Coaxial Transmission Lines

Definitions

Mechanical Characteristics

Cable weight

Weight per unit (meter or foot) of the complete cable.

Bending properties

A particular advantage of RF cables with corrugated conductors is their flexibility, as expressed in the data for minimum bending radii.

Minimum bending radius, single bending

After the cable has been bent to these minimum values it should not be bent back, as this could result in damage to the cable.

Minimum bending radius, repeated bending

This bending radius allows for several operations and indicates the minimum bending radius during the installation procedure of the cable. It also gives an indication of the minimum reel core radius.

Bending moment

A particular advantage of RF cables with corrugated conductors is their flexibility, as expressed in the bending moment. The cable under test is fixed in a straight support and a perpendicular force is introduced at a certain distance (50 times the cable diameter for LCF, 25 times for SCF and UCF) away from the support. The necessary force to deflect the cable by half this distance multiplied by the distance gives the bending moment.

Flat plate crush strength

Another advantage of the outer conductor corrugation is the fact that it gives the cable a very high crush resistance. If the given values are not exceeded the local impedance change is less than 0.5 Ω. For instance: In order to compress a 90 mm length section of CELLFLEX® LCF158-50 to reduce the local impedance by 0.5 Ω, it is necessary to apply a force of more than 2790 N.

Tensile strength

The tensile strength of RF cables is determined by a typical installation situation when pulling the cable with hoisting grips. In the case of corrugated conductors, tensile strength is naturally less than in the case of smooth conductors. To prevent damage to the cable, when hoisting it into masts or pulling it through ducts, the maximum admissible tensile force stated for the particular cable must not be exceeded. The values are based on a maximum cable elongation by 0.2%. Refer to the installation instructions for further details.

Electrical Properties

Characteristic impedance

The mean value of characteristic impedance is measured at around 200 MHz. The admissible deviation from the nominal value is ± 1% to ± 4%, depending on the cable type.

Relative propagation velocity

This ratio (in percent) is the propagation velocity of the electromagnetic wave inside the cable in relation to propagation velocity in free space. It determines the electrical length of the cable.

Capacitance

The capacitance of RF cables is independent of frequency and is determined by the relative dielectric constant, the effective outer conductor diameter and the effective inner conductor diameter.

Inductance

The inductance of RF cables is slightly frequency dependent and is determined by the effective outer and inner conductor diameter and the equivalent conducting layer due to the skin effect.

Maximum operating frequency

Up to this frequency, the properties of the cable are within the specifications given unless otherwise stated.

Peak power rating

Peak power rating is the input power for which the peak RF voltage rating is reached, when the cable is operating in its matched condition. Peak power rating is independent of frequency.

RF peak voltage

The RF Peak voltage is limited by the air gap between inner and outer conductor of a coaxial line and the voltage withstand of air. Air is also considered a dielectric for foam cables since there will always be a short section of air line at the interface between foam cable and connector. Depending on the connector used, a smaller connector mating interface can be the limiting factor.

Spark test

Within the production process, the cable jacket is tested by applying a pulsed high voltage to the jacket against the outer conductor. This is to ensure the integrity of the jacket regarding holes, inclusions and thickness.

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DC-resistance inner conductor

This value is the DC-resistance of the inner conductor in ohms per length (ohms/km or ohms/1000ft).

DC-resistance outer conductor

This value is the DC-resistance of the outer conductor in ohms per length (ohms/km or ohms/1000ft).

Storage temperature

During storage the given temperature range must not be exceeded. Otherwise the cable can be damaged.

Operation temperature

During operation the given temperature range must not be exceeded. Otherwise the cable can be damaged.

Installation temperature

During installation the given temperature range must not be exceeded. Otherwise the cable can be damaged.

Foundations

Transmission line parameters

Primary & secondary transmission line parameters

The relation between the primary parameters:

series resistance	R′ in Ω/km
inductance	L′ in H/km
parallel capacitance	C′ in F/km
parallel resistance	G′ in S/km

and the secondary parameters:

characteristic impedance	Z_c in Ω
propagation constant	γ
phase constant	β in rad/km
attenuation constant	α in N/km

is given by the following transmission line equations:

$$\gamma = \alpha + j\beta$$

$$\gamma = \sqrt{(R' + j\omega L') \cdot (G' + j\omega C')} \qquad (1)$$

$$Z_c = \sqrt{(R' + j\omega L') / (G' + j\omega C')} \qquad (2)$$

$$\omega = 2\pi f$$

These equations are valid for the entire frequency range of RF cables up to their cut-off frequency.

At radio frequencies where $R' \ll \omega L'$ and $G' \ll \omega C'$, the transmission line equations take the following form:

$$Z_c = \sqrt{\frac{L'}{C'}} \quad \text{in } \Omega \qquad (3)$$

$$\beta = \omega \cdot \sqrt{L' \cdot C'} \quad \text{in rad/km} \qquad (4)$$

$$\alpha = (R' / 2) / Z_c + (G' / 2) \cdot Z_c$$

$$= \alpha_R + \alpha_G \quad \text{in nepers/km} \qquad (5)$$

$$v_\varphi = 1 / \sqrt{L' \cdot C'} \quad \text{in km/s} \qquad (6)$$

α_R -conductor attenuation

α_G -dielectric attenuation

v_φ -propagation attenuation

The deviations between equations (3) to (6) as compared to equations (1) and (2) is below 0.1%, as long as

$$D_e \ f \geq 140 \qquad (7)$$

D_e -dielectric attenuation

f -propagation attenuation

Skin effect

At DC, current in a conductor flows with uniform density over the cross section of the conductor. At high frequencies, the current tends to flow only in the conductor surface; the effective conductor cross section decreases and the conductor resistance increases.

At radio frequencies, current flows only in a very thin "skin". Everywhere else the conductors are free from electromagnetic fields. Even very thin walled metal envelopes will, therefore, entirely screen the electromagnetic field within coaxial RF cables at radio frequencies.

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The depth of penetration illustrates the skin effect. It is defined as the thickness of a thin surface layer (assumed to have an even distribution of current flow), having the same resistance as an actual conductor, which is undergoing to the skin effect.

For non-magnetic materials the equivalent conducting layer is

$$\delta = 15,9 / \sqrt{\sigma \cdot f} \qquad \text{in mm} \qquad (8)$$

σ - conductivity in m/Ω mm²

f - frequency in kHz

Other than resistance, the skin effect also influences inductance and thereby characteristic impedance and propagation velocity.

Electrical characteristics

Capacitance

The capacitance of RF cables is independent of frequency:

$$C' = \frac{10^{-6} \cdot \varepsilon_r}{18 \cdot In\,(D_c / d_c)} \qquad \text{in F/km} \qquad (9)$$

ε_r - relative dielectric constant

D_c - effective outer conductor diameter (capacitive)

d_c - effective inner conductor diameter (capacitive)

Inductance

The inductance of a RF cable is:

$$L' = 2 \cdot 10^{-4} \cdot In \frac{D_i + \delta}{d_i - \delta} \qquad \text{in H/km} \qquad (10)$$

D_i - effective inner conductor diameter (inductive)

d_i - effective inner conductor diameter (inductive)

δ - equivalent conducting layer

At very high frequencies, inductance approaches: in H/km

$$L' = 2 \cdot 10^{-4} \cdot In(D_i / d_i) \qquad \text{in H/km} \qquad (11)$$

Characteristic impedance

The characteristic impedance of an RF cable is determined by its inductance and capacity according to equation 3. Because of the influence of the skin effect upon inductance, it also is frequency-dependent.

Characteristic impedance of RF cables is, therefore, understood as the value it approaches for very high frequencies. If we say $D_c \approx D_i = D_e$, $d_c \approx d_i = d_e$ and $\delta \ll d_i$ then

$$Z_c = \frac{60}{\sqrt{\varepsilon_r}} \cdot In(D_e / d_e) \qquad \text{in } \Omega \qquad (12)$$

D_e - electrically effective outer conductor diameter

d_e - electrically effective inner conductor diameter

ε_r - relative dielectric constant

As frequency falls, the characteristic impedance rises. The relative deviation from the value at very high frequency is approx.

$$\frac{\Delta Z}{Z_c} = \frac{4}{D_e \cdot \sqrt{f}}$$

D_e - electrically effective outer conductor in mm

f - frequency in kHz

Certain electrical properties of an RF cable can be optimized by proper choice of characteristic impedance. For coaxial cables with cylindrical conductors (of the same material) the following optimizations are possible:

	AIR DIELECTRIC CABLES	SOLID PE DIELECTRIC CABLES
minimum attenuation	77 ohms	51 ohms
max. operating voltage	60 ohms	40 ohms
max. peak power rating	30 ohms	20 ohms
max. mean power rating	=50 ohms*	

*approx. valid for HELIFLEX® transmission lines of larger diameter

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Today, RF coaxial cables are produced mainly with characteristic impedance of 50 ohms and to some extend in 75 ohms.

As the material properties and dimensions of RF cables are not constant along their length, the characteristic impedance will vary with length and deviate from the mean value of characteristic impedance of the particular cable; similarly the mean value will deviate from the nominal value (50 or 75 ohms).

The mean value of characteristic impedance of a cable is defined as follows:

$$Z_m = \frac{I_e}{c_o \cdot C} \quad \text{in ohms} \qquad (14)$$

I_e - electrical length in m

c_o - propagation velocity in free space in m/sec

C - capacitance in F

The mean value of characteristic impedance is measured at around 200 MHz. The admissible deviation from the nominal value is ±3/4 1% to ±3/4 4%, depending on the product group.

Uniformity of characteristic impedance

As mentioned, the material properties of RF cables are not uniform along their length and result in small deviations of the characteristic impedance. The impedance step ΔZ at position x of the cable results in reflection factor at the position as follows:

$$r_x = \frac{\Delta Z}{2Z_c} \qquad (15)$$

The magnitude and distribution of the various reflections determine their effect upon transmission properties. Two ways are commonly used to judge the effect of impedance variation.

Time domain reflectometry (TDR)

A defined voltage step is fed into the cable and partially reflected at each impedance variation. The display of the reflected energy versus time gives a view upon the local distribution of the inner reflections. The pulse reflection factor at a certain position is the ratio between the voltage of the reflected and the incident pulse. Instead of reflection factor, one can also use the term pulse return loss:

$$A_p = 20 \cdot \log \frac{100}{r_p} \quad \text{in dB} \qquad (16)$$

r_p - pulse reflection factor in %

The magnitude and nature of the pulse reflection factor depend very much upon the form of incident pulse.

Return loss/reflection factor (steady state condition)

The reflection factor sums up the effects of all the impedance variations within the cable and its ends, at a certain frequency. It is the ratio between the vectorial) addition of all reflections and the incident signal, measured at the near end of the cable.

As well as reflection factor, the term return loss is also used.

$$A_z = 20 \cdot \log \frac{100}{r} \quad \text{in dB} \qquad (17)$$

r - reflection factor in %

The reflection factor versus frequency may be plotted continuously. The reference impedance of test equipment and the load at cable end are equal to the nominal value of cable impedance.

It is also customary to use the term voltage standing wave ratio (VSWR), based upon the standing wave, which the cable under test would produce in a homogeneous transmission line connected to its near end and having its nominal characteristic impedance.

$$s = \frac{1 + r/100}{1 - r/100} \qquad (18)$$

$$r = \frac{s-1}{s+1} \cdot 100 \quad \text{in \%} \qquad (19)$$

s - standing wave ratio

Relative propagation velocity and delay

The relative propagation velocity is defined as follows.

$$\nu_r = \frac{\upsilon_\varphi}{c_o} \cdot 100 = \frac{l}{l_e} \cdot 100 \quad \text{in \%} \qquad (20)$$

υ_φ - propagation velocity in cable

c_o- propagation velocity in free space ($300 \bullet 10^3$ km/s)

l - geometrical length in m

l_e - electrical length in m

Delay is defined as follows:

$$t_\varphi = \frac{336.6}{\nu_r} = \frac{10^8}{\nu_r \cdot c_o} \quad \text{in ns/m} \tag{21}$$

ν_r - relative propagation velocity in %

Due to the skin effect, propagation velocity is frequency dependent. Velocity decreases with falling frequency, delay increases. The relative deviation can be calculated according to equation 13.

As in the case of characteristic impedance, relative propagation velocity of RF cables is understood as the value it approaches for very high frequencies. If $D_c = D_i$ and $d_c = d_i$ it is dependent solely upon the dielectric constant and is defined as follows:

$$\nu_r = \frac{100}{\sqrt{\varepsilon_r}} \quad \text{in \%} \tag{22}$$

Propagation velocity is measured at frequencies around 200 MHz as standard. Propagation velocity is also subject to variations. These variations have no direct influence upon transmission characteristics; they do, however, come to light, if cables have to be adjusted to equal electrical length, because after adjustment the cables of equal electrical length may show differences in geometrical length. If cables are to be used in applications where consistency of electrical length is important, we recommend that this is stated at the time of order placement, in order to allow us to select the cables from one manufacturing batch, whenever possible.

Electrical length and adjustment of length

The electrical length is defined as follows:

$$l_e = \frac{100 \cdot l}{\nu_r} \quad \text{in m} \tag{23}$$

l - geometrical length in m

ν_r - relative propagation velocity in %

Between electrical length and phase angle the following relation applies:

$$\varphi = 2 \cdot \frac{l_e}{300} \cdot f \quad \text{in rad} \tag{24}$$

l_e - electrical length in m

f - frequency in MHz

In many cases, cables with equal or defined differential electrical length are required. Typical examples are feeder cables for TV transmitters and cabling of antenna groups or antenna arrays. Such length adjustments can be made with precision. A typical value for the achievable accuracy is a phase angle tolerance of ± 5° in the 470 to 860 MHz frequency band. In order to eliminate length variations through handling after adjustment, we recommend to have long lengths of cables length adjusted after installation; short cable lengths may, however, be supplied factory-adjusted.

