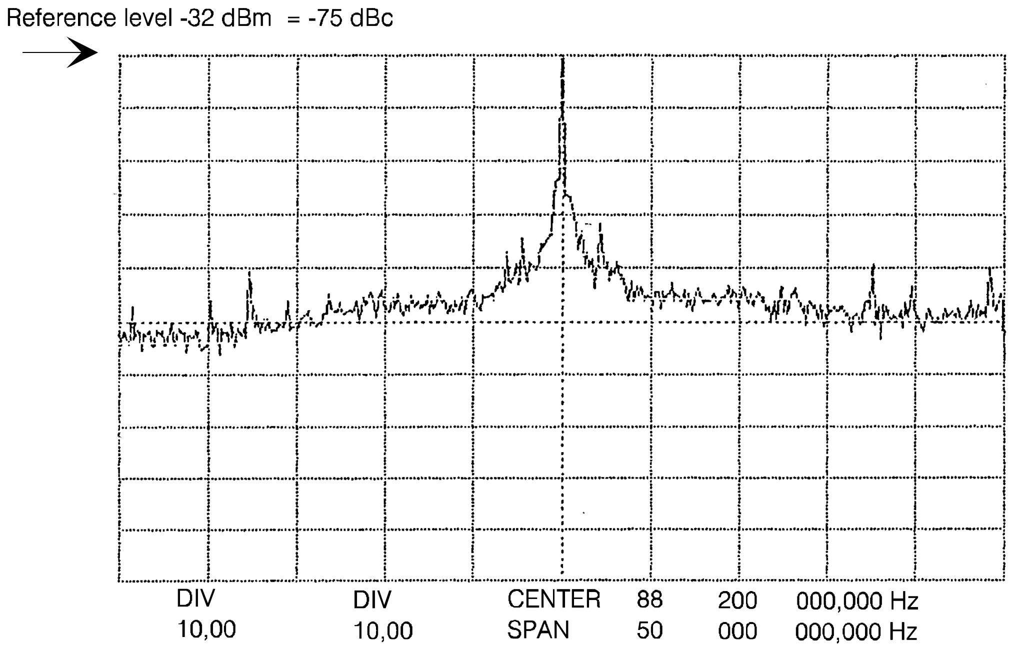


Figure 16: Broadband noise spectrum at transmitter output ± 25 MHz

It is rather difficult, to read the value at *f*c ± 2 MHz, but the following more or less accurate values may be found:

- at ± 2 MHz: - 150 dBc/Hz; and
- at ± 5 MHz: - 160 dBc/Hz.

For the limit value for *f*c ± 2MHz, it was found that for above transmitter aeronautical service Instrument Landing Systems (ILS) is just about achieved.

For the protection of the land mobile services:

- Power of the transmitter: 43 dBm.

Maximum acceptable disturbing power (from above):

a) For broadband noise: - 122 dBm/Hz;
    - S/N_{RFmin} = - 165 dBc/Hz.

b) For discrete interferer: - 87 dBm;
    - S/N_{RFmin} = - 130 dBc.

Assuming a frequency-distance to the land mobile service of 20 MHz, the limit for broadband noise is not fulfilled.

It was recognised that the measuring RF, the bandwidth should have been 10 times smaller in order to read the level - 130 dBc. There are products of *f*c ± 18 MHz which are about 15 dB too high.

Example: Figure 17 Broadband noise spectrum at the transmitter output, ± 25 MHz.
Transmitter type: 5000 W, synthesized, fully transistorized.
Load impedance = 50 Ω, broadband.
Measuring the absolute noise power in dBm/Hz.
Noise power ratio [dBc/Hz] = P_{RF}[dBm]-P_{NOISE}[dBm/Hz].

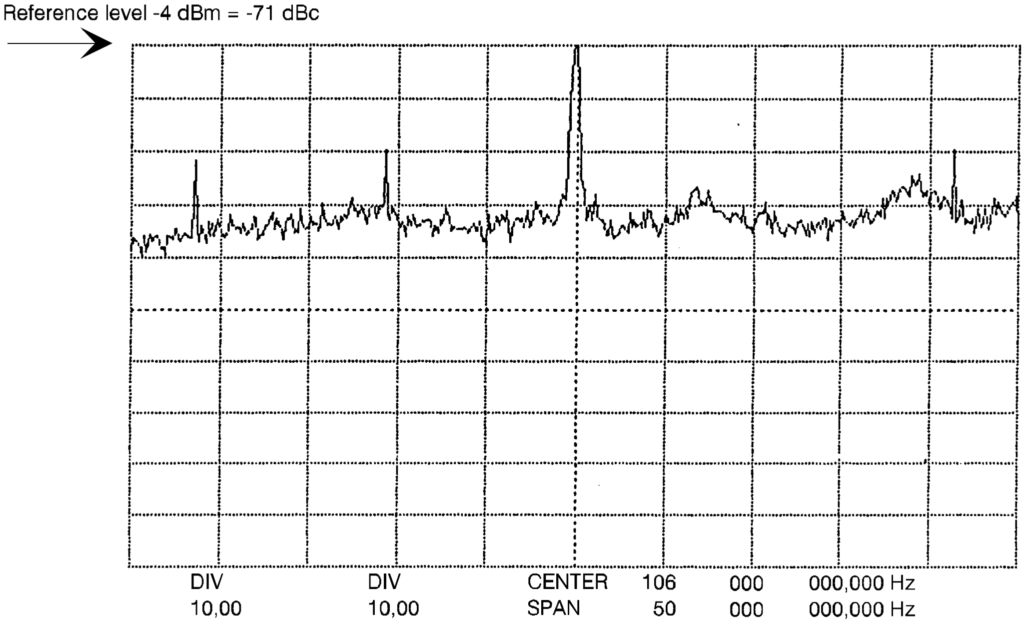


Figure 17: Broadband noise spectrum at transmitter output ± 25 MHz

We find: at ± 2 MHz: - 140 dBc/Hz and at ± 5 MHz: - 142 dBc/Hz.

EXAMPLE: Figure 18 Broadband noise spectrum at the transmitter output, ± 25 MHz.
Transmitter type: 10 kW tube.
Load impedance = 50 Ω, broadband.
Measuring the absolute noise power in dBm/Hz.
Noise power ratio [dBc/Hz] = P_{RF}[dBm] - P_{NOISE}[dBm/Hz].

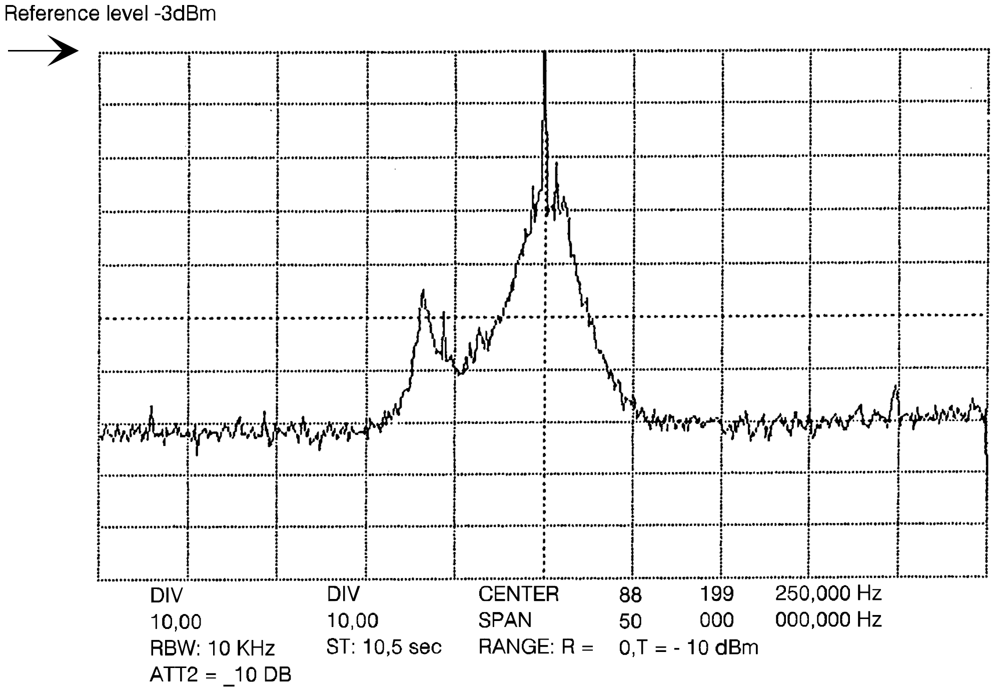


Figure 18: Broadband noise spectrum at transmitter output ± 25 MHz

We find:

- at ± 2 MHz: - 138 dBc/Hz (about the same as with the 5 kW solid state transmitter); and
- at ± 5 MHz: - 178 dBc/Hz (much less noise than with the solid state transmitter).

7.2 Spurious emissions

These are emissions on a frequency or frequencies outside the necessary bandwidth, which do not contribute to the transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products.

7.2.1 Intermodulation effects

These are products are caused by the mixing of two or more source frequencies which produce well defined and often high level signals. These are normally caused by a transmitter or transmitters coupling into another transmitters output stage, due to inadequate isolation in the combiners or between separate transmitting antennas.

Annex A describes the relationship between carrier frequencies and intermodulation products. The levels of intermodulation products generated are dependent upon the isolation between transmitters, the reverse intermodulation performance of the transmitter and the level of the transmitted signal. Figure A.1 in Annex A derives typical levels in the absence of the output filtering of narrowband combiners. In practice frequency dependent components between the transmitter output and antenna will further attenuate the intermodulation products.

7.2.2 Other spurious emissions

The level of other spurious emissions will depend upon the design of the transmitter and frequency response of any combiner or filter between the transmitter output and the antenna.

The level of other spurious emissions should not exceed the limits specified in ETS 300 384 [1].

7.3 Protection of re-broadcast reception

Although the specifications of receivers are well defined in existing standards, the effect of being operated in close proximity to transmitters may cause additional problems.

Particular attention should be paid to the attenuation of spurious emissions from transmitters which may interfere with the correct operation of co-sited receivers. Additional filtering or phase cancellation techniques may be applied selectively according to the situation.

7.4 Natural and man-made noise

The ambient RF noise level at a site will depend upon the location of the site in relation to sources of man-made noise.

CCIR Report 258-5 [2] gives details of the noise power at typical sites in different environments.

8 Audio processing limiter

8.1 Introduction

It is possible to control modulation of the transmitter below the maximum allowable deviation of ± 75 kHz using the following methods:

1) limiting the audio signal level (Mono or L and R), this is a preferred method of controlling the modulation and is widely used by the broadcasters (subclause 8.2);

2) multiplex signal limiters: a limiter on the multiplex signal would have the advantage, that it could be built directly into the transmitter (exciter), and for local broadcasting applications the limiter may be installed remotely.

The multiplex signal limiters have the following disadvantages:

- as soon as the limiter acts, it generates distortion and high frequency noise, which may spread outside the channel;
- low-pass filters are difficult to use. They would have little effect as the cut-off-frequency has to be higher than the highest subcarrier;
- the low-pass filter would also affect stereo performance of the multiplex-signal due to its phase response (phase and amplitude);
- a multiplex-signal-limiter does not only limit the audio-signal, but also the pilot-tone, the Radio Data System (RDS)-signal and all other sub-carriers.

It is, therefore, advisable not to use multiplex signal limiters.

8.2 Major limiter types

8.2.1 Principles of operation

Basically there are three types of limiters:

1) feedback-controlled broadband limiter;

2) forward-controlled broadband limiter;

3) multiband limiter.

8.2.1.1 Feedback-controlled broadband limiter

This limiter functions as shown in block diagram of figure 19. The control starts action as soon as the threshold level at the output is exceeded. Optionally a pre-emphasis (50 µs/75 µs) is taken into account in the feedback control path.