The electrical length of RF cables is dependent upon temperature, and in case of air dielectric cables also upon the pressure and humidity of contained air. The influences are quite small, but must, however, be taken into account in case where the cables are very long as compared to the operating wavelength.

It is advisable to install length-adjusted cables so that they are all subject to the same ambient conditions such as temperature, solar radiation etc. Length-adjusted HELIFLEX® cables should be operated under a slight overpressure (the same for all cables) of approx. 0.2 bar of dry air or nitrogen.

For less critical applications, phase-stabilized cables can be supplied. These are cables that are aged in order to reduce hysteresis effects.

The variation of electrical length with temperature is also influenced by the kind of cable attachment to the support structure. Cables that can expand freely with temperature have different values than cables which are rigidly clamped down.

In the following diagrams typical figures of the electrical length change are shown for several cable types.

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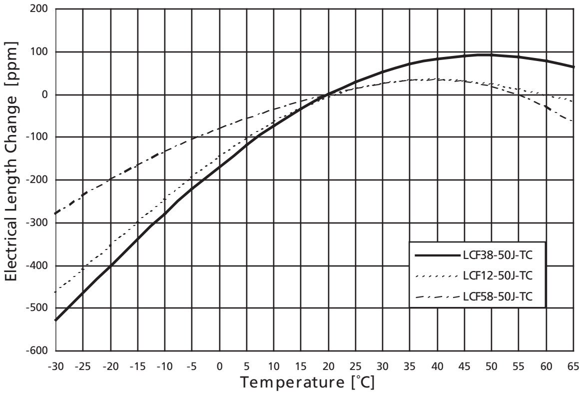
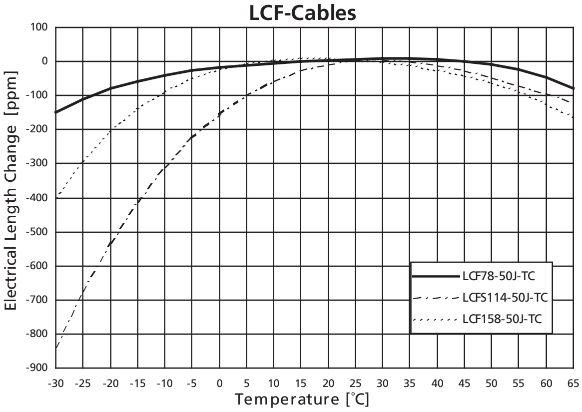
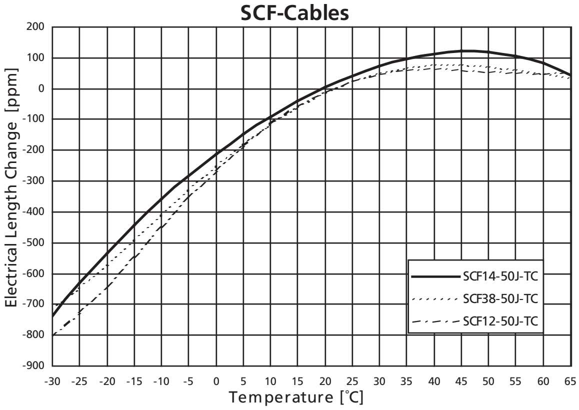
LCF-Cables



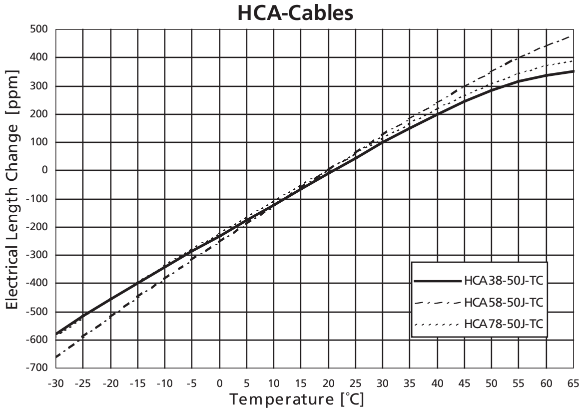
LCF-Cables



SCF-Cables



HCA-Cables



The phase change for a given cable length and temperature range can be calculated with equation(25).

$$\Delta\varphi = 120 \cdot 10^{-6} \cdot \frac{1}{v_r} \cdot \Delta ppm \cdot f \quad \text{in Deg} \qquad (25)$$

l	- cable length	in m
v_r	- relative propagation velocity	in %
Δppm	- electrical length change	in m
f	- frequency	in MHz

Example:
A 10 m run of LCF12-50 is used in the temperature range from -10°C to 40°C (14°F to 104°F) at 1 GHz.

In the above diagram the Δppm of approximately 280 can be read. The maximum phase change is

$$\Delta\varphi = 120 \cdot 10^{-6} \cdot \frac{10}{88} \cdot 280 \cdot 1000 = 3.8°$$

Attenuation

The attenuation of RF cables is defined as follows:

$$\alpha = 10 \cdot \log(P_1 / P_2) \quad \text{in dB/100 m} \qquad (26)$$

P_1 - input power into a 100 m long cable terminated with the nominal value of its characteristic impedance

P_2 - power at the far end of this cable

The construction of a cable influences the attenuation (in the case of copper conductors and at 20°C [68°F]) in accordance with the following equation:

$$\alpha_{20} = \frac{36,1}{Z_c}\left(\frac{k_i}{d_e} + \frac{k_a}{D_e}\right) \cdot \sqrt{f} + 9,1 \cdot \sqrt{\varepsilon_r} \cdot tg\delta \cdot f$$
$$= \alpha_R + \alpha_G \quad \text{in dB/100 m} \qquad (27)$$

Z_c	characteristic impedance in ohm
f	frequency in MHz
D_e	electrically equivalent outer conductor diameter in mm
d_e	electrically equivalent inner conductor diameter in mm
ε_r	relative permittivity of dielectric
$tg\delta$	loss factor of dielectric
k_i	shape factor of inner conductor
k_a	shape factor of outer conductor

The attenuation values are stated for 20 °C (68°F). The stated figures are typical. With rising ambient temperature the attenuation also rises, by 0.2% K. The attenuation also rises if the cable is heated up by the transmitted power. The maximum rise is as follows:

HELIFLEX® cable with PE dielectric $\alpha_t/\alpha_{20} = 1.14$

HELIFLEX® cable with PTFE dielectric $\alpha_t/\alpha_{20} = 1.20$

CELLFLEX® cable $\alpha_t/\alpha_{20} = 1.12$

α_t - attenuation of the cable at full mean power rating

Finally, attenuation rises in case of considerable mismatches at the cable end. The effect is illustrated in Fig. 1. The cable is assumed to be matched at the transmitter. The curve parameter is the total cable loss in dB.

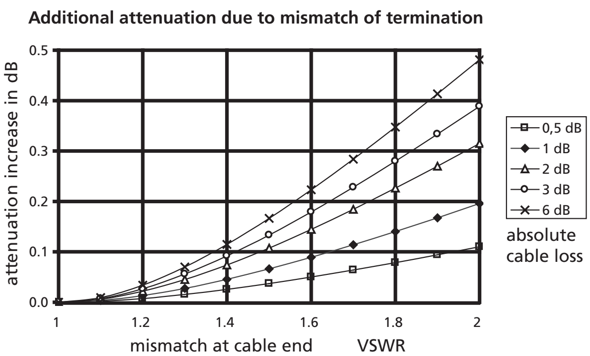


Fig. 1 Attenuation increase due to mismatch at cable end (with cable matched at transmitter end)

The attenuation of RF cables is mainly resistive attenuation α_r, which rises with the square root of frequency. For a given cable size and impedance, the resistive attenuation reaches a minimum for a dielectric constant of 1 (air dielectric) as the inner conductor size reaches a maximum. Resistive attenuation also decreases with increasing cable size.

Dielectric attenuation rises proportionally with frequency. It is independent of cable size and determined only by quantity and quality of the dielectric material. Its share in total attenuation rises with frequency and cable size. Therefore, in particular the larger HELIFLEX® cable sizes have a very low material content dielectric. The same fact also prompted the introduction of loss foam CELLFLEX® cables (LCF).

Efficiency

The efficiency of a cable is the ratio between the power available to a load at the far end of the cable and the power put into it at the near end and is therefore an important parameter to compare several feeder cables.

$$\eta = \frac{P_2}{P_1} = 10^{-\left(\frac{\alpha_t \cdot \frac{l}{100} + A_r}{10}\right)} \qquad (28)$$

P_2 - power at load

P_1 - input power

α_t - attenuation of cable (taking into account additional attenuation due to the power being used) in dB/100 m

A_r - additional attenuation through mismatch at cable end (see Fig.1)

l - cable length in m

Power Rating

Power rating is the lower of the following two values: peak power rating and mean power rating.

Peak power rating

Peak power rating is the input power for which the peak RF voltage rating is reached, when the cable is operating in its matched condition. It is defined as:

$$\hat{P} = 500 \cdot \frac{\hat{U}}{Z_c} \quad \text{in kW} \qquad (29)$$

$\hat{U}$ - RF voltage rating (peak value) in kV

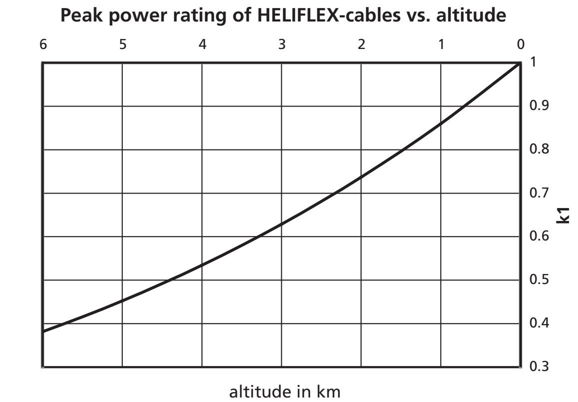
Z_c - characteristic impedance in Ω

Peak power rating is independent of frequency. The stated values for peak RF voltage rating and peak power rating of HELIFLEX® cables are valid for dry air or dry nitrogen under normal atmospheric pressure. RF voltage rating and peak power rating of HELIFLEX® cables are valid for dry air or dry nitrogen under normal atmospheric pressure.

As production testing of RF cables is done with DC voltage of twice the peak RF voltage rating, there is a safety factor of 2 in voltage and a safety factor of 4 in peak power rating.

Peak power rating of HELIFLEX® cables can be increased considerably by operating them under inner overpressure (suitable connectors for this operation are available for cable, sizes 3¨ and larger). Peak power rating decreases with altitude, if the cable inner is allowed to assume the pressure of the environment, see. Fig. 2.

Although CELLFLEX® cables due to their dielectric type have a higher voltage strength than air dielectric cables, in practice the short sections of air line present at the cable ends when terminated with commonly used connector types limit the peak voltage ratings of CELLFLEX® cables to those of equivalent size air dielectric cables.



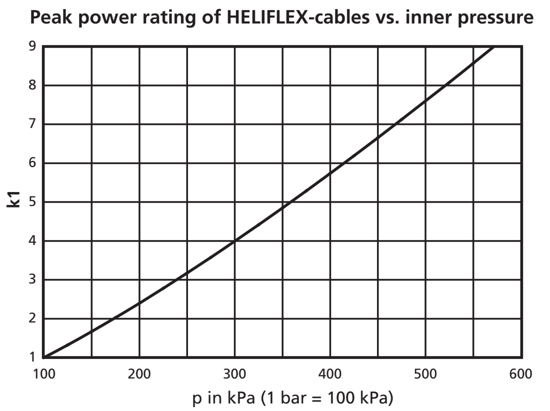


Fig. 2 Peak power rating of HELIFLEX® cables Factor k1 versus inner pressure and altitude

Mean power rating

Mean power rating is defined as:

$$P_{\max} = \frac{0,8686 \cdot P_v}{2 \cdot \alpha_t} \quad \text{in kW} \qquad (30)$$

P_v - maximum admissible power dissipation in W/m

α_t - attenuation under operation condition in dB/100 m

Mean power rating is the input power at which the inner conductor reaches a temperature agreed for a certain dielectric material. For most of the RFS cables these are:

HELIFLEX® (PTFE) 150°C (302°F)
HELIFLEX® (PE) 115°C (239° F)
CELLFLEX® 100°C (212°F)

Mean power rating decreases as frequency rises.

Mean power rating values are given for the following conditions:

- installed in still air of 40°C (104°F)
- in case of HELIFLEX® cables, filled with air or nitrogen, under normal atmospheric pressure.

The variation of mean power rating with ambient temperature is given in Fig. 3.

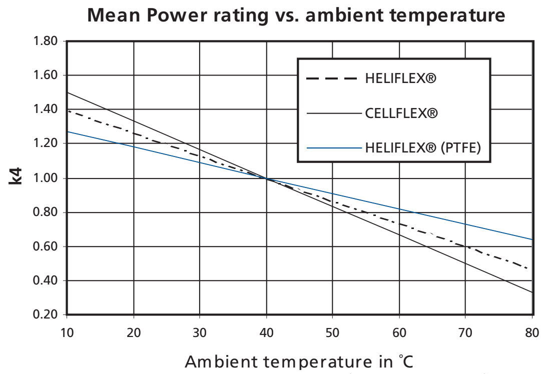


Fig. 3 mean power rating Factor k4 versus ambient temperature

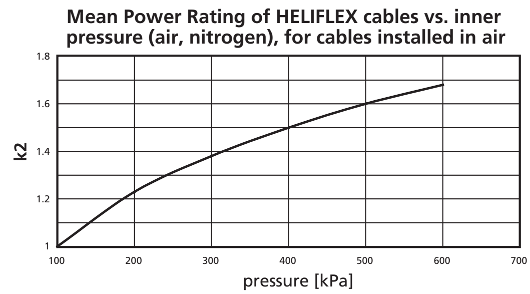


Fig. 4 Mean power rating of HELIFLEX®cables Factor k2 versus inner pressure (air, nitrogen) for cables installed in air

If RF cables are subjected to direct solar radiation, mean power rating will decrease. The derating factor is given in Fig. 5.

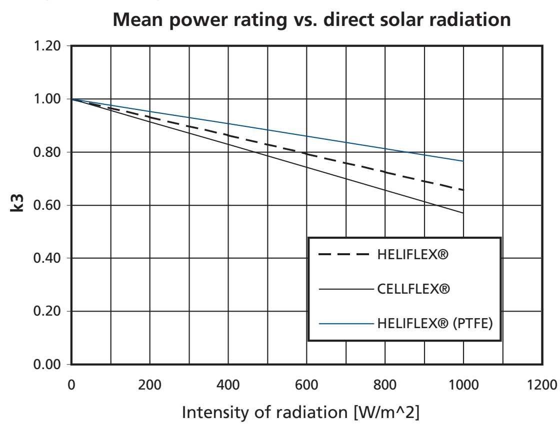


Fig. 5 Influence of direct solar radiation on mean power rating Factor k3. Worst case: cable fully exposed and perpendicular to sun rays

For mean power calculation of cables to be buried in the ground, the heat resistance of the cable jacket to air combination is replaced by the heat resistance of the soil, and the ambient temperature is replaced by the average soil temperature at the proposed cable laying depth.

As the heat resistivity of the soil is very dependent upon local conditions such as humidity and type of soil, and since the soil in the vicinity of RF cables which dissipate large heat power tends to dry out, it is necessary to have the correspondent information from the list given below.

Generally, it can be said for normal kinds of soil in moderate climates, that mean power rating of smaller cable sizes (if buried) increases whereas in the case of larger cable sizes it decreases.

If a buried, large cable is operating under inner overpressure, mean power rating doesn't increase as much as if this cable would be installed above ground.

When planning an RF cable system the following Data should be known:

Installation location details:

- height above sea level
- ambient temperature and intensity of solar radiation
- ground temperature, soil type and ground water level

Installation details:

- cable to be laid in masts, above-ground, in-ground or in ducts
- pressurization permissible
- heat dissipated by parallel cables
- connector types

Operating conditions:

- number and length of cables
- frequencies and permissible attenuation
- transmitter peak and average output power ($\hat{P}$ and $\bar{P}$)
- or the information to calculate these data, as given in Fig.6 antenna VSWR (s)

Power considerations summary

If the cable end is not terminated in its characteristic impedance, standing waves along the cable will result in higher power being dissipated at current and voltage maximums. Input power must, therefore, be reduced accordingly. In summary, therefore, the following conditions must be fulfilled when selecting a cable size for a certain power configuration.

$$\hat{P}_{max} \geq \frac{\hat{P} \cdot s}{k_1} \quad (31)$$

$$\bar{P}_{max} \geq \bar{P} \frac{s}{k_2 k_3 k_4} \quad (32)$$

$\hat{P}, \bar{P}$ - peak power and mean power of transmitter

$\hat{P}_{max}, \bar{P}_{max}$ - peak power rating and mean power rating of cable

s - VSWR

k_1 - peak power rating factor for inner pressure (Fig. 2)

k_2 - mean power rating factor for inner pressure (Fig. 4)

k_3 - mean power rating factor for direct solar radiation (Fig. 5)

k_4 - mean power rating factor for ambient temperature (Fig. 3)

For cables operated above half their cut-off frequency in a non-matched condition, heat compensation between the extreme values of temperature along the cable can be expected. In this case, the VSWR in equation 32 may be replaced by the term:

$(s^2 + 1) / 2\,s$

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If peak and average transmitter output power are known only in terms like carrier power, modulation depth etc., then these data can be computed as follows:

$$\hat{P} = P_R \cdot \hat{q} \quad (33)$$

$$\overline{P} = P_R \cdot \overline{q} \quad (34)$$

P_R - reference power of transmitter

$\hat{q}$ - factor according to Fig.6

$\overline{q}$ - factor according to Fig. 6

If several programs with peak power values P_1, P_2, etc., are transmitted simultaneously, then the resulting peak power is as follows:

$$\hat{P}_{res} = (\sqrt{\hat{P}_1} + \sqrt{\hat{P}_2} + \dots\dots\dots)^2 \quad (35)$$

Maximum operating frequency and cut-off frequency

Energy transmission in a coaxial RF cable takes place in the normal coaxial wave mode. Above cut-off frequency, which is a function of cables dimensions, other wave modes can also exist and the transmission properties are no longer defined. It is, therefore, generally not possible to operate RF cables above their cut-off frequency. An approximate value of cut-off frequency and the cut-off wavelength for RF cables can be computed as follows:

$$f_c = \frac{1,91 \cdot v_r}{D_i + d_a} \text{ in GHz} \quad (36)$$

$$\lambda_c = \pi \frac{D_i + d_a}{2} \cdot \frac{10}{1 \cdot v_r} \text{ in m} \quad (37)$$

v_r - relative propagation velocity in %

D_i - inner diameter of outer conductor in mm

d_a - outer diameter of inner conductor in mm

In addition to cut-off frequencies, maximum operating frequencies of RF cables are stated. These give a certain safety margin from cut-off frequency. For some cables the maximum operating frequency is determined by other construction criteria and may then significantly deviate from cut-off frequency.

Measurements

If no alternative arrangements have been made, then measurements of the electrical properties of RF cables are made in accordance with IEC 61196-1: Radio-Frequency-Cables; Generic specification - General definitions, requirements and test methods.

MODULATION	REFERENCE POWER P_R	$\hat{q}$	$\overline{q}$
amplitude modulation	carrier power	$(1+\hat{m})^2$	$1+\frac{\overline{m}^2}{2}$
frequency modulation	transmitter power	1	1
pulse modulation	pulse power	1	$t_p \cdot f_p$
television (CCIR Standard)	peak sync. Power	1.73 [1]	0.71 [1]
		1.50 [2]	0.66 [2]
DAB OFDM	sum power	10 [3]	1
DVB OFDM	sum power	10 [3]	1

Fig. 6

[1] audio to video power ratio 1:10
[2] audio to video power ratio 1:20
[3] Depending on the number of carriers, the theoretical value of can be very high. In practice, it is limited to about 10 by saturation effects of the transmitter output amplifier.

$\hat{m}$ - peak modulation depth
$\overline{m}$ - mean modulation depth
t_p - pulse length in µs
f_p - pulse repetition frequency in MHz

Base Station Antenna Systems

Definitions

Propagation

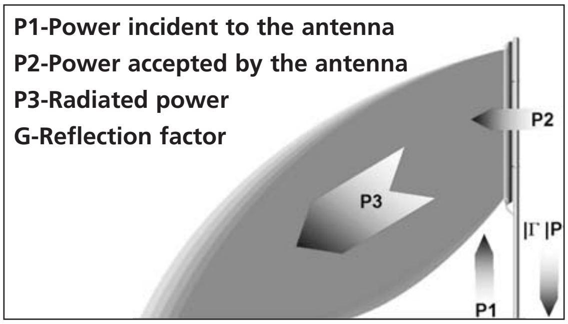
Need: The aim of telecommunications is to transmit, from one point to another, a signal carrier of an information.

Medium: Propagation of electromagnetic energy between a transmitter and a receiver.

Modes: Propagation in free space (without physical medium).

Antenna

Interface permitting to convert an electrical current into an electromagnetic field defined by its frequency, amplitude, and polarization. The antenna allows (in a reciprocal way) either to radiate, or to collect the energy, in a given direction. The radiation is optimal for radiating element dimensions comparable to the wavelength what is determining the antenna dimension regarding to a certain set of specifications.



Dipole

Radiating element.

Network of Dipole

Allow to reduce the vertical opening angle, as a consequence focalizing the energy and increasing the gain.

Butterfly Dipole

2 slants (+/- 45°)

- 2 polarization in one element

Perfect symmetry

- No squint

Full modularity 900/1800/UMTS

Extreme compactness

Simplified cabling for Intermodulation reliability

Dipole Head

To bring energy in the height of the radiating element.

Power Splitter

Associated to cables permit to share out the energy on dipoles and to build the vertical radiating diagram.

Connectors

Designed to ensure the more efficient energy transmission between the feeders and the antenna.

Chassis

Acting like a reflector, allows to design the horizontal aperture, to have an effect on the directivity, the F/B ratio, and also on the mechanical strength of the antenna.

Isotropic Radiation

Ideal case of an isolated transmitting source in space, which radiate an equal amplitude wave in an omnidirectional way.

Coupling

Express the reciprocal influence of a radiating disruptive element on its environment.

Polarization

Describe the propagation mode of electromagnetic waves, and more precisely the plane of the electro-magnetic vector. (vertical, horizontal, double, circular, elliptic...)

Double Polarization

To integrate two RX antennas in one, reduce the necessary number of antennas on site (gain of space and esthetic). With the use of duplexer, permit the integration of a TX channel.

Radiation Pattern

A diagram relating power flux density at a constant distance from an antenna to direction relative to the antenna main beam axis.

Radiation Pattern Envelope (RPE)

The envelope represent the worst values of measurements taken on the pattern test range at bottom, mid, top of the band, in both co & cross polarization, horizontal & vertical plan, over the full 360° of azimuth.

RPE Type

Omnidirectional: All directions are to be covered equally well. The horizontal radiation pattern is generally circular. The vertical radiation pattern may have some directivity in order to enhance the gain. Shaped: One of the principle plane is designed in order to have a specified type of coverage.

Bandwidth

All frequencies for which the antenna meets a given set of specifications, concerning both TX & RX band according to the standard.

RX: part of the bandwidth dedicated to the reception (Uplink).

TX: part of the bandwidth dedicated to the transmission (Downlink).

Base Station Antenna Systems

Definitions

Uplink

Transmitting direction from the mobile to the BTS.

Downlink

Transmitting direction from the BTS to the mobile.

Fading

The existence of various type of obstacles, generate reflections and diffraction of the transmitted wave. The uplink suffer generally of wide amplitude variations: Shadowing / path loss / multi-path propagation. The received signal is summation of several rays, sometimes leading to cancellation (regarding to the phase), which causes a drop call.

Multipath propagation

The mobile and environment moving induce a discrepancy on received signal frequencies.

Analog signal: intermodulation noise.

Digital noise: increase of the bit error rate.

Diversity Definitions

Solution designed in view of improving the drop call

Space diversity

Horizontal separation of 2 antennas for receive path.

Drawbacks:

Visual impact, heavy and expensive platform, large space requirement.

Benefits:

- Optimum gain for wide area.
- Normal spacing = l
- 6 m (20 ft) spacing in 800-900 MHz
- 3 m (10 ft) spacing in 1800-1900 MHz

Polarization diversity

Reception on perpendicular radiating elements (cross pol antenna): physical spacing no longer needed. May be associated to the cross polarization discrimination.

Horizontal/Vertical slants –

Drawbacks:

Problem to achieve good isolation between each ports. Unbalanced RX signal reduce polarization diversity. No possible Horizontal transmit.

Benefits:

- Optimal Vertical transmit
- +/- 45° slants –

Drawbacks:

Worse propagation in free space.

Benefits:

- Full RX TX equivalent propagation.
- Equivalent mean signal.
- H /V polarized coverage equivalent

Signal's Selection –

Selection diversity (Best SNR)
Maximum ratio (Amplitude or phase, or both)

Downtilt Definitions

Control of the signal such as the focus is below the horizon. Downtilt can be potentially achieved mechanically, electrically or with a combination of the two. Associated to the RET system, Downtilt could be done remotely. Downtilt improves coverage close to the site, reduce the cell site radius & interferences.

Mechanical downtilt / uptilt

Achieved by the mounting hardware.

Drawbacks:

Weaker mechanically, non-regular coverage reduction, notch effect in main direction, interference reduction in main direction only, not good for visual impact.

Benefits:

- Adjustment on site.

Electrical downtilt

Fixed electrical tilt –

Drawbacks:

Total freedom on site only with tuneable tilt.

Benefits:

- All lobes equally tilted
- Equal reduction of all interferences
- Regular reduction of coverage
- Best solution for visual impact
- Good mechanical withstanding

Variable electrical tilt –

Benefits:

- Easy cell size tuning according to capacity evolution
- Full network planning freedom.
- Keep low interferences
- Prevent change of antenna
- IMP free antenna providing no additional galvanic contact thanks to the dielectric built in VET system.

Remote electrical tilt –

Benefits:

- RET will provide interference mastering.
- Reduction of cells overlapping.
- Coverage versus Capacity easy adaptation.
- Fine Cell's tuning without sending crew on the site.
- Control of non accessible sites.
- Reduction of Network Optimization's cost.
- No limitation on frequency of tuning.
- Compatible with future dynamic capacity allocation

Definitions

Side by Side Configuration

Dual band application

2 single band antennas placed closed together in a single radome.

Benefits:

- Reaches the better performance on each band.
- Efficient interband isolation performance.
- Manages the external aspect.

Air combining application

Allows 3 dB saving in power budget.
2 identical antennas in view of having a thinner horizontal beamwidth. (Generally 2 times thinner than the HPBW obtained with a single band one).

Concentric cell application

2 antennas with the same gain, but different tilts (for different coverage policy).

Side sharing application

Different range of GSM1800/1800, PCC1900/1900, GSM1800/UMTS, UMTS/UMTS solution in order to manage site reuse between various operators, without site extra-negotiation.

Tower Mounted Amplifier (TMA)

Benefits:

- Fewer cell sites by increasing cell size.
- Improved coverage.
- Reduction of drop call.
- Improve uplink power budget – leads to a longer handset battery life size
- Compatible to all BTS providers.
- High reliability.

Base Station Antenna Systems

Antenna Types

Single band

Antenna developed for the coverage of one particular standard.
Optimized for the narrow band requirement.

Broad band

Antenna developed for the coverage of at least two different standards. Approached as a compromise due to the larger band aspect.

Multi band

Several dipole networks cohabiting in the same chassis: Dual band / Triple band antennas.