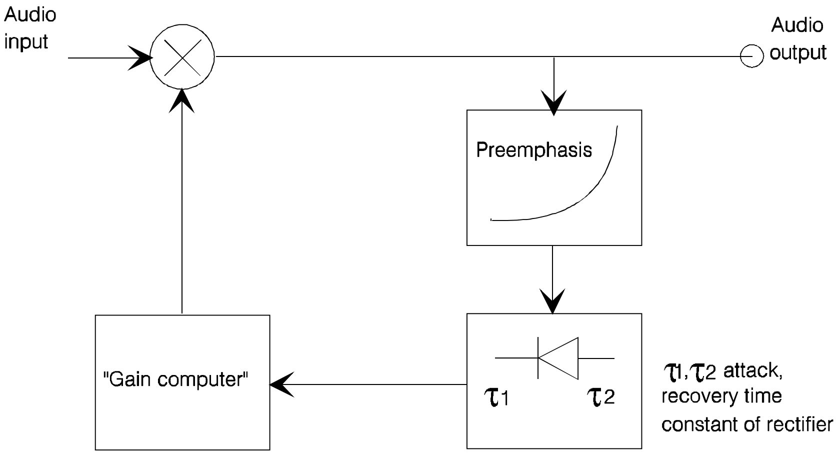


Figure 19: Feedback - controlled broadband limiter

8.2.1.2 Forward-controlled broadband limiter

This limiter functions as shown in block diagram figure 20. With the forward-controlled broadband limiter the control action is terminated when the audio signal reaches the multiplier. In most cases the forward-controlled broadband limiter is combined with a variable pre-emphasis (time constant regulation of pre-emphasis as a function of level and frequency) which is feedback controlled. To avoid short-term overshoot at higher frequencies, a clipper follows the pre-emphasis. Depending on the point where the limiter is used in the signal path, a de-emphasis is inserted after the clipper.

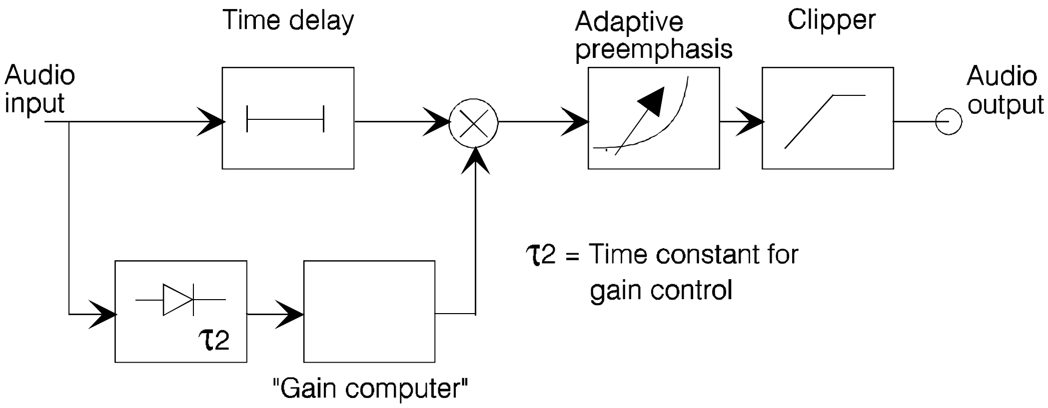


Figure 20: Forward controlled broadband limiter

8.2.1.3 Multiband limiter

For the operation see figure 21. The audio signal is split into several (3 or 4) frequency bands which are feedback-controlled independently and then combined again. Short-term over-shoot is handled by a subsequent clipper.

Generally this principle is combined with a pre-emphasis (50 µs/75 µs). Depending on the point where the limiter is used in the signal path, a de-emphasis is inserted after the clipper.

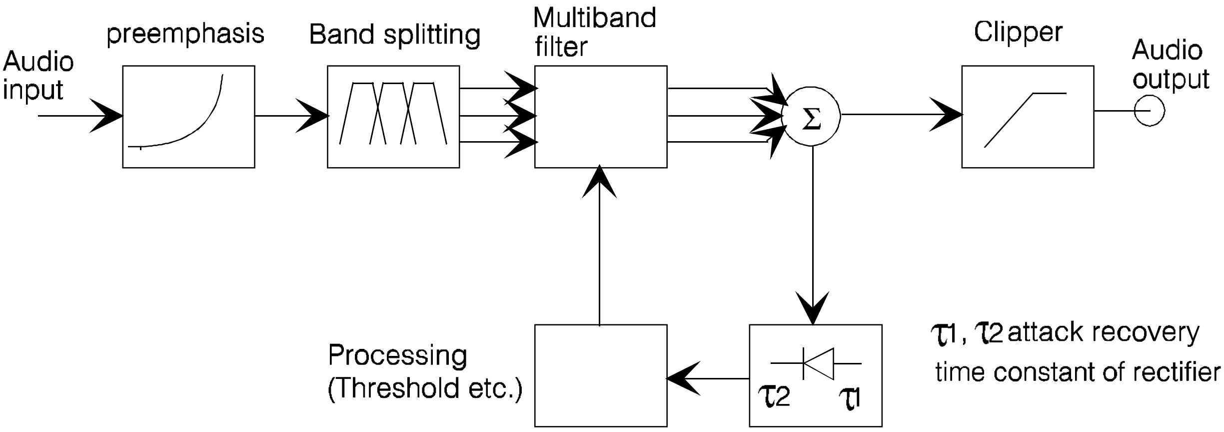


Figure 21: Multiband limiter

8.2.1.4 Advantages and disadvantages of the different types of limiters with regard to the limiting characteristics and its effect on the audio signal

Feedback controlled broadband limiter

Advantages:

- simple to build;
- simple alignment with calibrated signals;
- integration of the pre-emphasis in the feedback-loop results in a linear frequency response without adverse effects on subjective audio quality;
- good phase stability.

Disadvantages:

- limited overshoot-protection due to finite attack times. The choice of attack times is always a compromise between overshoot protection and audio quality (clicks, dynamic distortions at low frequencies);
- integration of pre-emphasis in the feedback loop results in lower audio volume and lower modulation;
- the recovery time of the gain-controlled amplifier is always a compromise (pumping effects, audible noise with short recovery times, loss of volume with long recovery times).

Limiter using delay networks (forward controlled broadband limiter)

Advantages:

- straight forward alignment with calibrated signals;
- good phase stability;
- absolute overshoot protection due to signal delay and clipping of high levels resulting from pre-emphasis;
- no loss of loudness.

Disadvantages:

- relatively complicated to realise;
- linear amplitude distortion from variable pre-emphasis;
- possible audio impairment;
- spectral modulation at low and middle frequencies.

Multiband limiter

Advantages:

- gain in loudness through separate control of each band;
- hardly any spectrum modulation;
- no overshoot because of post processing clipper.

Disadvantages:

- complicated setup-procedure (partly with programme material);
- problems with phase stability due to separate band processing;
- altered sound characteristic, dependent on the sum of signal content in the bands.

8.3 Static and dynamic response of limiters as a function of typical parameters

Settling response of control amplifiers

Depending on the response time, there may be click effects and dynamic distortions at low frequencies. Moreover, the magnitude of short-term overdrive due to level peaks and the dynamic range of the audio signal will be affected.

Recovery process time of control amplifiers

The time constants of the control action affects the average loudness of the audio signal. Hunting and noise effects can occur.

Frequency determining elements in the signal path

Frequency determining elements (pre-emphasis, filters) may change the average level (loudness) of the audio signal. Spectrum modulations represent a further effect.

Design of clipper circuits

Clipper circuits change the time response of the audio signal. Depending on the design (soft clipper, hard clipper, control amplifier thresholds as a function of the clipper), these distortions will be perceived differently. The loudness level is also affected.

Linear distortion along the signal path

Linear distortion along the signal path (amplitude and phase response) may cause perceived changes in the tone colour of the audio signal. The stereo balance may also be changed this way.

Coupling of two channels to form a stereo pair

Coupling may cause losses in loudness. Insufficient coupling changes the stereo balance.

Lowpass filter

A lowpass filter must be connected ahead of the control input to prevent the limiter from responding to high-frequency pulses.

Further effects of limiters

A properly set clipping level is assumed to limit FM-modulation to the maximum allowable ± 75 kHz. This assumption may be misleading since, under certain circumstances an overmodulation may arise when an audio signal is limited by hard clipping. This is possible for the following reasons:

In a common configuration the audio signal passes through a limiter with associated clipper before being fed to the stereocoder. This latter usually has an input low-pass filter that limits the audio bandwidth to approximately 15 kHz. Although the peak of the signal is removed, after the low pass filter of the stereocoder the amplitude may be of the same order as at the input to the limiter.

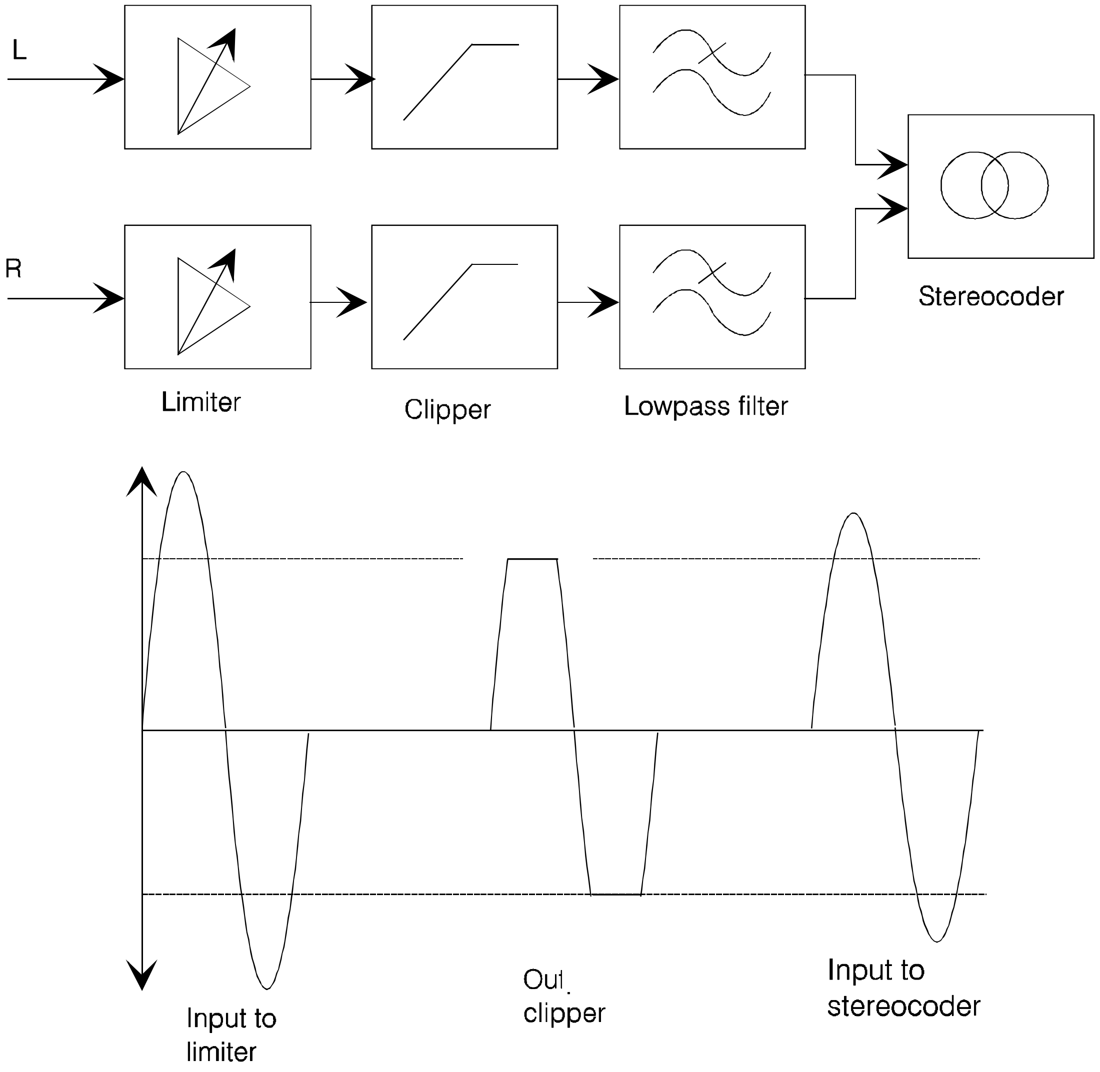


Figure 22

This phenomena can be explained when looking at the Fourier analysis of the signal.