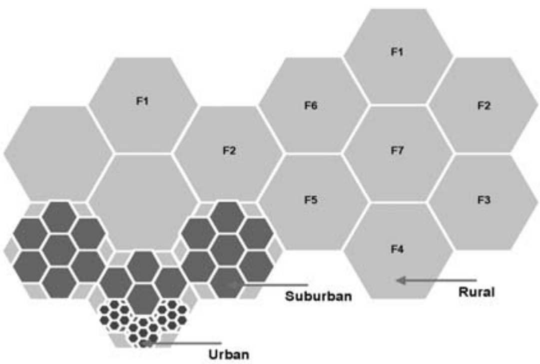
Network Planning

Cellular systems

The approximation of each cell represents a hexagon.

Low Power of transmitters induce:
- A limited range.
- Space split in elementary cells.

Reducing interferences induce:
- Space between frequencies.
- (limited spectrum/frequency reuse/large number of cells).



Deployment

Depends on:
- The number of simultaneous communications to sell.
- The relief of the covered area.

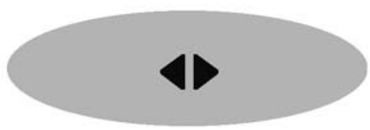
Omnidirectional site

1 dipole radiating isotopically, 360° beamwidth.

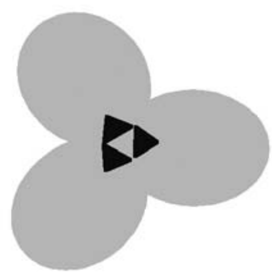
Bidirectional Site

1 helicoidal, or 2 panel antennas placed in opposite directions (with shaped horizontal beamwidth).

Trisectorial Site



3 Panel antennas separated by 120°



Technical Notes

Horizontal Radiation Pattern Parameters

Half power beam width (HPBW) [°]:

The angle, relative to the main axis, between the two directions at which the co-polar pattern is 3dB below the value on the main axis. The values are nominal and stated as the minimum for the frequency range.

1. Horizontal opening angle [°]:

HPBW in the horizontal plan. Gives the coverage geometry. Tolerance about +/- 5°.

2. Squint [°]:

Natural distortion of the horizontal pattern outcoming in a dissymetry compared with the main axis.

3. Horizontal tracking [dB]:

Natural horizontal pattern dispersion versus a frequency sweep. Specified at 3dB below the value on the main axis.

4. Co-polarization:

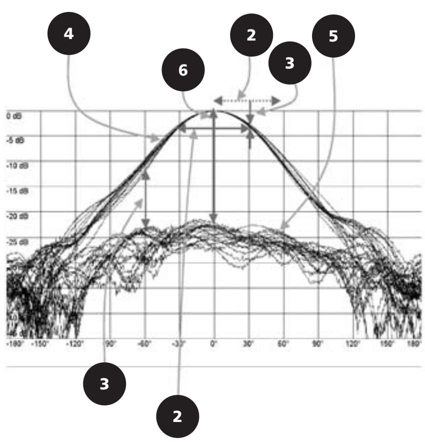
Horizontal diagram of the considered polarization. The co-polarization measurement correspond to the signal received by one dipole slant with the same polarization than the transmitter.

5. Cross-polarization:

Orthogonal diagram to the considered co-polarization. Unwanted radiated energy in a polarization which is different from the polarization in which the antenna was intended to radiate. For linearly polarized antennas, the cross-polarization is perpendicular to the intended polarization.

6. Cross-polarization discrimination [dB]:

The difference between the co-polarized main beam gain and the cross-polarized signal measured within an angular area in azimuth of twice the maximum HPBW of the frequency band. Better is the cross polarized discrimination, lower is the level of disturbing signal (coming from the opposite slant), in order to insure a safer reception. Measured both in the main axis and at 60° opening angle.



Vertical Radiation Pattern Parameters

Vertical opening angle [°]:

HPBW in the vertical plan. Gives coverage quality. Tolerance about +/- 0.5°.

Directivity:

D (dBi) = 10 log [27000/(Ov x Oh)]
Ov: Vertical opening angle
Oh: Horizontal opening angle

Effectiveness in focusing energy in a given direction.

Gain [dBi]:

G (dBi) = D (dBi) – estimated loss (dB)
The ratio of the radiation intensity in the main beam axis to the radiation intensity that would be obtained if the power accepted by the antenna were radiated in all directions. Gain is reciprocal, either transmitting or receiving. Practical value integrating internal losses and efficiency, specified as maximum in the main axis.

G (dBi) = G (dBd) + 2.15
dBi: expresses the gain as compared to radiating point.
dBd: expresses the gain as compared to radiating dipole.

1. Lobes suppression [dB]:

Secondary lobes are undesirable because of the direct relation with energy losses.

2. Upper side lobe suppression [dB]:

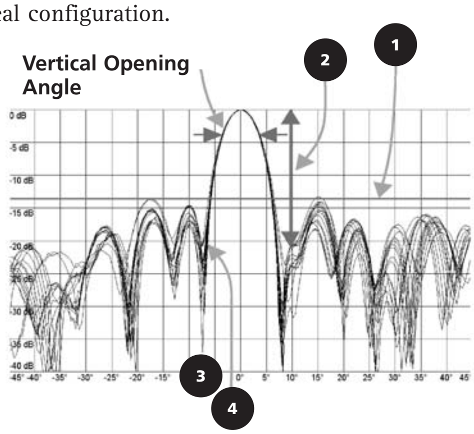
Suppression of the closest lobe to the horizon (adjacent to the main beam) critical for interferences mastering. The USLS impacts the frequency reuse and enhance noise rise in neighbor cells. The USLS is referred to the main beam. The smaller the magnitude of the USL, the larger will be the number of dB down.

3. 1st null:

First minimum corresponding to the lower side lobes adjacent to the main beam.

4. 1st null fill:

Trick allowing to reduce coverage attenuations due to the 1st null. Naturally filled by fading and multipath in real configuration.



Base Station Antenna Systems

Technical Notes

Other Parameters

Voltage standing wave ratio [VSWR]

Capacity of the antenna in radiating the energy without reflecting a part towards the BTS. Faculty of antenna impedance matching to system impedance. Value guaranteed across the frequency band of operation.

Impedance [Ω]

Fundamental electrical parameter allowing the complete adaptation between the antenna and the feeding system. Fixed as a standard at 50Ω.

Front to back ratio [dB]

- Denotes the highest level of radiation relative to the main beam in an angular area of 180o +/- 40o.
- Allows the evaluation of losses at the rear side of the antenna
- Controls back interferences
- Reduces site coupling.

Isolation between access [dB]

Denotes the ratio in dB of the power level applied to one port of a dual polarized antenna to the power level received in the other input port of the same antenna. Quantity of energy received by one port when the other port is supplied.

Power max [W]

Maximum power bearable for an antenna, without degradation of the feeding system, or radiating elements.

Intermodulation [dBc]

Spurious and unwanted signal issued from a non linear device or material, that could make the wanted signal difficult to be identified.

Several combinations of two carrier frequencies are generated, and occupy the frequency ranges that are used by an other service. Could consequently disturb the low receive signal. Become a criteria reflecting the quality of the product. Measured relatively to the carrier.

Survival wind speed [m/s]

The antenna should survive the specified wind speed without any permanent deformation or changes of shape. Depends essentially on the surface area of the radome.

Wind load [N]

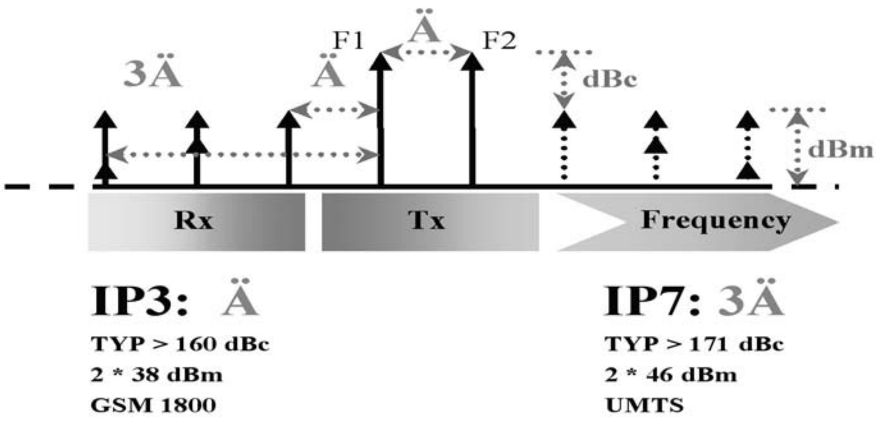
F= rair x V x 8 x C/2

rair: Air density (kg/m= ≈)

V: Wind speed (m/sec)

8: Surface area (m= ≈)

C: 4th coefficient



Technical Notes

Filters

Filters are important passive RF devices that perform selective frequency discrimination. As a class, filters also include duplexer and cavity resonators. Filters are designed to pass a band of frequencies, reject a band, or to combine those actions.

Four prime filter characteristics of concern to the system designer are insertion loss, attenuation, bandwidth, and selectivity. Each must be considered carefully in the selection of a filter product in order to ensure satisfactory system performance.

Insertion loss and attenuation

Both represent reduction of available signal power after filtering. Generally speaking, the designer selects the filter with the least loss and the most attenuation consistent with other application requirements.

Although one may discuss loss directly in terms of Watts, it is common practice to use the Decibel to express the ratio of power output to power input. Using Decibels makes insertion loss and attenuation performance characteristics independent of the actual powers or voltages in use.

The Decibel (abbreviated dB, where the B is in honor of Alexander Graham Bell) is computed as 10log (Pout/Pin). where log is the common logarithm function (base 10). Pout is the measured output power from the filter; Pin
is the measure of power input to the filter. A few useful ratios and their corresponding Decibels are tabulated on the following chart.

Decibel Loss =	Power Loss
0.5 dB	10.8%
1.0 dB	20.5%
2.0 dB	36.9%
3.0 dB	50.5%
10.0 dB	90.0%

As may be seen from the table, the often-heard expression “half-power point” signifies that spot on the response curve where the output power has been reduced by 3 dB, regardless of the actual power level.

Insertion loss is the amount of power unavoidably absorbed by the filter. It’s an unintended side effect... a “cost of doing business” with the filter. In the band pass region of the filter’s response curve, this figure sets the maximum amount of desired signal passed through to the output after processing. There are practical lower limits on insertion loss, around 0.5 dB. A 3 dB insertion loss, for example, spends half your power in the filter. Sometimes a relatively high amount is unavoidable, as in transmitter combiners.

More on attenuation

Attenuation is also power absorbed by the filter as an intentional benefit. It applies to band rejection, and is the extent to which the undesirable signal is blocked from the filter’s output. This is a key parameter in duplexers, whose task is to prevent transmitter power from entering the receiver’s input.

Some filters offer up to 100 dB or more attenuation, a very significant reduction in the unwanted signal. For repeater service, consult the radio manufacturer’s data sheet for recommended attenuation required.

Isolation

Isolation is the amount of attenuation between named ports of a filter. For example, a duplexer specified as having 80 dB of attenuation between the receiver port and the transmitter port may be said to have 80 dB port-to-port isolation.

Bandwidth

The amount of frequency spectrum within the insertion loss points specified of a filter’s response curve is defined as the filter’s pass bandwidth. In most cases this will be significantly less than the 3 dB bandwidth of the filter. If the filter has a complex response curve, there may be one or more pass bandwidths and reject bandwidths associated with the device.

Selectivity

The shape of the filter’s response curve defines the filter’s selectivity characteristics. Sharp curves with steep “skirts” have relatively narrow bandwidths, and are considered highly selective. A relatively wide bandwidth has broad selectivity. Each selectivity extreme has utility for a given set of circumstances facing the system designer.

Types of filters

Types of filters available to the designer include low pass, high pass, band pass, and band reject filters.

Low pass filters attenuate radio frequency energy above a certain cutoff point. In other words, they pass low. A typical use of a low pass filter involves suppressing the unwanted second harmonic and others above it from a transmitter. For example, a transmitter designed for 27 MHz service will generate a second harmonic at 54 MHz and, to a lesser extent, higher multiples. A good low
pass filter will only permit the 27 mHz energy to reach the antenna, thus preventing interference with other radio services.

High pass filters attenuate radio frequency energy below a certain cutoff point. These filters pass high. They are the electrical mirror image of low pass filters.

RF Conditioning

Technical Notes

Band pass filters pass a band of frequencies between specified low and high frequency cutoff points. RF energy above and below these cutoff frequencies is attenuated. Bandpass filters find wide application in land- mobile communications work. A typical application involves high power paging transmitters, where digital modulation tends to create adjacent channel interference with nearby receivers. Use of a band pass-style filtering device (usually a cavity resonator) will “sharpen” the paging transmitter’s RF output spectrum, permitting only the energy in the immediate vicinity of the carrier to be radiated from the antenna.

Band reject filters block, or “notch out” a band of frequencies between specified low and high frequency cutoff points. These devices are the electrical mirror image of band pass filters. RF energy below and above the cutoff points is passed to the filter output. Band reject filters also find wide application in the land mobile industry. As in the paging transmitter example, receivers with insufficient inherent selectivity that experience such interference can be outfitted with a notch filter adjusted to the offending transmitters frequency, which effectively eliminates the interfering signal. Sometimes filters are required on both radios to completely solve interference problems at a site.

Cavities

Resonant cavities

Successful commercial products are usually based on one of three basic designs: helical, transverse electromagnetic (TEM), and waveguide. In most common use at this time are the helical and TEM styles.

TEM cavities

TEM cavities are usually built as quarter- or three-quarter-wavelength resonators, with the long design used for low loss, high selectivity applications. The Q or quality factor of a TEM cavity increases as the diameter is increased to a limit point, depending upon the conductivity of the materials used in its construction. Silver plating can be applied to improve the cavity’s Q.

Frequency stability of a TEM cavity can be precisely controlled by incorporating an invar rod for tuning the inner conductor. Invar, with its low coefficient of expansion vs. temperature, allows the cavity to be tuned over a wide range of frequencies while the length of the tuning rod remains nearly constant over an extended range of ambient temperatures. RFS product designers take full advantage of all of these techniques to offer superior frequency stability performance.

Helical cavities

Helical cavities have generally been designed for low power, low Q applications such as receiver front-ends and mobile duplexers. As with the TEM style, the Q of the helical type is proportionate to the cavity diameter. Temperature compensation in helical cavities is more difficult to control than with TEM cavities, so helical designs are not specified for narrow bandwidth requirements.

Duplexers

These products are an integration of filter sections, generally cavity resonators, and are used predominantly to facilitate duplex repeater operation utilizing a single antenna and feedline. Duplexers range in size and power handling capability from small mobile types to high-power base station units. They provide the critical isolation between receiver and transmitter that allows both to be connected to the antenna simultaneously without the need for a transmit-receive relay.

A note of caution

The cost and construction of duplexers varies with the transmit-receive frequency separation (offset) required, power handling capability, and ambient RF environmental constraints. For applications in which the offsets are relatively wide duplexers can be constructed using band pass filters. The inherent advantage of this design is that unwanted signal rejection occurs for all frequencies outside the intended pass bands, not just at the duplexer’s own transmit frequency. This duplexer design is preferred for high ambient RF environments where it provides strong defense against unwanted signals from nearby antennas.

Where the frequency offsets are closer (between about 0.5 MHz and 4.5 MHz) band reject cavities can be used to build a duplexer. This cavity style offers the benefits of high isolation and low insertion loss, but the resulting duplexer generally lacks attenuation at frequencies other than the transmit and receive frequencies specified. Consequently, this design should not be used where high ambient RF levels exist, unless other auxiliary filtering is considered.

Filter tuning

A good rule-of-thumb to remember when tuning any RF filter of the types described above: Never tune the unit under full power. Always rely upon small-signal methods using service monitors, frequency generators, calibrated receivers, etc. The reason: during the tune-up process, off-resonance conditions occur when the tuning screws are adjusted for their optimum setting. At resonance, the reactive components increase sharply, as does the corresponding voltage drop across insulating parts. High voltage drops may lead to arcing, which can leave permanent carbon traces across internal insulating material. Leakage across these traces causes instability in the filter’s tuning, and noisy duplex operation. In designs employing moving finger stock for ground contact, arcing and pitting will occur when the finer stock position is changed in the presence of power, resulting in the same deteriorated performance. Damage of this nature is generally ruinous to the filter.

UHF Television Systems Utilizing Panel Arrays

Introduction

This guide is issued by RFS as an aid for those people involved in the design of UHF TV transmitting systems. It is based on the use of broadband panel arrays incorporating the PHP and PVP panels for horizontal and vertical polarization respectively. The guide is fully supported by our professional engineers who are available to give advice as required.

The systems described herein cover 1 to 16 bay antennas. Large arrays almost always require special engineering considerations which cannot be incorporated here, but the information provided is intended to cover the broader system aspects of panel array design. Please consult our engineers for further information and assistance.

Electrical Considerations

Polarization

Horizontal Polarization:

The model PHP panel is horizontally polarized. It covers all of 470-860MHz.

Vertical Polarization:

The model PVP panel is vertically polarized and like the PHP panel covers all of 470-860MHz.

Gain

All antenna systems considered here incorporate equal numbers of panels on all faces.

For such systems the peak gain of the antenna is the product of the horizontal and vertical pattern directives less any distribution losses incurred within the antenna feed system. Null fill loss is included in the vertical directivity.

So in decibels the antenna peak gain is given by:

$G_{APK} = GH + GV - LD$ dBd

where

GH = Horizontal pattern directivity (dB)
GV = Vertical patter directivity (dB)
LD = Distribution losses

For omni directional systems it is normal to consider the RMS gain which is given by:

$G_{ARMS} = GV - LD$

The distribution losses for an antenna will vary depending on the size of the array and the type(s) of distribution cables used. The latter is a function of the power handling requirements for the system. Typically, the following figures can be used for low/medium power systems.

ANTENNA SIZE	LOSS (DB)
1-Bay	0.05
2-Bay	0.1
3-Bay	0.1
4-Bay	0.2
6-Bay	0.3
8-Bay	0.3

Antennas incorporating larger distribution feeder and/or operating at lower frequencies will have lower losses than those described above. Higher powered arrays larger than eight bays usually have losses of approximately 0.2dB.

Impedance and VSWR

For low and medium power arrays the input VSWR of the arrays will be better than 1.1:1 over approximately 300 MHz bandwidth or greater.

For higher power arrays the VSWR will be better than 1.05:1 on each vision carrier and better than 1.1:1 over each operating channel. Other specifications to customer requirements are available.

Power Handling Capacity

Analog Services

The average power-handling requirement of an antenna is the sum of the average input powers. The average power of a black level PAL TV picture with 10:1 vision/sound ratio is 0.71 times the peak sync power.

The average power rating is a measure of the antenna capacity to dissipate the heat generated due to losses.

V_{PEAK} = 1.4 divided by Ppeak x 50

For low and medium power arrays the average power rating will be generally limited by the size of the input power divider as follows:

7/8” EIA:	2kW average
1-5/8” EIA:	5kW average
3-1/8” EIA:	12kW average
4-1/2” IEC	36kW average
6-1/8” EIA	55kW average

For high power arrays the average power rating can be limited by any part of the distribution system or the panels and will vary depending on the configuration of the array. Input connectors are usually 4-1/2” IEC or 6-1/8” EIA. 7-3/16” EIA and larger inputs are available on request.

Broadcast Antenna Systems

UHF Television Systems Utilizing Panel Arrays

The peak power rating is a measure of the voltage breakdown or flashover point of the antenna. It is common to express peak power rating in terms of the peak voltage rating. Generally the peak power handling capacity will not be a limiting factor in the antenna design, however it needs to be checked especially where there are a large number of input channels.

The peak power handling requirement of an antenna will be PPK = 1.4 n2 PAV where n = the number of input channels and PAV is the average power input per channel where all channels are of the same power.

Digital Services

Because of the much higher peak to average power ratios of digital services the peak power ratings are far more significant than for analog services. Digital services are rated using the peak power. The total power is the sum of the peak powers of the digital services.

System Losses

The system design must take account of losses incurred by the main feed cable(s) and any internal plant equipment such as combiners and switch frames.

Feeder Losses

The attenuation figures for Heliflex flexible coaxial transmission line can be found on the relevant specification pages of this catalog. This technical information section also contains a good explanation of how the specifications are derived.

Combiner Losses

Combiner losses vary according to the type of combiner used, frequency spacings between channels transmission line sizes utilized and the number of channels to be combined.

For the purposes of this guide it will be assumed that the frequency spacing is 3 channels and that between two and six channels will be combined.

Two different constant impedance combining systems are used: commutating line and balanced (bandpass filter). The former is commonly used for 2, 3 or 4 channel systems. The latter is used for any number of channels. The commutating line devices are less expensive however they generally have higher losses especially at close frequency spacing.

Typical Combiner Losses (per channel, 21 MHz spacing)

Commutating Line Combiner (CUC Series):

INPUT CONNECTOR	N	1-5/8"	3-1/8"	4-1/8"
2 channels Loss (dB)	0.7	0.4	0.3	0.25
3, 4 channels Loss (dB)	1.3	0.6	0.45	0.4

Bandpass Filter Combiner (CU Series):

INPUT CONNECTOR	1-5/8"	3-1/8"
First Channel Loss (dB)	0.4	0.3
Additional Channels Loss (dB)	0.1	0.1

Switch Frame Loss

If a switch frame is incorporated in the system allow 0.1dB insertion loss.

Internal Rigid Line Loss

Allowance should be made for any internal rigid line (or jumper cables) between the transmitter and any switch frames, combiners and main feed cables.

Rigid line losses are as follows.

LINE SIZE	1-5/8"	3-1/8"	4-1/8"
Loss dB/100m at 500 MHz	1.6	0.8	0.55
Loss dB/100m at 800 MHz	1.95	1.0	0.70

Typical Performance Summary

An example of a system performance summary of an 8 channel directional system as shown in the table below for a low power site. (only 3 of the 8 channels are included). The antenna directivity shown is the sum of the horizontal and vertical pattern directivities.

Typical System Performance Summary

FREQUENCY, MHZ	813-820	750-757	547-554
Antenna Directivity, dBd	15.9	16.8	17.4
Antenna Losses, dB	0.3	0.3	0.3
Feeder Loss (50m of HF 1-5/8"), dB	0.95	0.90	0.75
Combiner Loss, dB	0.5	0.8	0.9
U Link panel and rigid line loss, dB	0.2	0.2	0.2
10m of HF 7/8" internal feeder, dB	0.35	0.33	0.28
System Peak Gain, dBd	13.6	14.3	15.0
Peak ERP (5kW), kW	5.0	5.0	5.0
Tx Power, Watts	218	187	159

UHF Television Systems Utilizing Panel Arrays

Mechanical Considerations

Support Columns

Standard support columns are available for 1 to 16-bay systems for both cantilever and side-mounting. They are made of hot dipped galvanized steel.

Columns up to eight levels are provided as a single piece. Six and eight level columns may be provided as an option in two modules to facilitate ease of transport and installation. Columns above eight levels are always provided in modules.

Small arrays can be pole mounted.

Ladders

On cantilever columns external ladders can be provided to allow external access to the antenna for horizontally polarized systems. For vertically polarized systems climbing spikes are available. Internal ladders are usually incorporated into all columns.

Pressurization

All feed systems are pressure-tight to the panel inputs. It is strongly recommended that these systems be pressurized with dry air to inhibit the ingress of moisture. Pressure is supplied via the main feed cable. Recommended operating pressure is in the range 20-35kPa.

All pressure-tight components are tested in the factory at 70kPa. The entire antenna system is also pressure-tested.

Lightning Protection

Cantilever columns are provided with one or two 1.5m long lightning spikes. The antenna system is firmly bonded to the column. On installation it is important that the column is solidly bonded to the support structure.

Shipping

Up to eight bay arrays are shipped fully assembled unless modular antenna systems are requested. Antennas are supported on steel frames for shipment.

Interface and Tower Design Considerations

As well as designing a tower capable of accommodating the weight and wind loading of the column, the physical deflection of the tower must also be limited. This is necessary because of the very narrow beam in the vertical plane. Excessive tower deflection may cause TV pictures to flutter as the signal in the viewer's direction fluctuates from the main beam to the nulls on either side in the vertical plane.

A deflection of 3/8 wavelengths (139mm at 800 MHz) is a reasonable limit for the top of the antenna at the serviceability wind speed.

The main feeder cable may be a significant weight (6-1/8" feeder weighs approximately 11kg/m) and it must be protected so it is recommended that the tower incorporates a vertical cable runway inside the tower, usually alongside the ladder.

Access is required at the base of the antenna column to commission the antenna and it is recommended that a maintenance platform be situated approximately 1.5 - 2m below the base of the antenna.

Installation Considerations

Care should be taken during the lifting operation to ensure that the feeder or antenna is not damaged.

Once the antenna has been installed it should be purged with dry air for a minimum of 6 hours to ensure that all moisture is removed. Consult the antenna handbook for the correct purging procedure.

If the antenna has dual inputs it will be necessary to equalize the main feeder cables to ensure each antenna stack is fed with the correct phase.

Balanced Combiner Modules

The balanced combiner module, also referred to as a "constant impedance" or "Lorenz" combiner comprises two 3dB couplers, two band-pass filters and a balancing load.

Balanced combiners provide the best technical performance, offering a broadband low VSWR input (hence the term "constant impedance") and good isolation performance.

A single channel signal enters via the narrow band input. This signal is split by the input 3dB coupler and passes through the band pass filters. Because of the phase relationship, the two signals enter the output 3dB coupler and are combined at the output port.

The wideband input port is isolated by the output 3 dB coupler, so the level of the narrow band input signal at this point is determined by the directivity of the 3 dB coupler. A level of 30 - 35 dB below the input level is typical.

Because the narrow band input signal passes through the band pass filters, they experience some insertion loss. This loss depends on the selectivity of the filter and also the physical size of the filters Broader filters, suitable for wider channel spacings, have lower insertion loss, and larger filters have more surface area, making them suitable for higher powers also have lower loss.

The signal entering the combiner at the wide band input port can be any frequency in the operating band except the narrow band input frequency. This signal is split by the output 3 dB coupler, and passes to the band pass filters, where the signal is reflected back to the coupler. Again, because of the phase relationship between these signals, they combine to the output port.

The balancing load absorbs any signal arriving at that point due to finite directivity of the input 3dB coupler and any signal from the wideband input that passes through the band-pass filters.

Balanced combiner modules can be cascaded to form a combiner chain, as shown in Figure 2.

The isolation between narrow band inputs in a balanced combiner chain is determined by the directivity of the 3 dB couplers and also the selectivity of the band pass filters. Generally, at least 20 dB additional isolation is obtained from the band pass filters for non adjacent channel operation, so the isolation between inputs is typically > 50dB. For adjacent channel operation, the filters provide minimal rejection at the channel edge, although the high selectivity of the filters ensures high isolation across most of the operating channels.