Assume the shown input signal is sinusoidal and leads to a fair amount of clipping. The resulting waveform is similar to a trapezoidal waveform which is described, using Fourier analysis, as:

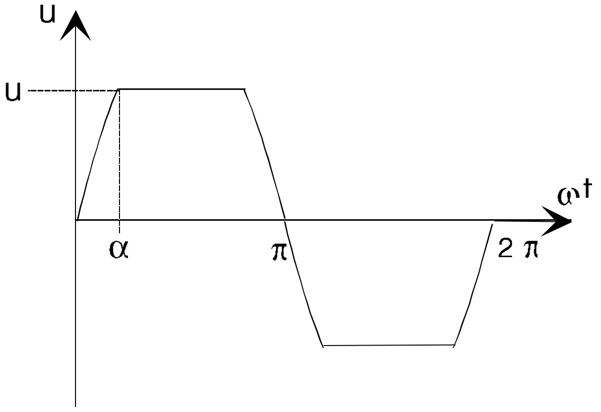


Figure 23

$$f(t) = \frac{4U}{\pi\alpha}\left(\sin\alpha\sin\omega t + \frac{\sin 3\alpha}{3^2}\sin(3\omega t) + \frac{\sin 5\alpha}{5^2}\sin(5\omega t).....\right)$$

The amplitude of the fundamental wave is:

$$\frac{4U}{\pi\alpha}(\sin\alpha)$$

If the frequency and the level of the sinusoidal input signal are fairly high so that the harmonics > 15 kHz are filtered by the stereocoder's low-pass filter, the remaining waveform into the coder may reach a level of $4/\pi$ times the clipping threshold.

NOTE: A properly set clipping level alone, therefore, does not guarantee no overmodulation.

One may assume that it would be better to remove the low pass filter at the input of the stereocoder. But the result would be, that, according to the above formula, rather high levels would appear on the 3rd, 5th etc. harmonics of the audio signal. This may interfere with other multiplex signals (e.g. RDS) and/or create even more and worse RF components (after the FM process) than overmodulation only.

The example below shows that the low pass filter is absolutely necessary.

Example: (clipper without following lowpass filter).
The audio signal is clipped by 3 dB;
amplitude 3rd harmonic approximately 0,15 clip level (- 16 dB);
amplitude 5th harmonic approximately 0,024 clip level (- 32 dB).

Lowering the clipping level below approximately. 80% of the maximum input level results in increasingly higher signal amplitudes after the low pass filter or, in other words: if the clipping level is not set below approximately 80% of the maximum input level, which corresponds to about 2 dB, then no overshoot can arise.

NOTE: It is, therefore, recommended that this fact be considered when setting the limiter and the clipper.

8.4 Measurement methods to characterise audio-frequency limiter circuits

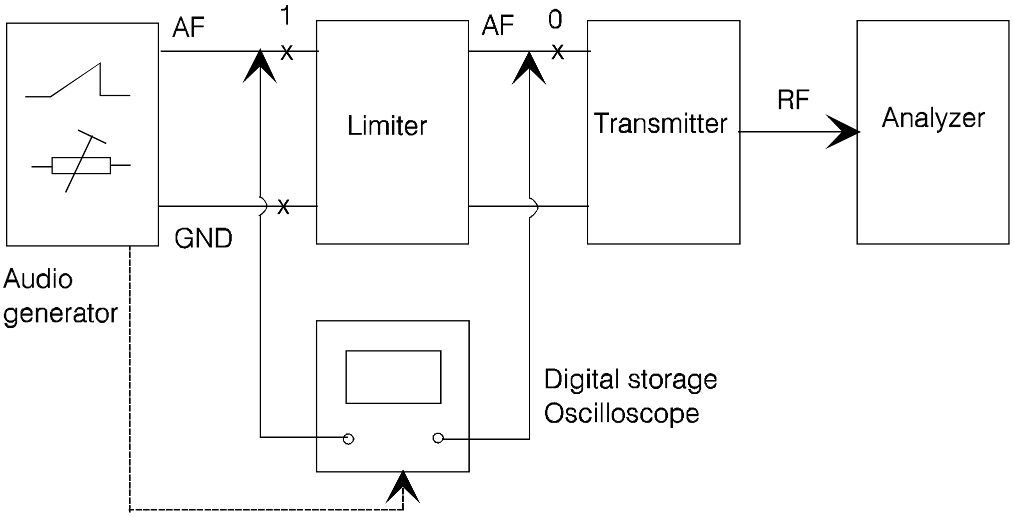


Figure 24: Set up to measure the characteristics of audio frequency limiters

Test method

The AF Generator is required to apply both continuous and step-variable signals to input 1 of the limiter circuit. Switchover should be as far as possible without delay so that attack time measurement of the limiter is not affected. A resistive divider with bounce-free switchover handles this task. At the same time a trigger impulse is used to activate the digital storage oscilloscope.

Basic quality parameters of a limiter circuit

Limiter range (static)

The static behaviour of the limiter may be described with the recording of the control characteristics, in relation to frequency. The response in the limiting range is of special interest. This is the level range at input 1 within which the limiter has to keep output 0 at a preset nominal value. The nominal value should be flat within for instance ± 1 dB versus the frequency (or the frequency bands).

The basic audio transfer characteristic of a limiter can be described with following parameters:

- gain;
- linear distortions (amplitude and phase);
- non-linear distortions (harmonics and differential tone distortions);
- noise level;
- stereo cross-talk.

Attack time (dynamic)

When the input level changes by a defined amount, the gain should be reduced instantaneously. The time which the limiter takes to do this is the attack time, e.g. 1 ms to 2 ms. This is determined according to IEC 268-8 [3]. The peak at the start of the control action is not produced with the forward-control limiter which is therefore recommended.

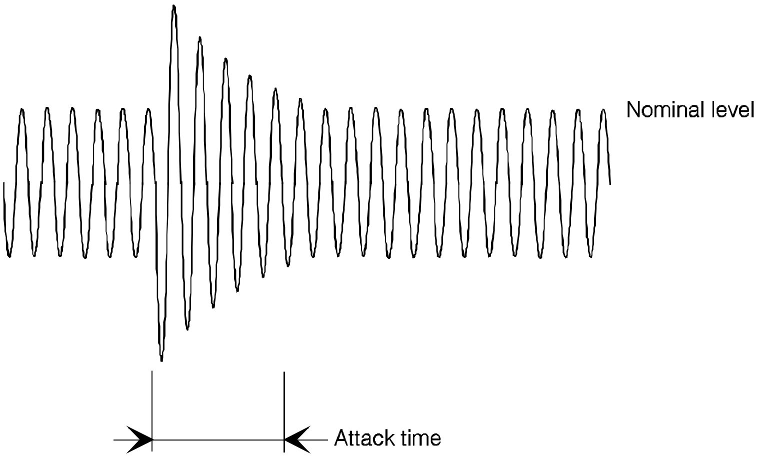


Figure 25

Recovery delay time (dynamic)

After the input level has returned, the limiter must bring back the gain to the original higher level. The time required is called recovery time, e.g. 20 ms to 50 ms (measurements according to IEC 268-8 [3]). On some limiters it is possible to set a delay time, e.g. 0,1 s to 5 s to ignore closely spaced pulses (bursts).

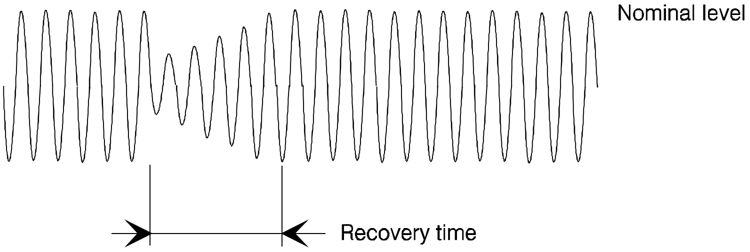


Figure 26

Effect on the spectrum with FM

Apart from additional services (using the VHF FM signal), the theoretical maximum RF spectrum for stereo broadcast is created by modulating the right channel = - left channel with f_{mod} of 15 kHz to a deviation of ± 75 kHz.

The resulting envelope of the RF spectrum components should not be exceeded (even in the case of overmodulation by single tones or with any music/speech modulation, if a limiter is inserted).

If the "**Peak hold**" function is activated on the spectrum analyser, the dynamic response of the limiter can be determined with the aid of music/speech modulation.

8.5 Measurements and assessment with the help of programme signals

Qualitative assessment of overshoot protection

The limiter output may be monitored with a PPM (Peak Programme Meter) according to CCIR Report 292-6 [4] with general programme material such as music and speech. The pre-emphasis then has to be taken into account. The measurement is more precise when using a fast integration time (0,1 ms). The best (qualitative) judgement may be realised with the registration of frequency and amount of overshoot on an oscilloscope.

Quantitative assessment of the characteristics (inc. overshoot protection) of the limiter

A clear statement of the behaviour of the limiter is reached when the limiter's output signals are sampled and classified. The result of such a measurement is shown in a diagram with the statistical occurrence of exceeding a certain amplitude.

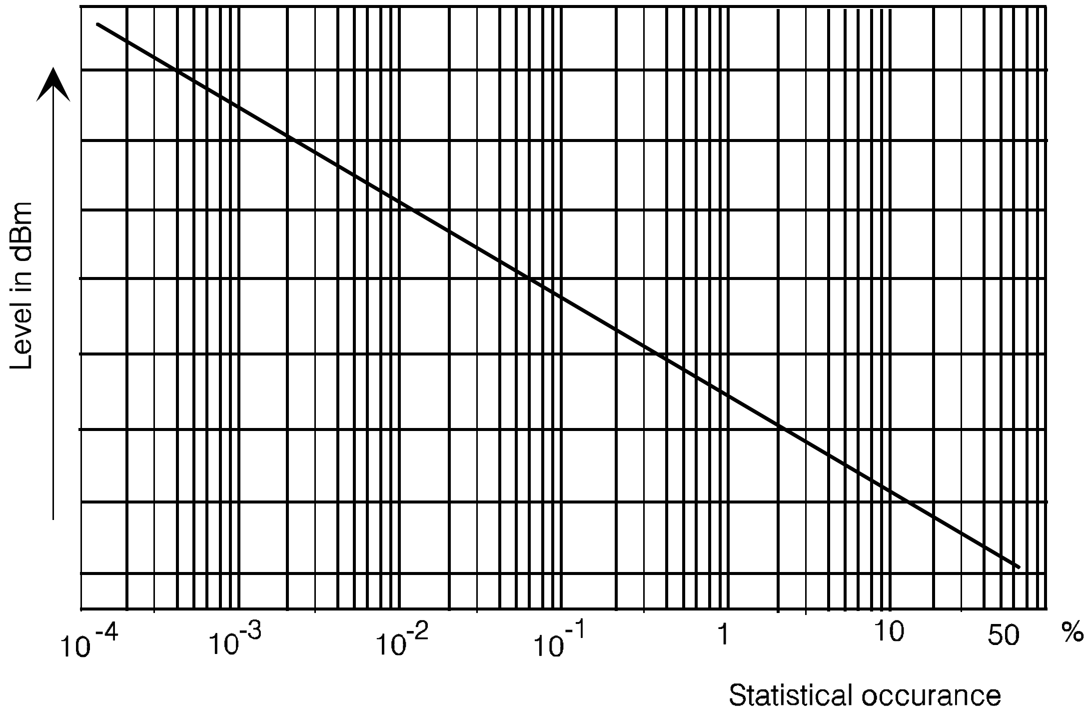


Figure 27

This assessment too has to be done with real programme material (music and speech) taking into account the pre-emphasis. With this method an unequivocal result about the function of the limiter can be gained. When comparing the amplitude distribution with the untreated audio signal, level changes can be judged.

Subjective tests

With subjective tests statements may be gained about degradation effects. CCIR Recommendation 562 [5] describes these tests. Preferably the critical sequences of the test compact-disk Sound Quality Assessment Material (SQAM) are chosen. Descriptions of those test sequences are to be found in the EBU Document Tech. 3253-F [6]. For limiter tests, the track numbers 05, 06, 07, 11, 26 (index 01 and 02), 39, 58, 60, 61, 65, 66, 67 and 68 are well suited.