Particular care is required when designing balanced combiner chains, in order to keep the overall combiner system specifications within reasonable limits. For example, the VSWR at the wideband input

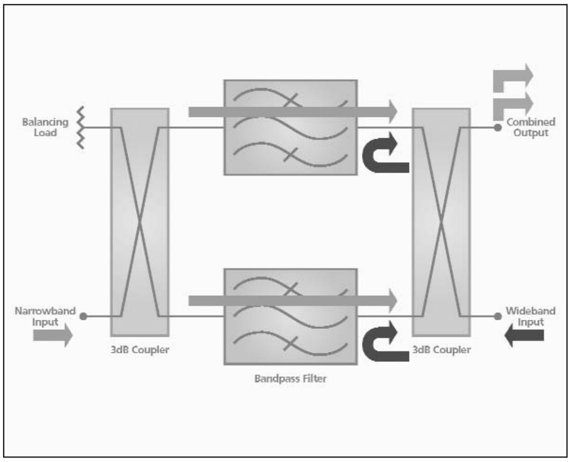


Figure 1 – Balanced Combiner Module

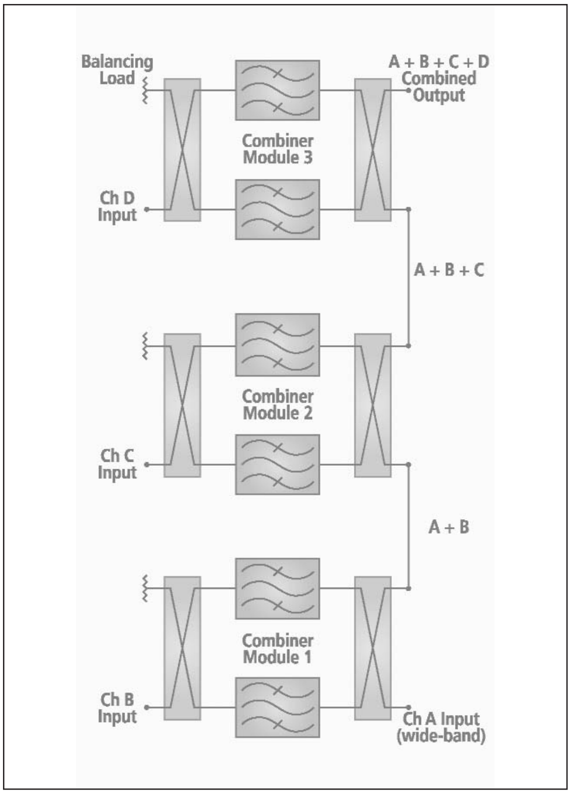


Figure 2 – Balanced Combiner Chain

of each module is cumulative, so unless the reflections from these ports are controlled, they will add in phase on some frequencies, causing very poor VSWR performance at the bottom of the chain.

RFS designs the combiner chains (usually in frequency ascending or frequency descending order) and tunes the combiner chains to obtain the quoted overall system specifications. These system specifications can differ quite significantly from the specifications of a single module because of the interaction of the various modules.

Balanced Combiner Modules

Interference (intermodulation products generated in the output stage of the transmitter) are minimized by both the isolation performance of the combiner and also the band pass filtering inherent in the combiner.

It is also possible to use the band-pass filters in the combiner to perform the DTV mask filtering function. In this case, high selectivity band pass filters are used, whether or not adjacent channel operation is required. In this case, no mask filter is required within the transmitter. This approach has the advantage that overall filtering of the signal is reduced (only one band pass filter is used), so cost and insertion loss, group delay distortion, etc. are also minimized. Consult RFS for further information, if required.

The measured isolation of the combiner after installation may differ from factory tests, owing to antenna VSWR. Generally, the difference is expected to be minor and reasonable correlation between factory tests and final performance is expected.

RFS TV Combiner Range

RFS manufactures a large range of components for virtually all required channel combining applications.

The CW series of waveguide directional combiners are for broadband high powered applications. These combiners cover a wider frequency range than traditional waveguide combiners and are also much more compact, whilst still handling very high powers, that is possible with waveguide.

For these reasons, the CW series has been employed for the most technically difficult projects, requiring very high powers and many channels within a compact space. At the Sears Tower in Chicago, no other channel combiner could be accommodated within the available space. Many combiner chains have been supplied globally, with up to 10 channels per chain.

The CA series combiners use coaxial technology - 3dB couplers and band-pass filters. RFS manufactures filters in four sizes, for various power ratings - 50 mm, 100 mm 150 mm and 200 mm (50E, 100E, 150E and 200E series, respectively). For each basic filter size, 3 pole, 5 pole and 6 pole cross-coupled and 8 pole filters are available for various channel spacings (7 pole is available for 50E series, rather than 6 pole cross-coupled).

6 pole cross-coupled and 8 pole filters are used for adjacent channel combining and for DTV mask filtering. 5 pole filters are used for 1 channel spacing and 3 pole filters are used for wider frequency spacings. 8 pole filters are also available.

The 50E series of combiners are designed as integrated combiners, with the 3dB couplers built into the filter bodies. This ensures minimum component count, reducing the cost and also ensures minimum insertion losses, as there are no discrete connections between couplers and filters.

The 100E, 150E and 200E combiners are supplied with discrete filters and couplers.

The power rating of lower order filters is higher because of the lower insertion loss, meaning that there is less heat generated.

The CA series of combiners are fully tuneable across the 470 - 860 MHz frequency range and are temperature compensated to a drift of < 2 kHz / °C.

Power monitoring is available as an option on all RFS combiners, and a directional coupler to monitor narrowband input power is standard on the 50E series.

RFS channel combiners can also be integrated into U-Link systems, ensuring low VSWR systems and compact designs. Consult RFS for further details.

Channel Combiner Design

RFS has been manufacturing channel combiners for VHF and UHF applications for more than 20 years. Many features of RFS designs have been developed to ensure the optimum technical performance:

- **Welded construction in areas of high RF current ensures high Q - low insertion losses and higher power ratings**
- **Efficient use of available space - filters are as large as possible with the design size of the combiner to ensure lowest loss, and highest power ratings.**
- **Connections between components and modules are as simple as possible to ensure minimum losses and optimum VSWR.**
- **Filters are designed in an “in line” configuration whenever power rating is important - this allows best heat dissipation and also minimizes the combiner footprint.**

RFS combiner components are modeled using sophisticated computer techniques and then tested to destruction to ensure adequate power and voltage safety factors. As a consequence, combiners can be operated at their maximum ratings for long periods of time with a high degree of confidence.

Generally, RFS combiners (except the 50E series) are designed with vertical inputs and outputs, which ensures that interconnecting rigid line is simple and easy - no additional elbows are required.

Television Channel Frequency Allocations

CH.	U.S.	EUROPE	AUSTRALIA
		Channel Limits (MHz)	
0	-	-	45 - 52
1	-	-	56 - 63
2	54 - 60	47 - 54	63 - 70
3	60 - 66	54 - 61	85 - 92
4	66 - 72	61 - 68	94 - 101
5	76 - 82	174 - 181	101 - 108
5A	-	-	137 - 144
6	82 - 88	181 - 188	174 - 181
7	174 - 180	188 - 195	181 - 188
8	180 - 186	195 - 202	188 - 195
9	186 - 192	202 - 209	195 - 202
9A			202 - 209
10	192 - 198	209 - 216	209 - 216
11	198 - 204	216 - 223	216 - 223
12	204 - 210	-	223 - 230
13	210 - 216	-	-
14	470 - 476	-	-
15	476 - 482	-	-
16	482 - 488	-	-
17	488 - 494	-	-
18	494 - 500	-	-
19	500 - 506	-	-
20	506 - 512	-	-
21	512 - 518	470 - 478	-
22	518 - 524	478 - 486	-
23	524 - 530	486 - 494	-
24	530 - 536	494 - 502	-
25	536 - 542	502 - 510	-
26	542 - 548	510 - 518	-
27	548 - 554	518 - 526	-
28	554 - 560	526 - 534	526 - 533
29	560 - 566	534 - 542	533 - 540
30	566 - 572	542 - 550	540 - 547
31	572 - 578	550 - 558	547 - 554
32	578 - 584	558 - 566	554 - 561
33	584 - 590	566 - 574	561 - 568
34	590 - 596	574 - 582	568 - 575
35	596 - 602	582 - 590	575 - 582
36	602 - 608	590 - 598	582 - 589
37	608 - 614	598 - 606	589 - 596
38	614 - 620	606 - 614	596 - 603
39	620 - 626	614 - 622	603 - 610
40	626 - 632	622 - 630	610 - 617
41	632 - 638	630 - 638	617 - 624
42	638 - 644	638 - 646	624 - 631
43	644 - 650	646 - 654	631 - 638
44	650 - 656	654 - 662	638 - 645
45	656 - 662	662 - 670	645 - 652
46	662 - 668	670 - 678	652 - 659
47	668 - 674	678 - 686	659 - 666
48	674 - 680	686 - 694	666 - 673
49	680 - 686	694 - 702	673 - 680
50	686 - 692	702 - 710	680 - 687
51	692 - 698	710 - 718	687 - 694
52	698 - 704	718 - 726	694 - 701
53	704 - 710	726 - 734	701 - 708
54	710 - 716	734 - 742	708 - 715
55	716 - 722	742 - 750	715 - 722
56	722 - 728	750 - 758	722 - 729
57	728 - 734	758 - 766	729 - 736
58	734 - 740	766 - 774	736 - 743
59	740 - 746	774 - 782	743 - 750
60	746 - 752	782 - 790	750 - 757
61	752 - 758	790 - 798	757 - 764
62	758 - 764	798 - 806	764 - 771
63	764 - 770	806 - 814	771 - 778
64	770 - 776	814 - 822	778 - 785
65	776 - 782	822 - 830	785 - 792
66	782 - 788	830 - 838	792 - 799
67	788 - 794	838 - 846	799 - 806
68	794 - 800	846 - 854	806 - 813
69	800 - 806	854 - 862	813 - 820
70	806 - 812	-	
71	812 - 818	-	
72	818 - 824	-	
73	824 - 830	-	
74	830 - 836	-	
75	836 - 842	-	
76	842 - 848	-	
77	848 - 854	-	
78	854 - 860	-	
79	860 - 866	-	
80	866 - 872	-	
81	872 - 878	-	-
82	878 - 884	-	-
83	884 - 890	-	-

VSWR CONVERSIONS

Reflection Coefficient	VSWR	Return Loss dB	VSWR	Reflection Coefficient	Return Loss dB	Return Loss dB	Reflection Coefficient	VSWR
0.005	1.010	46.0	1.01	0.005	46.1	10	0.316	1.925
0.01	1.020	40.0	1.02	0.010	40.1	11	0.282	1.785
0.015	1.030	36.5	1.03	0.015	36.6	12	0.251	1.671
0.02	1.041	34.0	1.04	0.020	34.2	13	0.224	1.577
0.025	1.051	32.0	1.05	0.024	32.3	14	0.200	1.499
0.03	1.062	30.5	1.06	0.029	30.7	15	0.178	1.433
0.035	1.073	29.1	1.07	0.034	29.4	16	0.159	1.377
0.04	1.083	28.0	1.08	0.039	28.3	17	0.141	1.329
0.045	1.094	26.9	1.09	0.043	27.3	18	0.126	1.288
0.05	1.105	26.0	1.10	0.048	26.4	19	0.112	1.253
0.06	1.128	24.4	1.11	0.052	25.7	20	0.100	1.222
0.07	1.151	23.1	1.12	0.057	24.9	21	0.089	1.196
0.08	1.174	21.9	1.13	0.061	24.3	22	0.079	1.173
0.09	1.198	20.9	1.14	0.065	23.7	23	0.071	1.152
0.10	1.222	20.0	1.15	0.070	23.1	24	0.063	1.135
0.11	1.247	19.2	1.16	0.074	22.6	25	0.056	1.119
0.12	1.273	18.4	1.17	0.078	22.1	26	0.050	1.106
0.13	1.299	17.7	1.18	0.083	21.7	27	0.045	1.094
0.14	1.326	17.1	1.19	0.087	21.2	28	0.040	1.083
0.15	1.353	16.5	1.20	0.091	20.8	29	0.036	1.074
0.16	1.381	15.9	1.21	0.095	20.4	30	0.032	1.065
0.17	1.410	15.4	1.22	0.099	20.1	31	0.028	1.058
0.18	1.439	14.9	1.23	0.103	19.7	32	0.025	1.052
0.19	1.469	14.4	1.24	0.107	19.4	33	0.022	1.046
0.20	1.500	14.0	1.25	0.111	19.1	34	0.020	1.041
0.21	1.532	13.6	1.26	0.115	18.8	35	0.018	1.036
0.22	1.564	13.2	1.27	0.119	18.5	36	0.016	1.032
0.23	1.597	12.8	1.28	0.123	18.2	37	0.014	1.029
0.24	1.632	12.4	1.29	0.127	18.0	38	0.013	1.026
0.25	1.667	12.0	1.30	0.130	17.7	39	0.011	1.023
						40	0.010	1.020

DBM - DBW - POWERS OF 10 AND PREFIXES EXPRESSED IN WATTS

dBm	dBW	Watts	Multiple	Prefix
+150	+120	1,000,000,000,000	10^{12}	1 Terawatt
+140	+110	100,000,000,000	10^{11}	100 Gigawatts
+130	+100	10,000,000,000	10^{10}	10 Gigawatts
+120	+90	1,000,000,000	10^{9}	1 Gigawatt
+110	+80	100,000,000	10^{8}	100 Megawatts
+100	+70	10,000,000	10^{7}	10 Megawatts
+90	+60	1,000,000	10^{6}	1 Megawatt
+80	+50	100,000	10^{5}	100 Kilowatts
+70	+40	10,000	10^{4}	10 Kilowatts
+60	+30	1,000	10^{3}	1 Kilowatt
+50	+20	100	10^{2}	1 Hectrowatt (100 w)
+40	+10	10	10^{1}	1 Decawatt (10 w)
+30	0	1	10^{0}	1 Watt
+20	-10	0.1	10^{-1}	1 Deciwatt (100 mw)
+10	-20	0.01	10^{-2}	1 Centiwatt (10 mw)
0	-30	0.001	10^{-3}	1 Milliwatt
-10	-40	0.0.001	10^{-4}	100 Microwatts
-20	-50	0.00.001	10^{-5}	10 Microwatts
-30	-60	0.000.001	10^{-6}	1 Microwatt
-40	-70	0.0.000.001	10^{-7}	100 Nanowatts
-50	-80	0.00.000.001	10^{-8}	10 Nanowatts
-60	-90	0.000.000.001	10^{-9}	1 Nanowatt
-70	-100	0.0.000.000.001	10^{-10}	100 Picowatts
-80	-110	0.00.000.000.001	10^{-11}	10 Picowatts
-90	-120	0.000.000.000.001	10^{-12}	1 Picowatt

HF Antenna Systems

Application Overview

Introduction

HF communication systems offer an independence that makes them unique compared to other types of communication. This has led to continued use by military forces, no matter what other means they have for communication. Personnel in embassies and consulates have also found that HF can be advantageous during times of civil disturbance. There are also many civilian applications, where the cost-effectiveness of HF provides a useful solution, particularly in remote areas.