9 Earthing

Station earthing at a VHF transmitting station is basically provided for safety as, unlike at LF and MF sites, there is no requirement associated with propagation of the transmitted signal. In this context safety relates to electric shock caused by faults in electrical equipment and to the consequences of lightning strikes to the site mast or to an incoming service. Further information on the subject may be found in EBU Technical Monograph 3117 [7].

9.1 Electric shock

In the case of electric shock, we are concerned with the effects of an earth fault; that is an unintentional connection or low impedance path between a live conductor or low impedance path between a live conductor and earth. An earth fault may cause a rise in potential of metalwork relative to true earth and a difference of voltage between adjacent metal parts.

In order to minimise risk, the earth loop impedance from transformer starpoint to any point in the network must be within specification (generally less than 1Ω). In circumstances, usually on very low power installations where there is no on-site HV/LV supply transformer, protection may be achieved by fitting a Residual Current Device (RCD). Equipotential bonding, which uses appropriately sized conductors to connect together all earthing systems, should be provided. The latest edition of the Institution of Electrical Engineers (IEE) wiring regulations will dictate many aspects of the station wiring and earthing system design.

9.2 Lightning

Lightning discharges create problems for the protection of broadcasting stations due to their random nature and the susceptibility of modern electronic equipment. A typical impulsive discharge current is 20 kA, however, maximum intensities of several hundreds of kiloamperes have been recorded with durations of up to 1 ms. Sustained currents with amplitudes of up to 500 A and durations of several milliseconds may follow impulsive discharges. The damage that lightning strike can cause to a typical stations is caused primarily, by the resulting electric and magnetic fields produced by the passage of the lightning current on earth, giving rise to thermal, electrodynamic and electrochemical effects.

9.2.1 Thermal effects

Heat is generated at the point where the lightning current enters a good conductor, and the quantity of heat may be sufficient to cause fusing of the conducting material and/or ignition of adjacent non-conductors. Because the duration of a pulse of lightning current is very short, the heating effect within good conductors is not usually enough to cause fusing; calculation and experience agree that copper of cross-section 16 mm^2 and steel of 25 mm^2 can carry typical lightning currents without damage from thermal effects, a temperature rise of 100 K being generally tolerable.

Very large quantities of heat are generated when the lightning current passes through a non-conductor, such as wood or brickwork. Moisture within the material is instantaneously evaporated with the resulting high pressure causing an explosion. This effect is most likely to occur where humidity can collect and where the lightning current is concentrated at a junction between a poor conductor and a good conductor.

9.2.2 Electrodynamic effects

Where two parallel conductors both carry the lightning current, a mechanical force acts between them. This may damage insulation between conductors or damage the conductors themselves. If a fixed conductor is struck at an angle perpendicular to its longitudinal axis, a force in the direction of the lightning channel is exerted. Rise time of the discharge current may be of the order of <1 µs. Bends or kinks in the conductor will tend to straighten.

9.2.3 Electrochemical effects

There will be little decomposition of metallic objects due to the lightning current, however, accelerated corrosion of buried metal objects under the influence of earth currents should be considered.

9.2.4 Electromagnetic field effects

The high currents associated with lightning strikes give rise to intense magnetic fields in the vicinity of the conductor through which the current is flowing. Induction effects in metallic loops can be observed at distances of up to several hundred metres.

9.3 Feeder earthing

- All feeders, transmitting and receiving, should be earthed at the lowest possible point on the tower or mast;
- the earthing should not take place at a point where there is mechanical strain on the feeder, e.g. on a bend;
- a suitable 14 mm clearance hole on the mast steelwork should be near to the earthing point on the feeder;
- the connection should be made as follows:
  - remove 40 mm band of the PVC jacket from each feeder, taking great care not to damage the outer conductor;
  - clean off any tar or other compound using a suitable non-inflammable non-toxic solvent;
  - wrap two layers of braid around the feeder outer and secure with a stainless steel jubilee clip taking care not to crush the outer. This braid should be aluminium for aluminium feeders, and copper braid for copper feeders;
  - if aluminium braid is used, this may be bolted directly to a cleaned part of the tower galvanised surface;
  - if copper braid is used, proceed as follows:
    - tin the end of the copper braid, and join to a suitable length of 25 mm x 3 mm aluminium tape using two M10 galvanised nuts, bolts and spring washers;
    - bolt the aluminium tape to a cleaned part of the tower galvanised surface.
- the connections to the feeders must be covered with several layers of Denso tape;
- if copper braid is used, all of the copper braid, an all of the joints to aluminium tape should also be covered with several layers of Denso tape;
- keep aluminium tape as straight (free of bends and kinks) as is practicable.

9.4 Recommended earthing arrangements for UHF and VHF transmitting aerial masts generally high and medium powered stations

Lightning zone: any.

Earth rods: eight at mast base (or equivalent value of earth plates), two at each stay block.

a) For sites on clay and arable land;
Radial conductors extend to stay blocks as shown: __________.

b) For sites on sand or rock;
Additional radial conductors shown: ----------.

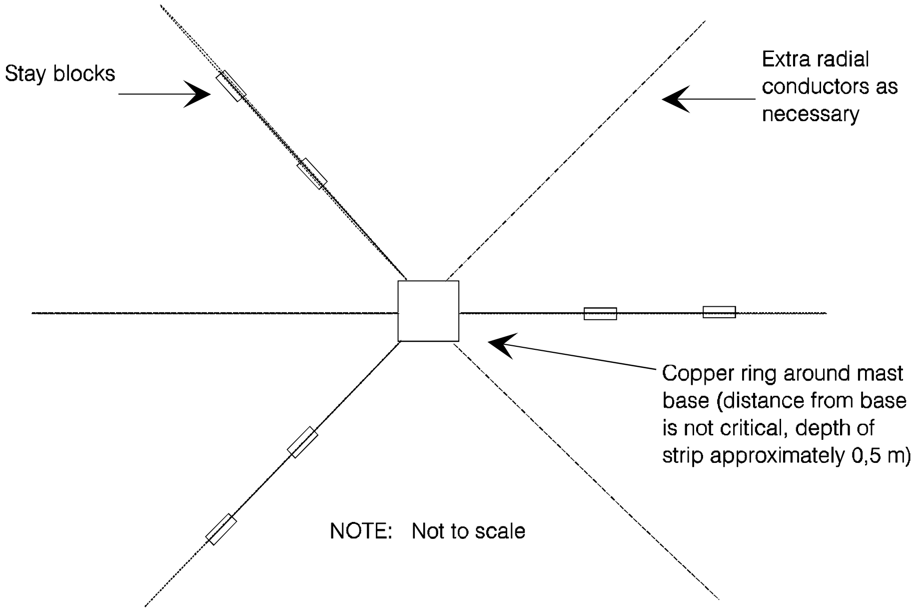


Figure 28: Layout of buried copper conductors

9.5 Recommended earthing arrangements for UHF and VHF transmitting aerial towers generally high and medium powered stations

Lightning zone: any.

Earth rods and plates: two per leg:

a) For low/medium soil resistivity (clay/arable land);
Radial conductors with lengths: 1/2 tower height shown: __________.

b) For high soil resistivity sites (sand or rock etc.);
Additional radial conductor lengths shown: ----------.

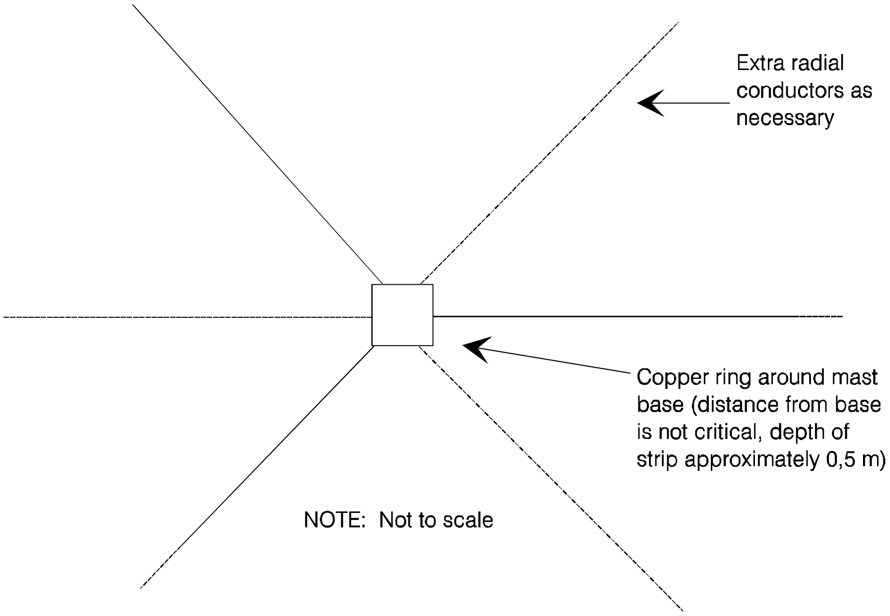


Figure 29: Layout of buried copper conductors

9.6 Recommended earthing arrangements for UHF, VHF and SHF transmitter towers generally low powered stations

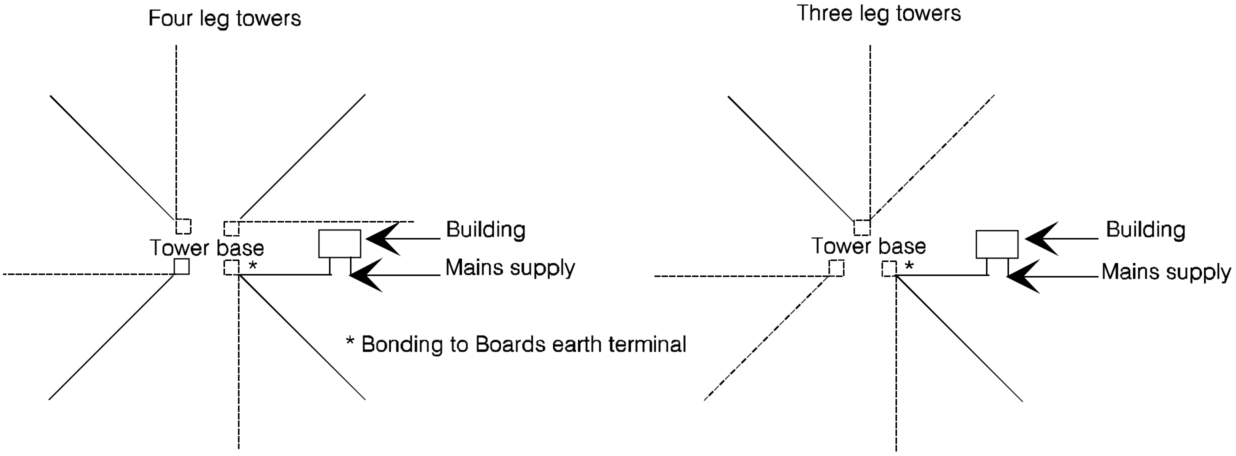
NOTE: The sites envisaged are small (e.g. 20 m x 20 m) and it is not desirable or possible to extend any radial conductors beyond the site boundary.

Lightning zone: any

a) For sites on clay and arable land;
one earth rod or earth plate at each leg of tower (only).

b) For sites on sand or rock;
one earth rod or plate at each leg of tower and four 25 mm x 3 mm (1" x 1/6") conductors shown: __________.

c) For sites on solid rock (in mountainous terrain);
four 25 mm x 3 mm radial conductors shown: __________;
three or four 25 mm x 3 mm radial conductors shown: ----------.



NOTE: Not to scale

Figure 30: Site conditions B and C layout of buried copper conductors

10 Compatibility with aeronautical services

10.1 Background and introduction (see also CCIR Recommendation 591 [11])

FM broadcasting service interference to ILS localizer, VHF Omnidirectional Radio range (VOR) and VHF Communications (COM) equipment, as described in CCIR Report 927 [12], is a widely recognised problem among users of aviation facilities. In air/ground communication receivers, this interference problem ranges from distracting background audio to distorted and garbled reception of air traffic control signals. In airborne ILS localizer and VOR receivers, the interference problem ranges from distracting background audio to errors in course deviation and flag operation. The interference to these navigation receivers is thought to be the more serious problem, as an error in course deviation, especially during the critical approach and landing phase, is not as readily evident to the pilot as the disruption of communications.

Interference to aircraft receivers varies with the make and model of the navigation and communication receiver. There is an increasing probability of harmful interference due to the growing need for additional aeronautical and broadcasting frequency assignments.

10.2 Types of interference mechanisms

In general, from an ILS and VOR point of view, FM broadcasting transmission modulation may be regarded as noise. However, the frequencies 90 Hz and 150 Hz are specific vulnerable frequencies for ILS, and the frequencies 30 Hz and 9 960 Hz are specific vulnerable frequencies for VOR because these frequencies provide critical guidance for the systems concerned and are, therefore, sensitive to interference.

10.2.1 Type A interference

Introduction

Type A interference is caused by unwanted emissions into the aeronautical band from one or more broadcasting transmitters.

Type A1 interference

A single transmitter can generate spurious emissions or several broadcasting transmitters can intermodulate to produce components in the aeronautical frequency bands; this is termed Type A1 interference.

Type A2 interference

A broadcasting signal can include non-negligible components in the aeronautical bands; this interference mechanism, which is designated Type A2, will in practice arise only from broadcasting transmitters having frequencies near to 108 MHz and will only interfere with ILS/VOR frequencies near 108 MHz.

10.2.2 Type B interference

Introduction

Interference to an aeronautical receiver as a result of radiation from broadcasting frequencies outside the aeronautical band is designated Type B interference.

Type B1 interference

Intermodulation generated in an aeronautical receiver as a result of the receiver being driven into non-linearity by a broadcasting signal outside the aeronautical band is designated Type B1 interference. In order for this type of interference to occur, at least two broadcasting signals need to be present and they must have a frequency relationship which, in non-linear combination, can produce an intermodulation product within the wanted RF channel in use by the aeronautical receiver. One of the broadcasting signals must be powerful enough to drive the receiver into regions of non-linearity but interference may then be produced even though the other signal(s) may be significantly less powerful. Only third-order intermodulation products are considered which take the form of:

$f_{\text{intermod}} = 2f_1 - f_2$ (two-signal case); or

$f_{\text{intermod}} = f_1 + f_2 - f_3$ (three-signal case);

with $f_1 > f_2 > f_3$.

Type B2 interference

Desensitization occurring when the RF section of an aeronautical receiver is subjected to overload by one or more broadcasting transmissions is designated Type B2 interference.

10.3 Compatibility assessment parameters

Introduction

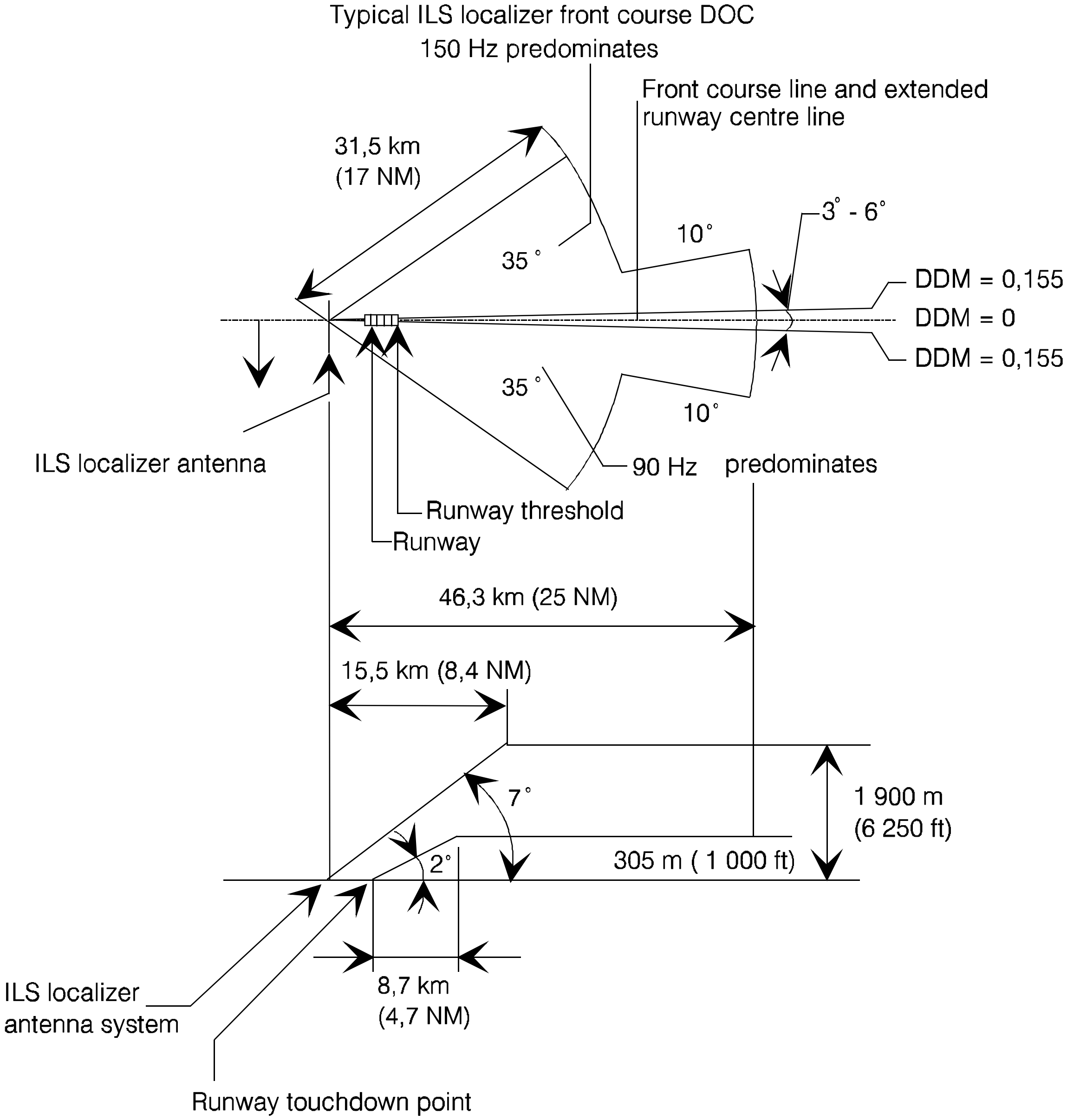
ICAO Annex 10 contains specifications and characteristics for ILS, VOR and COM aeronautical transmitters and receivers. This Clause identifies the parameters relevant for a compatibility assessment.

10.3.1 Characteristics of aeronautical systems

10.3.1.1 ILS localizer

Designated operational coverage

The standard ILS localizer Designated Operation Coverage (DOC) specified in ICAO Annex 10 is illustrated in figure 31. A smaller DOC may also be used and is also described in Annex 10. The ILS localizer may also have a back-beam signal.



NOTE 1: All elevations shown are with respect to ILS localizer site elevation.

NOTE 2: Not drawn to scale.

Figure 31: ILS localizer designated operational coverage

Field strength

The minimum field strength to be protected throughout the DOC is 32 dBµV/m (40 µV/m). If service is provided in the localizer back-beam volume, the field strength to be protected is also 32 dBµV/m. In certain areas of the ILS DOC, ICAO Annex 10 requires a higher field strength to be provided in order to increase the received signal-to-noise ratio thereby increasing system integrity. This is the case within the localizer course sector from a range of 18,5 km (10 NM) up to runway touchdown point where signals of 39 - 46 dBµV/m (90 - 200 µV/m) are required, depending upon the Facility Performance Category (I, II, III) of the ILS involved.

Frequencies

ILS localizer frequencies lie in the band 108 MHz to 112 MHz. The 40 available channels range in frequency from 108,1 MHz 108,15 MHz 108,3 MHz 108,35 MHz etc. to 111,75 MHz 111,9 MHz and 111,95 MHz.

Polarization

The ILS localizer signal is horizontally polarized.

10.3.1.2 VHF omnidirectional radio range (VOR)

Designated Operation Coverage (DOC)

The DOC of a VOR may vary widely (from a 74 km (40 NM) radius for a terminal VOR to a 370 km (200 NM) radius for an enroute VOR). Details may be obtained from the appropriate national Aeronautical Information Publication (AIP).

Field strength

The minimum field strength to be protected throughout the DOC is 39 dBμV/m (90 μV/m).

Frequencies

In the band 108 MHz to 112 MHz, VOR frequencies are located between ILS localizer frequencies and range from 108,05 MHz 108,2 MHz 108,25 MHz 108,4 MHz 108,45 MHz etc. to 111,6 MHz 111,65 MHz 111,8 MHz and 111,85 MHz. VOR frequencies occupy 50 kHz channel spacing in the band 112 MHz to 118 MHz.

Polarization

The VOR signal is horizontally polarized.

10.3.1.3 VHF communications (COM)

Designated Operational Coverage

The DOC of a COM facility may vary widely (from a 9,3 km (5 NM) radius to a 370 km (200 NM) radius). Details may be obtained from the administration operating the facility.

Field strength

ICAO Annex 10 does not specify a minimum field strength for COM; rather, it states that 38 dBμV/m (75 μ V/m) shall be exceeded for a "large percentage of occasions".

Frequencies

COM frequencies occupy 25 kHz spaced channels in the band 118 MHz to 137 MHz (e.g. 118 MHz 118,025 MHz 118,050 MHz etc. to 136,950 MHz and 136,975 MHz).

Polarization

The COM signal is vertically polarized.

10.4 Methods to assess the compatibility

Introduction

There are different methods to assess the compatibility of VHF FM broadcast services to aeronautical services.

One of them is the General Assessment Method (GAM) method which is based on the analysis of designed by the Limited Exploratory Group for Broadcast to Aeronautical Compatibility (LEGBAC).

Philosophy of the General Assessment Method

The central objective of the GAM is to calculate all significant potential incompatibilities within an aeronautical volume at a number of defined calculation points or test points. For a particular set of broadcasting and aeronautical frequency combinations, the maximum degree of potential incompatibility associated with a particular aeronautical service is identified in the form of a protection margin.

An extension of the compatibility assessment method contained in the ITU-R Recommendation IS.1009 [13] is needed because of subsequent refinement of the compatibility criteria and identification of the need for a more thorough assessment method. In addition, because of the need to identify and examine potential incompatibilities associated with a large assignment plan, it is necessary to develop an assessment method suitable for automated implementation in an efficient manner.

The GAM is based upon the need to protect the aeronautical radionavigation service at specified minimum separation distances from broadcasting station antennas, depending on the aeronautical service (ILS or VOR) and the particular use made of that service.

ILS

When assessing compatibility with ILS the GAM is based on a number of fixed test points, supplemented by an additional test point for each broadcasting station within the ILS DOC.

VOR

The DOC's employed in the VOR service are large and consequently there is likely to be a large number of broadcasting stations located within each VOR DOC. The GAM assesses compatibility with VOR by generating a test point above each broadcasting station inside the DOC and taking account of broadcasting stations outside the DOC.

10.4.1 Location of test points with maximum interference potential

Aircraft at the same height as a broadcasting station antenna

Consider the situation of an aircraft flying near a broadcasting station. If the aircraft flies at the same height as the broadcasting antenna, the maximum value of broadcasting field strength perceived by the aircraft will be at the point of nearest approach. In the case of an omni-directional broadcasting antenna, the points of maximum field strength lie on a circle centred on the antenna.

Aircraft at a greater height than a broadcasting station antenna

If the aircraft flies at a constant altitude on a radial line towards and over the site of a broadcasting antenna, the point of maximum field strength is vertically above the antenna.

Relationship between vertical and horizontal separation distances

If the maximum value of vrp reduction for the broadcasting antenna is 14 dB, the maximum value of field strength achieved for a vertical separation by y metres is the same as that for a separation of 5y metres in the horizontal plane through the broadcasting antenna where the vrp correction is 0 dB.

Location of maximum interference potential

For A1, A2 and B2 calculations, the vertical separation and horizontal separation concepts are equivalent because the broadcasting signals have a common source location. In the B1 case, the contributing sources are generally not co-sited and the location of the maximum interference potential may not be immediately obvious if the horizontal separation concept is used.

However, if the vertical separation concept is used, the point of maximum interference potential is above one of the other of the broadcasting antennas.

Thus, a unique pair (or trio) of points has been defined for a worst-case calculation without having to rely on a very large number of calculation points on some form of three-dimensional grid.