HF communication systems operating in the range of 2 to 30MHz primarily use sky waves reflected and refracted by the ionosphere. Successful propagation depends greatly on ionospheric conditions, and changes within the ionosphere may require a change of operating frequency. Wide band antennas are therefore, preferred for HF communication systems, and will be discussed in detail later in this guide.

Expectations of HF operation can cause early challenges, particularly if the user has been involved with satellite, VHF or UHF communications. High quality communication can be affected by sunspots, bad choice of frequencies, low power and an inefficient antenna.

The usefulness of an HF system depends on:

- power output
- selection of frequency
- ionospheric variations
- the antenna system.

Power is important, but only if it can be radiated. An increase in power must be considerable if it is to have a significant effect. An increase from 100 to 400W is only 6dB, which at HF may, or may not, be noticeable. A change from an inefficient to an efficient antenna can be far more significant. It is the antenna that ultimately determines the efficiency of an HF system. The modern HF antenna has radiation pattern characteristics that are matched to the required transmission distance, so that the maximum amount of power is received at the receiving location.

The choice of frequencies is also extremely important. Since the radio spectrum is a valuable resource and is finite, the allocation of frequencies is usually the function of a government authority. Propagation characteristics of HF radio waves are such that the lower frequencies are more suitable for short distance communications, whereas higher frequencies are suitable for long distance communications. The choice of frequencies is based on the distances to be covered and variations in the ionosphere. The ionosphere directly affects radio signal reflection or absorption and, therefore, the distance of communication.

Ionosphere

These effects are due to the various ionized layers of the ionosphere that are caused by radiation from the sun (Fig. 1). Therefore any change in solar radiation will affect these layers. Variations in the ionosphere and the nature of radio waves mean that no radio system will give 100% communications all the time.

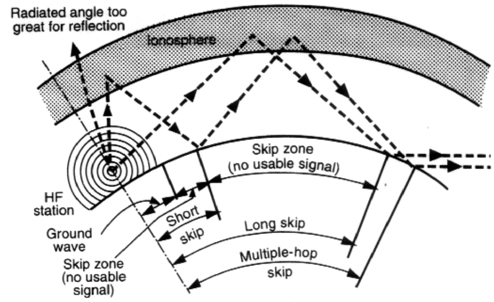


Fig. 1 Ionospheric propagation

The predictable variations occur with the time of day, seasons of the year and the regular ll-year sunspot cycle (Fig. 2). Solar flares and solar storms may also affect HF communications.

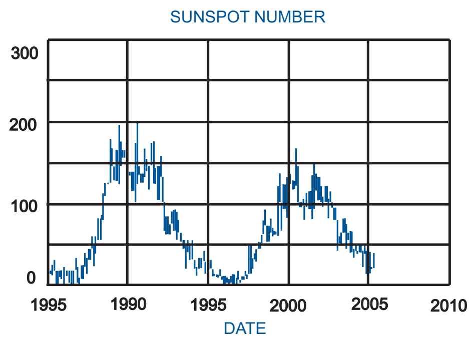


Fig. 2 Picture of 11 year sunspot cycle

Take-off Angle

The take-off angle is the elevation angle, measured from the ground, at which the maximum radiation takes place, or is desired to take place. Whether the antenna is directional or omni-directional there are three basic needs for take-off angle corresponding to the following transmission distances.

Groundwave propagation

For very short distance communication: 0-100km. Effectively, the desired take-off angle is zero degrees and only vertical polarization can be used.

High angle radiation

Using a single reflection or refraction from the ionosphere to achieve short distance communication over the distance 0-1000km. For this requirement, an antenna with maximum radiation at high elevation angles is most suitable.

HF Antenna Systems

Application Overview

Low angle radiation

Using a single refraction from the ionosphere, or multiple refractions combined with reflections from the earth's surface, to achieve medium to long distance communication over the distance 1000km or more. An antenna with maximum radiation at low elevation angles is most suitable.

The angle of take off appropriate for the range to be covered can be selected by varying the height above ground, as shown for a simple half wave dipole (Fig. 3). For short distances a high angle of radiation is required, e.g. H = /4. For longer distances a lower angle, where H= or higher, will produce better results. For more complicated broadband antennas, the principle is the same, except that it is the effective height of the antenna that is optimized over the frequency band.

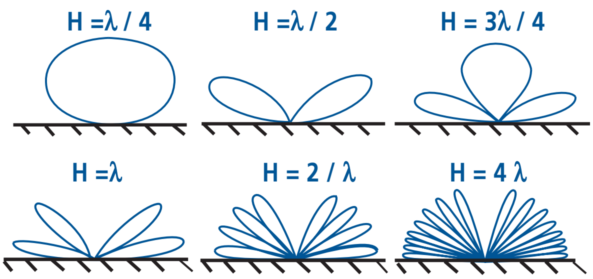


Fig 3. Dipole Take-off Angle Variation with Mounting Height

Horizontal & Vertical Polarization

What is the meaning of polarization in HF communication systems? Many publications present radiation patterns for horizontal as well as vertical polarization. However, the polarization of waves refracted and reflected from the ionosphere is in many cases different from the polarization of the wave radiated from a transmitting antenna. It is, therefore, most important and more practical to consider the total radiated power intensity than the field strength of one or two components.

However, there is one area where the polarization has a great impact. The interaction of an HF antenna with real or "lossy" ground is very dependent on the polarization. The reflection of a horizontally polarized wave is almost perfect from real ground, regardless of the incident angle. However, a vertically polarized wave is substantially absorbed by real ground, and at a certain angle of incidence, known as the Brewster angle, may be almost completely absorbed. A vertically polarized antenna may therefore have much less gain over real ground, than is predicted on the basis of a perfectly conducting or "ideal" ground model. The use of ground screens to recover this gain will be discussed later.

Transmitting or Receiving

When considering an antenna to do a specific task at frequencies below 30MHz, some of the essential differences between transmitting and receiving requirements can be overlooked, frequently to the detriment of overall cost-effectiveness. Often the same transmitting antenna type is also specified for reception, without consideration of the differing roles - a good transmitting antenna is not always a good receiving antenna.

Requirements For Transmitting

The main requirement is to obtain the highest possible field intensity in the desired area of coverage at the appropriate take-off angle. For this, we need to

- maximize the realized gain of the antenna
- ensure that antenna efficiency is as high as possible
- optimize the impedance match to the source to be as close as possible.

Gain and Radiation Pattern

The gain, or more exactly, directive gain of an antenna when used for transmitting, may be regarded as the sensitivity of that antenna when receiving a plane wave of the same polarization. The three-dimensional geometrical surface representing the directive gain, or sensitivity as a function of direction, is called the radiation pattern, which describes equally the performance of either a transmitting, or a receiving antenna.

Directive gain for HF antennas is usually specified with reference to a radiator that radiates uniformly in all directions, the so-called isotropic radiator. Gain specified in this way is designated as X dBi. An alternative method of specifying gain is with reference to a resonant half-wave dipole under the same conditions, in which case, the gain is stated as Y dBd. The dipole has a directive pattern, having a directive gain of 2.13dBi, therefore the gain expressed in dBi is 2.13dB more than the figure expressed in dBd.

Input impedance and VSWR

Another antenna characteristic, which is the same when connected to either a transmitter or receiver, is its input or feed point impedance. When driven from a transmitter, this represents the load impedance appearing across the feed point terminals of the antenna. When connected to a receiver it represents the internal impedance of the antenna, acting in series with the voltage induced by an incident wave. A quantity that describes the effect of the antenna on connected equipment, and vice versa, is the voltage standing wave ratio (VSWR). The meaning and the limitations of this quantity will be investigated later. It will be shown that there is a marked difference

HF Antenna Systems

Application Overview

between the transmitting and receiving operation of an antenna, and that the VSWR assumes different significance, when considered for transmit or receive antennas.

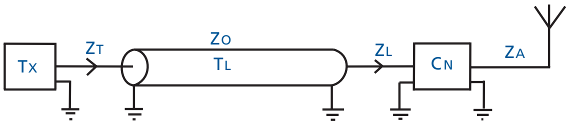


Fig. 4 Radio Transmission System

Fig. 4 shows a schematic circuit diagram of a typical radio transmission system. The power of a transmitter is usually delivered to an antenna by means of a transmission line, in the frequency bands under consideration. TX designates the transmitter operating into a load impedance ZT. TL is the transmission line of characteristic impedance Z0, feeding the output power of the transmitter to the transmit antenna via the coupling network CN, which transforms the antenna input impedance Z0 into ZL, the terminating or load impedance of the transmission line.

Some antennas have been developed to match directly to suitable transmission lines. The coupling network CN, Fig. 4, is then unnecessary, and the antenna terminals are directly connected to the transmission line. Examples include:

- Wideband HF conical vertical monopoles with a typical unbalanced input impedance of 50 ohms.
- Wideband HF biconical horizontal dipoles, with a typical balanced input impedance of 300 ohms allowing direct connection to 300 ohm balanced line.
- Wideband HF vertical or horizontal HF log-periodic dipole antennas, also designed for 300 ohm balanced line.

The wide-band properties of these antennas make them very useful for transmitting stations. Although it is practically not possible to obtain a constant resistive antenna input impedance over the wanted wide frequency band, the designer keeps the fluctuations of the antenna input impedance ZA with respect to Z0, the characteristic impedance of the line, within specified limits. A departure of ZA from Z0 produces a partial reflection of the electromagnetic power from the antenna feed point thus producing standing waves along the feeder line TL.

The standing waves are characterized by the "voltage standing-wave-ratio (VSWR), which is the ratio of the maximum voltage on the line to the minimum voltage. The transmitter is adjusted for optimum operation when the line, TL in Fig. 4, is terminated in a resistive load equal to Z0. The power delivered to this load is the practically obtainable maximum. If the line feeds the antenna and ZA differs from Z0, a part of the power will be reflected back towards the transmitter and the antenna radiated power is reduced, correspondingly, loss on the transmission line increases when VSWR rises. In a high power transmitting system corona effects can occur on the line due to high VSWR.

A practical characteristic of a transmit antenna is the maximum permissible VSWR, which may be designated by SA. A frequently specified maximum VSWR, for antennas in the HF and MF bands is 2:1 (i.e. SA = 2). This means that the mis-match between antenna impedance ZA and characteristic impedance Z0 of the line reflects {(SA-1) / (SA+1)}2 x 100% = 11% of the power and the signal strength is reduced by 0.5dB.

Coupling Networks

A more general problem is encountered when an antenna is used which has a nominal impedance ZC different from the characteristic impedance Z0 of the selected transmission line. A coupling network CN will then be inserted between antenna and line, as in Fig. 4. The maximum VSWR of the antenna in the operating frequency range, with respect to a line of characteristic impedance ZC, may be designated by SC. The coupling network, designed for transfer of a terminating impedance ZC, into an input impedance ZL = Z0, will exhibit some fluctuations of the input Impedance ZL due to variations in its frequency response. The maximum VSWR appearing on the Z0 line when the network CN is terminated by a resistive impedance ZC, may be designated by SC.

If a coupling network is used with the antenna, as shown in Fig. 4, the standing waves produced on the transmission line TL will depend on the frequency response of the antenna and the coupling network. The corresponding VSWR on the line TL may be designated by S0. Its value will be between limits given by the inequality:

SASC S0 SA/SC, when SA > SC (If SA < SC, the last term has to be inverted).

Antenna Efficiency

The output power of the transmitter, reduced by the loss on the transmission line and in networks inserted between transmitter and antenna, represents the input power PA to the antenna. A part of this input power may be dissipated in conductors and dielectric components of the antenna and in the environment. e.g. in a ground system. The remaining power

P = hPA (h£1) is radiated

The antenna efficiency depends on the frequency, the type of the antenna and on the environment.The efficiency can be improved in certain cases, e.g. by improving the ground system to reduce losses. Many

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antennas, at HF and higher frequencies experience a negligible loss with respect to the radiated power; i.e. the efficiency is practically unity.

Radio Noise

At frequencies below 30 MHz, radio noise is a significant factor in Signal to Noise Ratio S/N. The graph, Fig. 5, adapted from C.I.R. Report 322-3: "World Distribution and Characteristics of Atmospheric Radio Noise", Geneva, 1963, page 345, indicates for 2.5 KHz bandwidth, average noise values for midnight in summer.

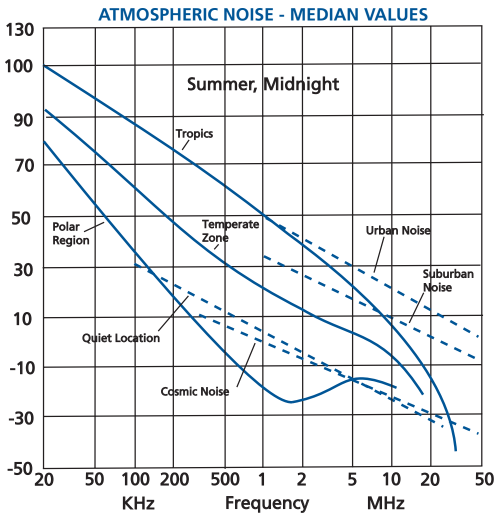

Fig. 5 Radio Noise Levels

The radio noise level is dependent upon geographical position, the operating frequency band, the time of day, season, etc. The noise power N is therefore a given design parameter, and the antenna must be designed or selected so that the operating S/N satisfies the condition S/N >S0/N where S0 is the minimum signal power required at the receiver input.

There are two ways available to increase the signal power if required - either by increasing the radiation of the transmit antenna as described earlier, or by increasing the directivity of the receive antenna.