Test points for VOR

In the GAM, this direct approach is used for VOR compatibility calculations and is extended by means of additional test points situated at (or near) the DOC boundary to ensure that broadcasting stations outside the DOC are properly taken into account.

Test points for ILS

In contrast to the VOR situation, relatively few broadcasting stations are situated inside or below an ILS service volume, and in consequence it is easier to demonstrate that compatibility has been fully evaluated by using a set of fixed test points to supplement test points generated above or near any broadcasting stations inside the service volume.

Effect of increased test point height

Calculations of 2 or 3 component B1 type potential interference give worst-case results at the minimum test point height for any given sub-set of broadcasting stations which are within line-of-sight of the test point. However, at greater test point heights it is possible for additional broadcasting stations to become line-of-sight to the test point and further calculations are needed to determine if these stations can contribute to a B1 type potential interference. The maximum value of any potential interference occurs at the minimum height for which all relevant broadcasting stations are within line-of-sight of the test point. The greatest height which needs to be considered is the lower of:

- the maximum height of the DOC; or

- the maximum height at which the signal level from a broadcasting station achieves the trigger value.

11 Safety

11.1 Introduction

The safety of the working environment on, and in the vicinity of, radio sites must always remain a consideration of high importance to site operators and engineers. This subclause of this ETR is not intended as a comprehensive guide to all of those health and safety aspects, but is intended as a précis of health and safety issues that will need to be considered by existing and potential site operators.

In some European countries, health and safety issues are subject to national legislation. This legislation has been introduced for the protection of employers, employees and the public. Therefore it is essential that in the construction and operation of radio sites, professional advice is obtained on the legislative requirements that prevail in each country.

11.2 Radio frequency radiation

Radio frequency radiation is a source of hazard to personnel at a radio site.

Exposure to high levels of RF radiation may cause damage to body tissues, as a result of electric shock, RF burns, or heating effects, according to the frequencies in use. In the VHF range, body heating is the primary problem. Therefore, exposure of personnel to high level RF fields near to transmitters or antenna systems must be avoided.

The issue of radio frequency radiation limits is a contentious one, and work in this field is continuing world-wide. A European Directive, a CENELEC standard (TC III), and an EBU technical document are being prepared, which include the subject of RF hazards. In the meantime, several European countries use a value for the power flux density, in the VHF range, of 10 W/m^2 as a basis for considering whether or not an area is safe.

NOTE: This value is not a limit as such. It is beyond the scope of this ETR to give a detailed discussion on RF exposure standards.

Careful consideration should be given to the safety of personnel working in radio site environments and, in particular, the level of exposure experienced whilst climbing an antenna support structure. In many cases it will be necessary to reduce the power output of the transmitters before work commences. Consideration should also be given to the levels of radiation experienced outside the site boundary. In all cases of doubt, the guidance of the relevant national body should be sought.

11.3 Electrical safety

Appropriate guidance on electrical safety matters may be found in the document IEC 215 [8], dealing with broadcast transmitters.

11.4 Physical safety

A safe system of work should be in place for all staff. Particular points to note for transmitting stations include the following:

- in many cases the wearing of a hard hat is a legal requirement when work is undertaken on the antenna support structure, and the dangers of falling objects make their use essential;
- there is a danger of falling ice, in colder climates during the winter. The structure design and site layout should take this into account i.e. the danger of falling ice to personnel and the damage to buildings, equipment, antennas and feeders;
- care should be taken to ensure that sharp projections are avoided and interior walkways remain clear and unhindered. This is particularly important when additional services are added and equipment rooms become crowded;
- where soldering irons are in use, care should be taken such that hot irons are not left unprotected, but are placed in suitable holders;
- where lead acid battery power supplies are installed, the first aid aspect of acid splashes must be considered and, in particular, the requirement for eye wash solution in first aid cabinets;
- high power devices commonly found on radio sites may contain beryllium, usually in the form of an oxide (beryllia). Where work is undertaken on such equipment, the safety hazards of this substance should be made clear. Beryllium is a toxic substance, particularly as an oxide, and is suspected of being a carcinogen. In its mildest form, the inhalation of beryllium dust may cause inflammation of the nose, throat and chest. If a beryllium devices is broken, then the utmost care should be taken in removing the fragments and dust from the site. It is recommended that professional advice be obtained in all cases before removal of the substance is attempted;
- the insulating oil from transformers and capacitors is a fire hazard and believed to be carcinogenic after prolonged use;
- PTFE (Teflon) insulators give off Hydrogen Fluoride when heated above 205 °C. This is a toxic and extremely corrosive vapour.

11.5 Fire hazards

The requirements for the prevention and extinguishing of fires is often governed by legislation. In particular, the storage of paper, cardboard boxes, paint and other inflammable goods is not desirable. The number and type of extinguishers that are required at a site should be decided in consultation with the appropriate fire authority.

Annex A: Intermodulation interference

At the output of a transmitter of frequency B, the level of the interfering signal due to a transmitter on frequency A will be attenuated by the isolation between the transmitters. In this case the amplitudes of the intermodulation products of the same order will not be equal (CCIR Report 739-1 [10] appendix 3 refers).

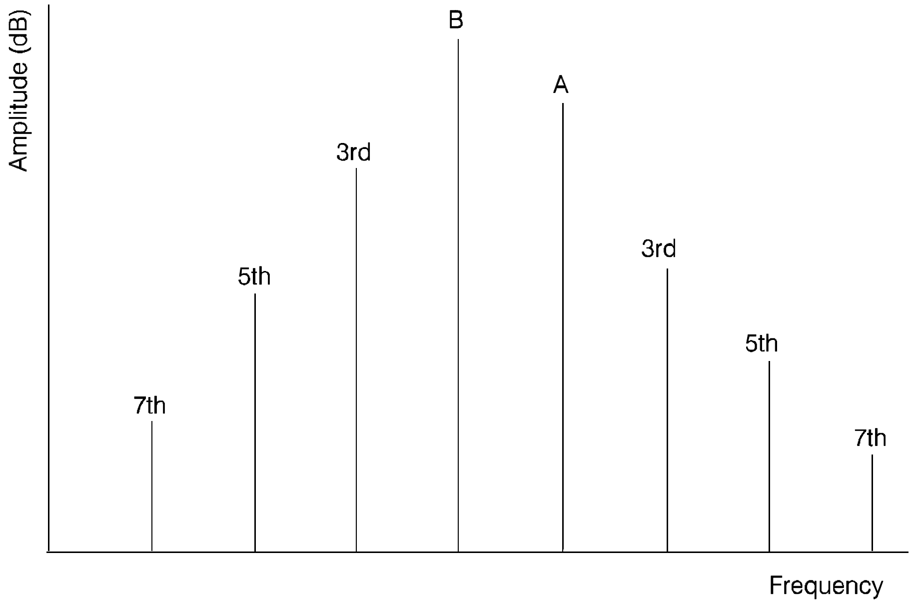


Figure A.1: Intermodulation spectrum (at the output of transmitter frequency B, interfering signal frequency A)

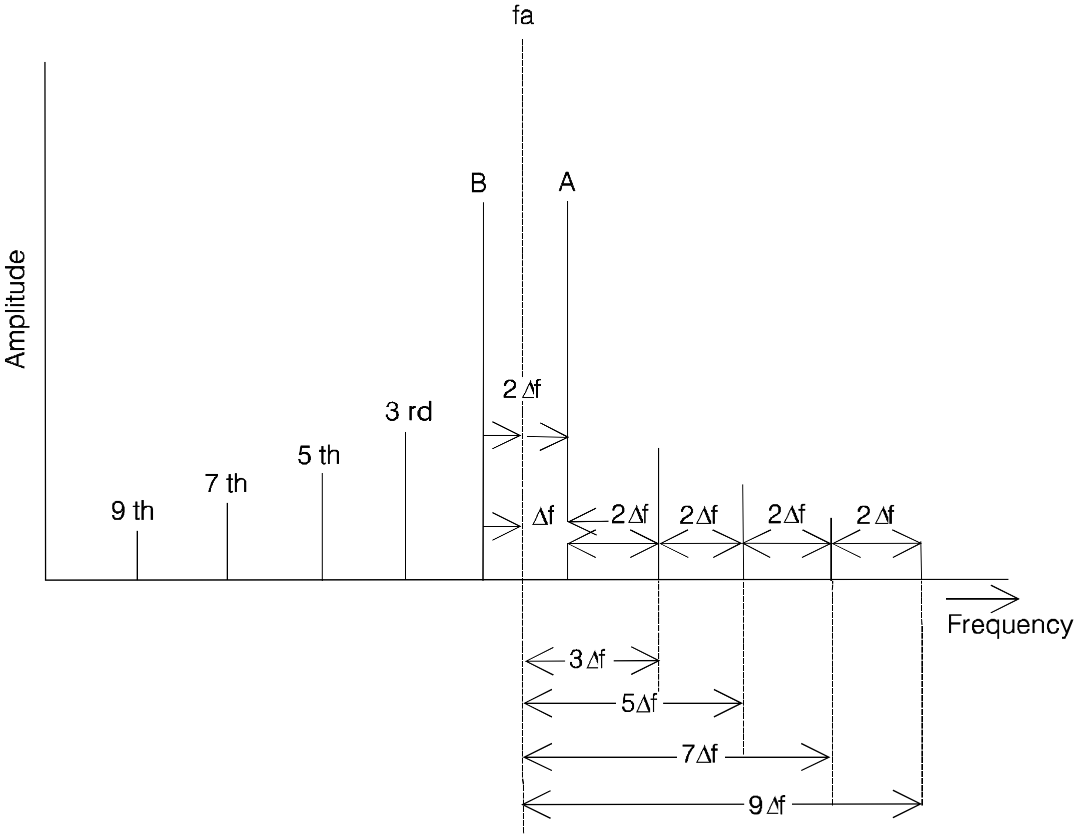


Figure A.2: Intermodulation spectrum

Products: combinations of two frequencies.

A and B excluding pure harmonics.

Let: $A = fa + \Delta f$ and $B = fa - \Delta f$

where: $fa = \frac{A+B}{2}$ and $\Delta f = \frac{A-B}{2}$

Table A.1: Intermodulation products

2nd order (2 ips)	$A+B=2fa$ $A-B=2\Delta f$	3rd order (4 ips)	$2A+B=3fa+\Delta f$ *$2A-B=fa+3\Delta f$ $2B+A=3fa-\Delta f$ *$2B-A=fa-3\Delta f$
4th order (7 ips)	$2A+2B=4fa$ $2A-2B=4\Delta f$ $2B-2A=-4\Delta f$ $3A+B=4fa+2\Delta f$ $3A-B=2fa+4\Delta f$ $3B-A=2fa-4\Delta f$ $3B-A=4fa-2\Delta f$	5th order (8 ips)	$3A+2B=4fa+\Delta f$ $3B+2A=4fa-\Delta f$ *$3A-2B=fa+5\Delta f$ *$3B-2A=fa-5\Delta f$ $4B+A=5f-3\Delta f$ $4A+B=5fa+3\Delta f$ $4A-B=3f+5\Delta f$ $4B-A=3f-5\Delta f$
6th order (11 ips)	$5A+B=6fa+4\Delta f$ $5B+A=6fa-4\Delta f$ $5A-B=4fa+6\Delta f$ $5B-A=4fa-6\Delta f$ $4B+2A=6fa-2\Delta f$ $4A+2B=6fa+2\Delta f$ $4B-2A=2fa-6\Delta f$ $4B-2B=2fa+6\Delta f$ $3A+3B=6fa$ $3A-3B=+6\Delta f$ $3B-3A=-6\Delta f$	7th order (12 ips)	$4A+3B=7fa+\Delta f$ $4B+3A=7fa-\Delta f$ *$4A-3B=fa+7\Delta f$ *$4B-3A=fa-7\Delta f$ $5A+2B=7fa+3\Delta f$ $5B+2A=7fa-3\Delta f$ $5A-2B=3fa+7\Delta f$ $5B-2A=3fa-7\Delta f$ $6A+B=7fa+5\Delta f$ $6B+A=7fa+5\Delta f$ $6A-B=5fa+7\Delta f$ $6B-A=5fa-7\Delta f$
8th order (15 ips)	$5A+3B=8fa+2\Delta f$ $5B+3A=8fa-2\Delta f$ $5A-3B=2fa+8\Delta f$ $5B-3A=2fa-8\Delta f$ $6A+2B=8fa+4\Delta f$ $6B+2A=8fa-4\Delta f$ $6A-2B=4fa+8\Delta f$ $6B-2A=4fa-8\Delta f$ $7A+B=8fa+6\Delta f$ $7B+A=8fa-6\Delta f$ $7A-B=6fa+8\Delta f$ $7B-A=6fa-8\Delta f$ $4A+4B=8fa$ $4A-4B=8fa+8\Delta f$ $4B-4A=8fa+8\Delta f$	9th order (16 ips)	$5A+4B=9fa+\Delta f$ $5B+4A=9fa+\Delta f$ *$5A-4B=fa+9\Delta f$ *$5B-4A=fa-9\Delta f$ $6A+3B=9fa+3\Delta f$ $6B-3A=9fa-3\Delta f$ $6A-3B=3fa+9\Delta f$ $6B-3A=3fa-9\Delta f$ $7A+2B=9fa+5\Delta f$ $7B+2A=9fa-5\Delta f$ $7A-2B=5fa+9\Delta f$ $7B-2A=5fa-9\Delta f$ $8A+B=9fa+7\Delta f$ $8B+A=9fa-7\Delta f$ $8A+B=7fa+9\Delta f$ $8B-A=7fa-9\Delta f$ *inband

Intermodulation products

Intermodulation between frequencies of channels allocated in a bandwidth B Hz will be spread over the spectrum from DC to n times the highest frequency used (where n is the order of the non-linearity producing the intermodulation). Of particular interest are those products which fall back within and around the band B. This group will extend over a range of n x B Hz, the distribution within this being dependent on the initial distribution within B. In addition the modulation of the generating carriers will cause each individual product to be spread over n times the occupied bandwidth.

For example if the band B were 2 MHz wide from 154 MHz to 156 MHz then 9th order intermodulation products would extend from 146 to 164 MHz and each product would cover a band of 72 kHz if the occupied bandwidth is taken as ± 4 kHz.

The number of such products is given in table A.2.

Table A.2: Number of intermodulation products

Non-linearity order number **Number of channels**	**3rd**	**5th**	**7th**	**9th**
2	2	2	2	2
3	9	15	21	27
4	24	64	124	204
5	50	200	525	1 095
6	90	510	1 770	4 626
7	147	1 127		

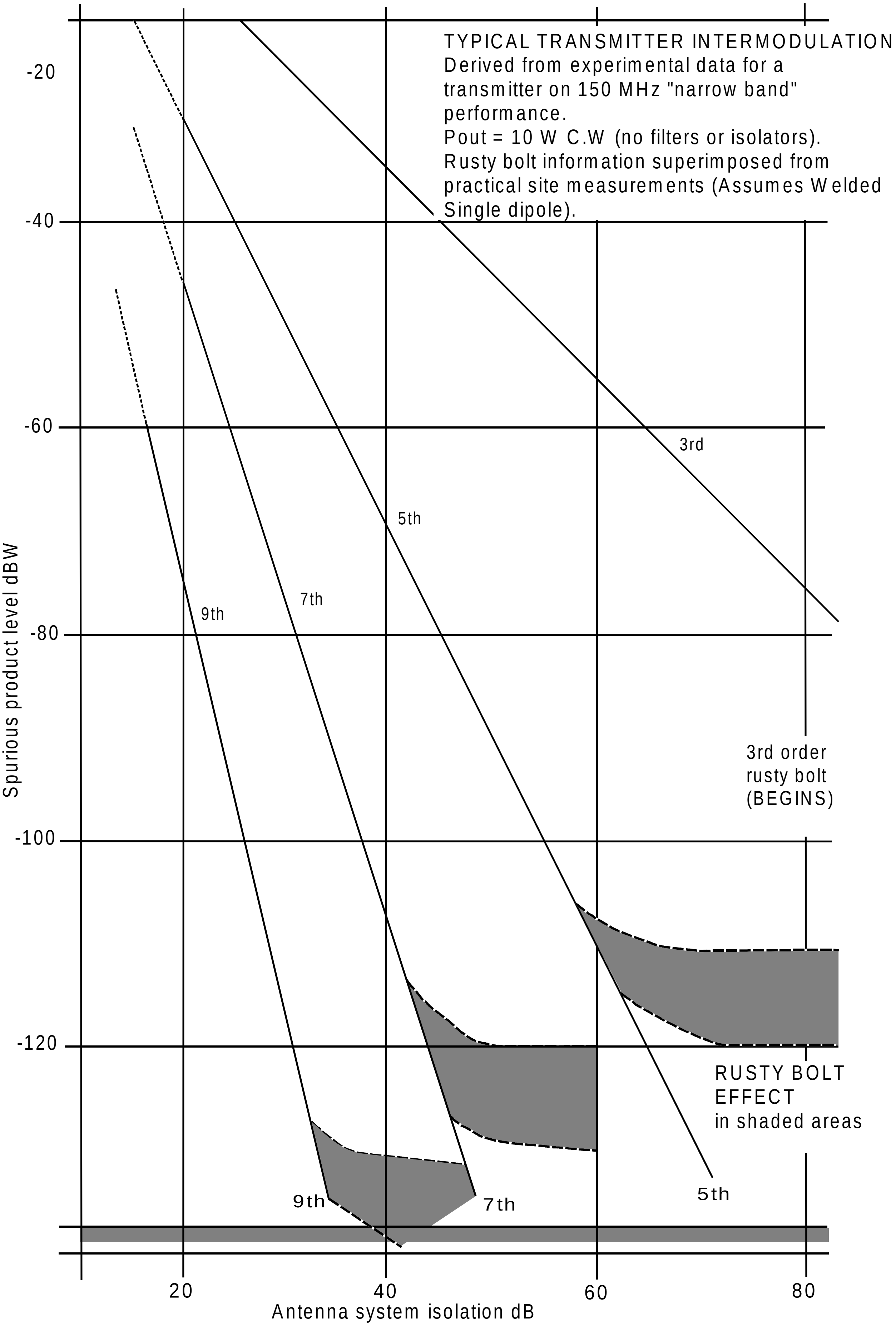


Figure A.3: Typical transmitter intermodulation

Annex B: Common antenna configurations

B.1 Mounting of the radiating elements

Two main forms of antenna are employed which influence the design, and to a limited degree the type, of structure selected for broadcasting purposes in the VHF bands:

a) the radiating elements are mounted on the main structure with or without reflector screens;

b) the radiating elements are mounted on a topmast or pole not greatly exceeding 0,5 m diameter.

These are broad generalisations and the two types overlap considerably.

B.1.1 Mounting on the main structure (type a)

Many types of antennas falling into category (a) have been developed for VHF use and in some cases the supporting structures were designed before the form and therefore the loading of the antennas were unknown. A high initial cost has sometimes been accepted in order that the structure should be strong enough for technical changes and additional requirements to be incorporated. Most masts are designed for pre-determined forms of antennas. The radiating elements may readily be grouped round a pre-determined mast column to provide either a directional or circular radiation pattern.

Some of the types used are:

a) dipoles;

b) panels of four or more dipoles vertically disposed, the panels acting as a screen or reflector;

c) skew arrangements of Yagi antennas.

Such antennas may be phased to fill nulls in the vertical radiation pattern or the power distribution over the antenna aperture may be arranged to give a similar result.

For all types, when the power gain exceeds 10 exclusive of losses, the deflection of the supporting structure from the true vertical is restricted to about 0,5° to prevent unacceptable field-strength variations in the service area which would otherwise occur.

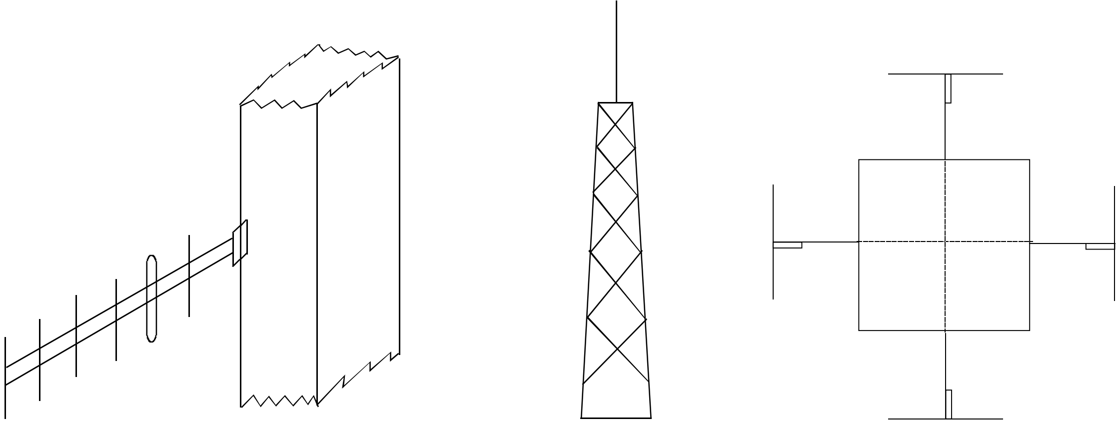
B.1.2 Mounting on topmasts or poles (type b)

The type (b) antennas tend to have a narrower bandwidth than (a) and include helices, "super turnstiles", slotted cylinders, Yagi's, dipoles and rings of three or more dipoles either horizontal or vertical. The main structural characteristic is that they are mounted on unstayed topmasts, often added to a structure designed primarily for other antennas, and therefore restricted to an overall length often not exceeding 30 m and usually between 10 m and 20 m.

B.2 Behaviour of some antenna-mast configurations

a) Good performance:

- little gain or pattern change;
- good cross-polar performance;
- good intermodulation performance.

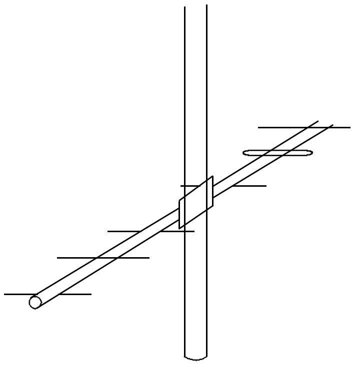


Solid structure Triangular mast Tier of four array

Figure B.1: Good performance

b) Medium performance:

- acceptable gain loss;
- small loss of cross-polar performance;
- small degradation of intermodulation.

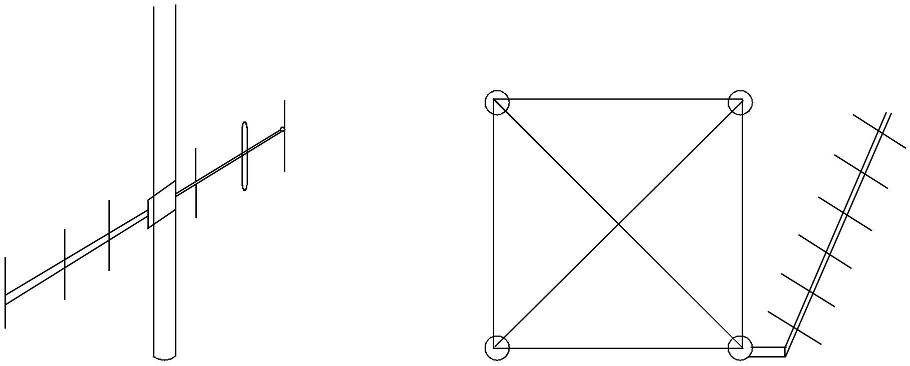


Pole mounted

Figure B.2: Medium performance

c) Low performance:

- loss of gain and directivity;
- dubious cross-polar performance.



Pole mounted

Square section mast

Figure B.3: Low performance

B.3 Horizontal radiation pattern (hrp)

The number of co-phased elements required in plan to give a nearly circular radiation pattern, increases with the transversal dimensions of the mast and this may influence the choice of the type of support since stayed masts will generally be of smaller section than towers and may result in a cheaper antenna.

By using a number of dipoles per tier, the variation of gain may be limited to 2 dB overall, but this result may be achieved with fewer elements by careful design.

To limit hrp variations the mast-face dimension should be kept below 1,8 m.

Annex C: The position of metals in the galvanic series

The use of dissimilar metals in an antenna support structure may cause considerable trouble due to electrolytic corrosion.

Unless metals of similar potential are used, or the appropriate protective paints applied, corrosion will occur at the point of contact even when care has been taken to exclude moisture. An example of this phenomena when iron is used is known as the Rusty bolt effect, which may result in intermodulation interference (see Annex A).

The various metals may be arranged in groups according to their electro-potentials. Metals from the same group may be used together with little risk. However, metals from different groups will suffer corrosive effects.

Data is available detailing the electro-potentials of various metals. The data is normally expressed as the potential difference of the metal relative to a Hydrogen electrode as given in table C.1. This serves as useful information, but more relevant would be the position of metal in the galvanic series relative to a saline solution. Table C.2 gives the position of various metals in the galvanic series in sea water. To avoid corrosion metals should be selected from the same group wherever possible.

Table C.1: Galvanic series (Potential between metal and a hydrogen electrode)

Metal	Potential (Volts)		Metal	Potential (Volts)
Magnesium	+2,40		Iron	+0,045
Aluminium	+1,70		Brasses	
Duraluminium			Bronzes	
Zinc	+0,762		Nickel/Copper	
Chromium	+0,557		Copper (CU2+)	-0,344
Chromium/Iron Alloys			Copper (CU+)	-0,470
Iron	+0,441		Silver	-0,798
Cadmium	+0,401		Lead	-0,80
Chromium/Nickel/Iron			Platinum	-0,863
Nickel	+0,231		Gold (AU4+)	-1,360
Tin	+0,136		Gold (AU+)	-1,50
Lead	+0,122			
Iron	+0,045			
Brasses				
Bronzes				
Nickel/Copper				
Copper (CU2+)	-0,344			
Copper (CU+)	-0,470			
Silver	-0,798			
Lead	-0,80			
Platinum	-0,863			
Gold (AU4+)	-1,360			
Gold (AU+)	-1,50			

Table C.2: Galvanic series in sea water

Magnesium alloys
Zinc Galvanised steel Galvanised wrought iron
Aluminium: 52SH, 4S, 3S, 2S, 53ST Aluminium clad
Cadmium
Aluminium: A17ST, 17ST, 24ST
Mild steel Wrought iron Cast iron
Ni-resist
13% chromium stainless steel type 410 (active)
50-50 lead-tin solder
18-8 stainless steel type 304 (active) 18-8-3 stainless steel type 316 (active)
Lead Tin
Muntz metal Manganese bronze Naval Brass
Nickel (active) Inconel (active)
Yellow brass Admiralty brass Aluminium bronze Red brass Copper Silicon bronze Ambrac 70-30 copper-nickel Comp.G, bronze Comp.M, bronze
Nickel (passive) Inconel (passive)
Monel
18-8 stainless steel type 304 (passive) 18-8-3 stainless steel type 316 (passive)

Annex D: Antenna noise power on typical radio sites

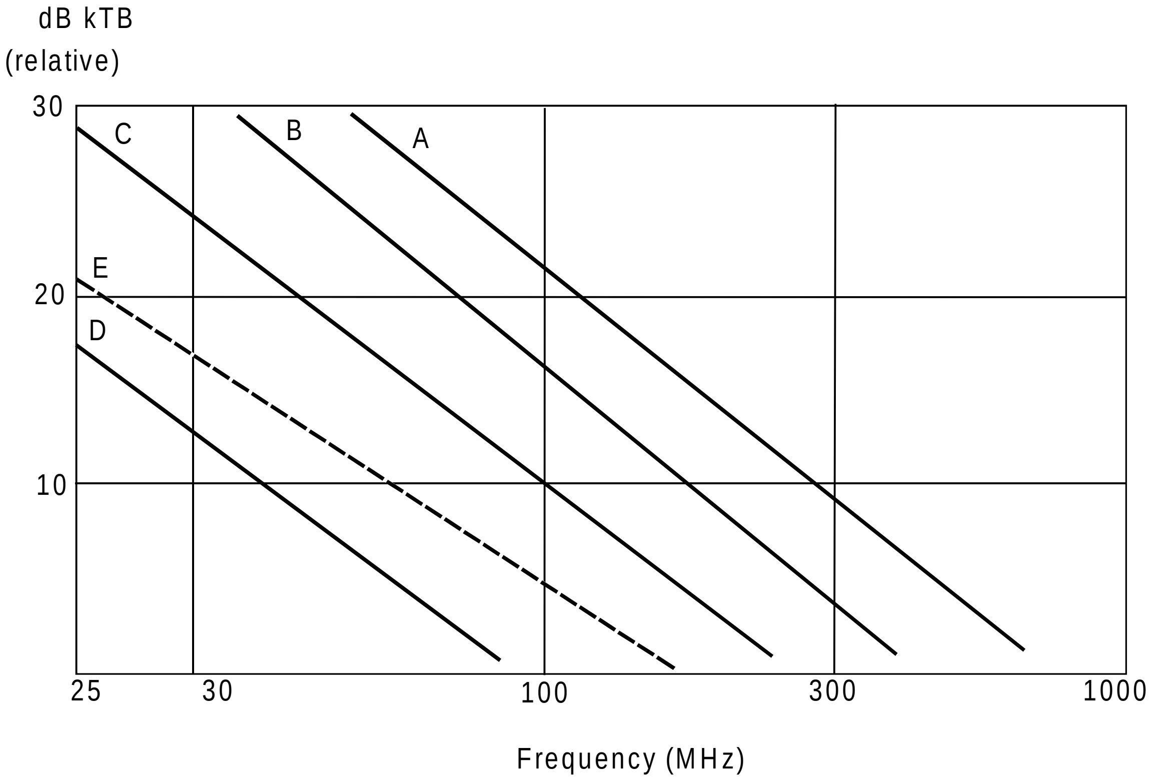


Figure D.1: Median values of man-made noise for a short vertical lossless ground plane monopole antenna

Environmental category:

A: business;
B: residential;
C: rural;
D: quite rural;
E: galactic.

The above graphs have been taken from CCIR Report 258-4, and have been expanded from 25 to 1 000 MHz for ease of reference to the Land Mobile Service (LMS).

Annex E: Typical example of good earthing practice

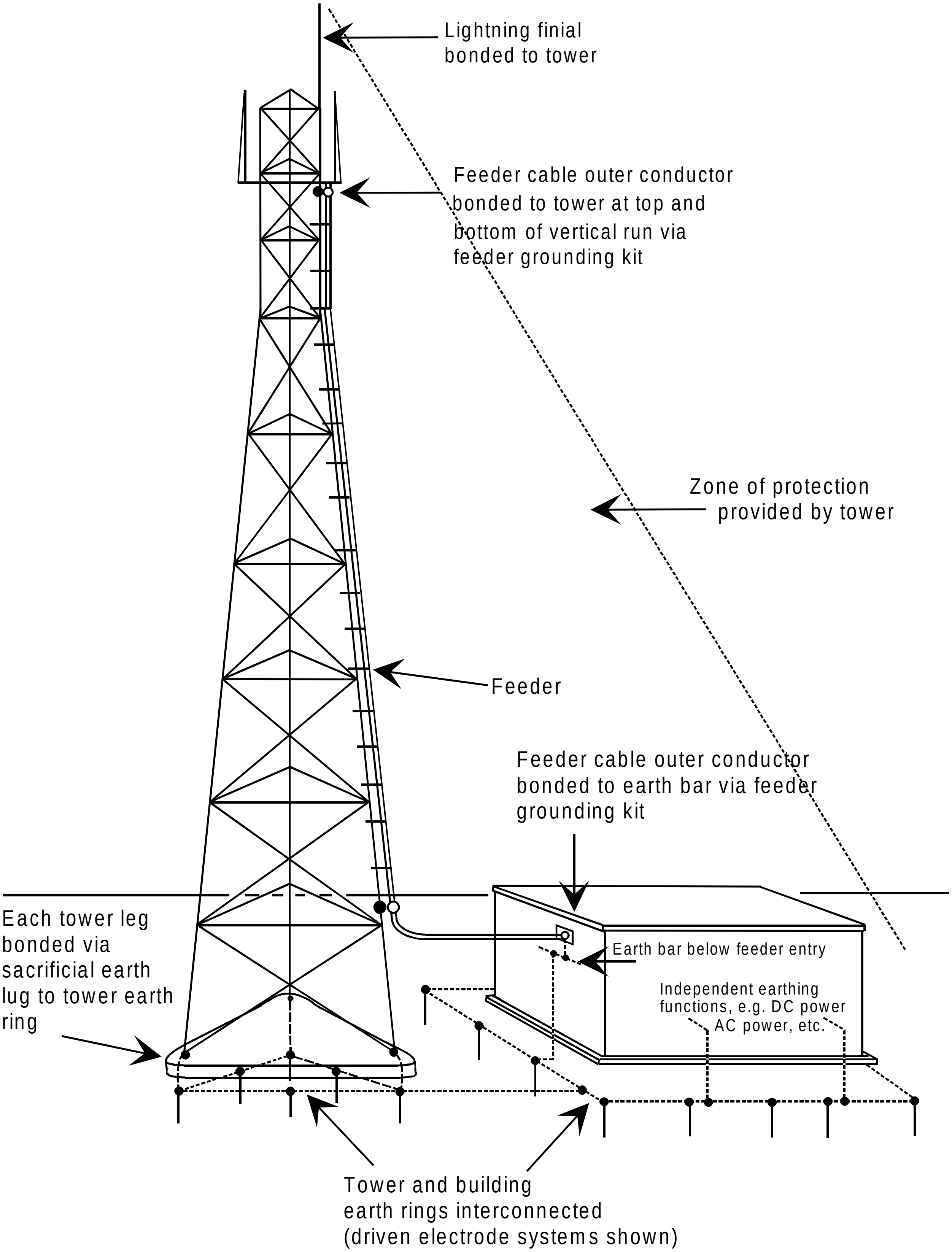


Figure E.1

Annex F: Starpoint, directional filter, and stretchline combiners and multiplexers

Table F.1: Comparison

Combiner type:	**Starpoint combiner**	**Directional filter combiner**	**Multiplexer**	**Stretchline combiner**
Set-up	Bandpass filters + starpoint	Bandpass filters + 3 dB couplers	Combination of starpoint and directional filter	3 dB couplers + stretchline
Minimum frequency spacing				
FM				
30 W - 1 kW	2,5 MHz	2 MHz	2 MHz	
3 kW - 20 kW	2,0 MHz	0,8 - 1 MHz	0,8 - 1 MHz	
UHF				
10 W - 200 W	3 channels (special version: 2 channels)	3 channels (special version: 2 channels)	3 channels (special version: 2 channels)	3 channels (special version: 2 channels)
Matching (VSWR)	All inputs matched in passband range, mismatched outside.	All inputs broadband matched.	**Starpoint inputs:** as for starpoint combiner **Directional filter inputs:** broadband mismatched	All inputs broadband mismatched.
Frequency response	All inputs are narrowband according to the frequency response of the bandpass filter.	**Narrowband inputs:** according to the frequency response of the bandpass filter **Broadband input:** not selective.	All inputs are narrowband according to frequency response of the bandpass filters.	Depends on channel combination.
Isolation	Like stop band attenuation of filter.	**From NB to BB:** attenuation through directional coupler. **From BB to NB and from NB to NB:** Attenuation through directional coupler + stop band attenuation of filter. Very high values attainable.	Between starpoint inputs: like stop band attenuation of filter; all other inputs: attenuation through directional couplers + stop band attenuation of filter. Very high values are attainable.	Attenuation through directional couplers.
Extensions	New starpoint cabling necessary	Very simple through connecting up a directional filter module. Existing cables need not be altered.	Insert a directional filter between starpoint and directional filter. Alteration of existing cabling necessary.	
Costs	Economical solution for wide frequency spacing.	Sophisticated solution with several technical advantages.	Costs between starpoint and directional filter. Advantage: smaller frequency spacing possible than with a starpoint.	Economical solution for wide frequency spacing.

Annex G: Bibliography

1) CCITT Recommendation P.53: "Psophometers (apparatus for the objective measurements of circuit noise)".

History

Document history	
August 1994	First Edition
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