The resulting S/N ratio, which affects the quality of the signal on demodulation, depends on the cumulative effect of all noise sources, i.e. the external radio noise mentioned above, plus thermal noise due to the resistance of antenna elements and transmission line, and also due to active elements – transistors in the receiving system, particularly in the input stages.

Requirements For Receiving

- main requirement is to obtain the largest possible signal to noise ratio.
- high efficiency and a good match may not be essential to maximize the signal to noise ratio.

External Factors Affecting Signal to Noise Ratio:

- **Interfering Signal**

Where a strong interfering signal is present, a radiation pattern null in that direction is main requirement.

- **High External Noise Environment**

At frequencies below 10MHz, the external atmospheric noise produced by distant thunderstorms is of such a level that a resonant dipole antenna may receive 20 to 30dB more external noise than that generated by the receiver stages, the feeder, or the antenna itself. An appreciable mismatch between antenna and the receiver system reduces the signal level to the receiver, but since the noise level is also reduced in proportion. S/N remains unchanged.

Under these conditions a loss of 10dB or more due to antenna efficiency or poor impedance match to the receiver has virtually no effect on signal to noise ratio.

This situation can often be used to advantage since it allows the use of resistively loaded broadband travelling wave antennas, which have a low efficiency at low frequencies. It also allows the use of compromise matched short antennas, e.g. whips, which are a poor impedance match to the receiver, but offer great advantages in terms of cost and portability.

In some applications, antennas of reduced efficiency may actually improve the receiving system performance. By offering lower signal levels of the same S/N to the receiver, the receiver operates at a more favorable point in its dynamic range, reducing the likelihood of overload conditions, so reducing intermodulation products and improving spurious signal rejection capability of the receiving system.

The frequency range 10 to 30MHz represents a transition stage from predominantly external noise which is reducing (see graph. Fig. 5) as the equipment noise component is increasing with frequency. In practice, therefore in this band system VSWR limits should be generally less than 3:1, if degradation of S/N by the antenna system is to be avoided.

Receiving Antennas

A receive antenna responds to waves incident to the antenna, from all directions if the antenna is omnidirectional, or from specified directions if the antenna has directional properties. The sensitivity as a function of direction follows the same law as the radiation of the same antenna when transmitting. The radiation pattern of the antenna therefore also describes its directional response as a receive antenna.

At any one time, a receiving system is usually required to receive information carried on a wave

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originating from one transmitting station of a complete communication system. All other waves in the operating frequency band of the antenna are either interfering transmissions, or random radiation from space and environment, described as radio noise. Satisfactory communication is possible, only if the power extracted by the antenna system from the wanted wave, (the signal S) is sufficiently higher than the power received from interfering waves so that, after processing in the receiver, the demodulated signal is reasonably clear and undistorted.

Assuming that interference received by the antenna is only radio noise, the noise power N in the ratio S/N refers to the radio noise received by the antenna and the thermal noise in the receiving system. S/N is the most important design parameter of any receiving antenna installation since it is of primary importance in the complete receiving system. A secondary design parameter is the signal level, the signal power S delivered to the receiver input. Modern receivers are highly sensitive, so that the choice of the antenna is not usually affected by the required minimum signal level, but by a specified S/N.

S/N Ratio of a Receiving Antenna System

It can be shown, under the assumption that radio noise is received equally from all directions (not always the case in practice) that:

noise power N received by the antenna is independent of its directivity. The S/N ratio can be increased by increasing the directivity.

In practice, since noise levels received from different directions can vary e.g. man-made noise from an adjacent city, or electric power lines, it is important to try to select the best site available. The directional receiving antenna's advantages are enhanced, whenever its directional pattern discriminates against unwanted interference, in favor of the desired radio wave.

Broadband vs. Narrowband Antennas

HF antennas can be separated into broadband and narrowband groups according to their frequency response.

Narrow Band Antennas

Monopoles

The vertical radiator or monopole (Fig. 6) often has an insulated mast as the antenna. It can be resonant at a quarter wavelength (half the length of a dipole) or non-resonant and tuned with an antenna tuning unit, but that introduces inefficiencies. The guy wires must be interrupted with insulators at regular intervals, although part of the top guy wire may be a component of the antenna circuit.

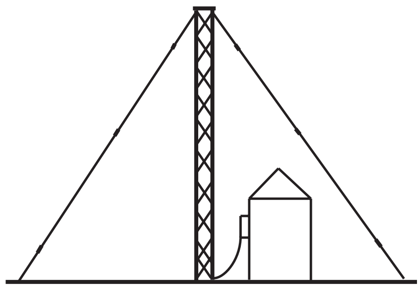

Fig. 6 Vertical Radiator (Monopole)

A good ground is required, and, since top soil often has low conductivity, an artificial ground mat is used. This consists of 60 or more radials of heavy copper wire laid on, or just below, the soil surface and connected to a central copper ring. The length of the radials should be at least a quarter wavelength at the lowest operating frequency. Sometimes metallic spikes are driven into the ground at regular intervals and soldered to the radials to improve contact with the surrounding soil.

A good ground wave makes communication with mobiles over short ranges more reliable. However, high angle radiation is poor, so that performance may be unsatisfactory at intermediate distances. Receiver noise level is generally high, since man-made noise is predominately vertically polarized.

Dipoles

The simple dipole (Fig. 7) is efficient and inexpensive, but will only operate on one frequency.

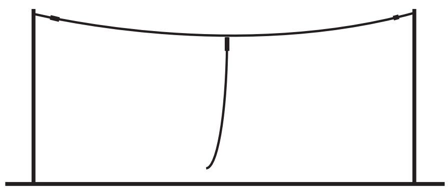

Fig 7 Dipole

A variation is the inverted vee dipole (Fig. 8). This has basically the same characteristics as the horizontal dipole, but requires only one mast.

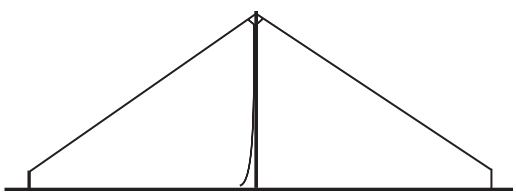

Fig 8 Inverted V Dipole

Broadband Antennas

The clever way to go, when more than one frequency is involved, is to use a broadband antenna that will operate on all the required frequencies without adjustment. RFS broadband antennas operate on either

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the travelling wave principle or the log-periodic principle. The pictures in this guide illustrate the great variety of broadband antennas available for a multitude of operational needs.

Travelling Wave Antennas

Travelling wave antennas are very successful. With these the input impedance remains within reasonable limits and so does the radiation pattern. Two techniques are available to obtain travelling waves in antennas – to avoid reflections leading to standing waves:

- antennas having a conical shape of the radiators, which increases the energy radiated along the antenna conductors so that very little energy is reflected back to the input.
- insertion of resistive components into more simple wire radiators to avoid reflections and standing waves.

Conical Antennas

Fig 9 is a horizontal dipole based on the geometrical principle. With this the conical or biconical shape of each dipole arm causes waves starting at the feed point to become disengaged, i.e. to be radiated. Biconical dipole antennas are designed for short to long range communication with power ratings in excess of 40kW PEP and are available in 2-30MHz or 3-30MHz frequency ranges.

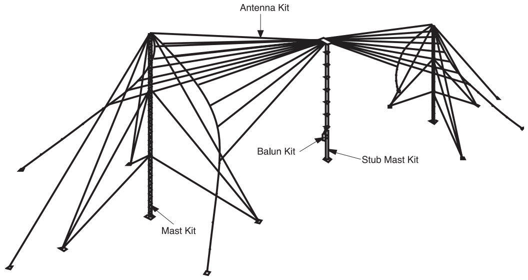

Fig 9 Broadband Dipole (BDH Series)

The monopole (Fig. 10) is designed for medium to long range omni-directional coverage, and covers the standard bands of 2-30MHz or 3-30MHz. Power ratings are usually up to 80kW PEP.

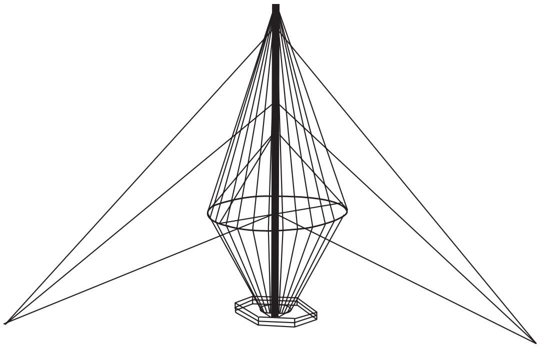

Fig 10 Broadband Monopole (WM Series)

Resistively Loaded Antennas

Fig 11 shows a horizontal travelling-wave dipole based on the principle of inserting resistive components to avoid reflections. In each dipole arm is a resistor inserted at about two-thirds of an arms length from the feed point. There are several models of broadband travelling wave dipole covering 2-30MHz, 3-30MHz and 5-30MHz. Standard power rating is 1kW Av or 4kW PEP. These antennas are ideal for short to medium range communication up to 3000km.

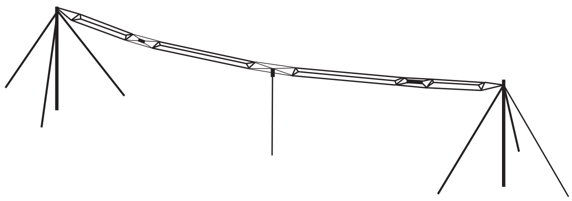

Fig 11 Travelling Wave Dipole (TWD Series)

If one mast and one half of the dipole are removed, and the remaining arm is tilted, the semi-delta antenna of Fig 12 is obtained, i.e. a tilted travelling-wave monopole. Between the lower longer section of the monopole and the upper section, a resistor with a parallel inductor is inserted to avoid standing waves. Operation is from 2-30MHz with a power rating of 250W Av, 1000W PEP. Where soil is poor and operation below 3.5MHz is essential, a low frequency kit is available.

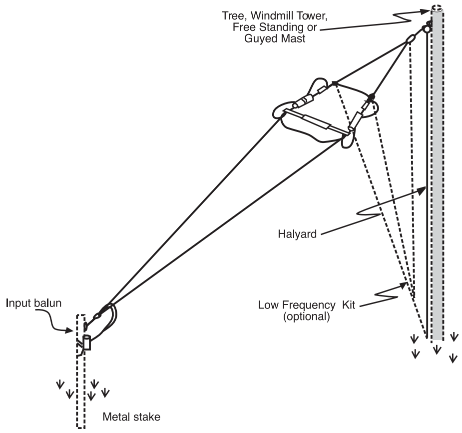

Fig 12 Semi-Delta Antenna (SD Series)

Another popular HF antenna, the Sloping Vee illustrated in Fig 13 has been used for decades for directional transmitting and receiving. This antenna consists of two wires assembled as a Vee with the apex at the top of a mast. Each wire slopes down and is terminated in a grounded resistor RE. A balanced feeder transmission line is used to drive the Vee at the apex. Experience has shown that VSWR with these antennas is affected by ground conditions. This is because ground existing between the earth terminals

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of the terminating resistors acts like a resistive/capacitive component and VSWR usually exceeds acceptable values at some frequencies.

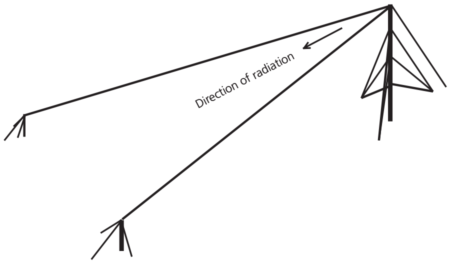

Fig 13 Sloping Vee

To improve the VSWR performance of the historical Sloping-Vee antenna, RFS developed the Sloping-Triangle Antenna shown in Fig 14. VSWR does not exceed 2:1, because antenna current does not pass through the soil. It is designed for medium to long distance communication over 3-30MHz or 5-30MHz. Power ratings are up to 1kW Av, 4kW PEP.

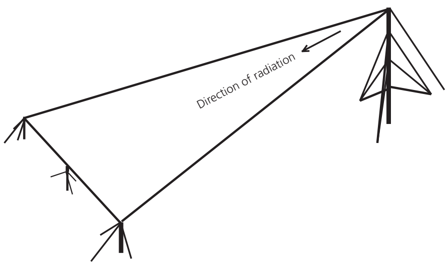

Fig 14 Sloping Triangle (ST Series)

Broadband delta antennas (Figs 15 - 18) are possibly the most used series of broadband antennas in the world. These antennas are designed for high-angle ionospheric propagation over short to medium distances from 0-1000km or more. Radiation results from a wave travelling upward to a resistive termination of the apex of the antenna.

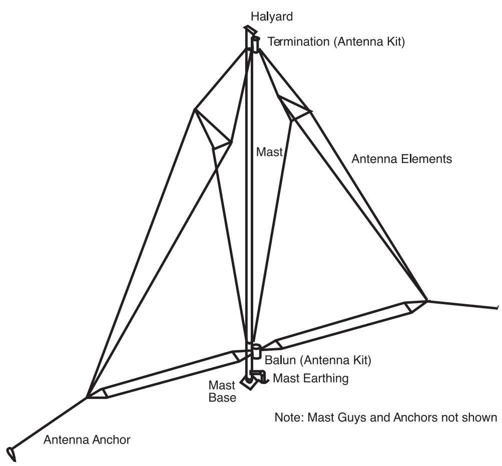

Fig 15 Delta Antenna (D Series)

The dual wing delta in Fig. 15 is omni-directional. There are two versions: 2-30MHz and 3-30MHz. Power ratings available are up to 1kW Av, 4kW PEP. The radiating wings are fed via open wire line, or by coaxial cable using a balanced/unbalanced impedance transformer (balun).

The antenna in Fig. 16 is similar to that in Fig. 15 but the radiating elements are fed by co-axial cable that can be buried instead of above-ground open wire line. This enhancement can be useful where personnel have access – on parade grounds, etc.

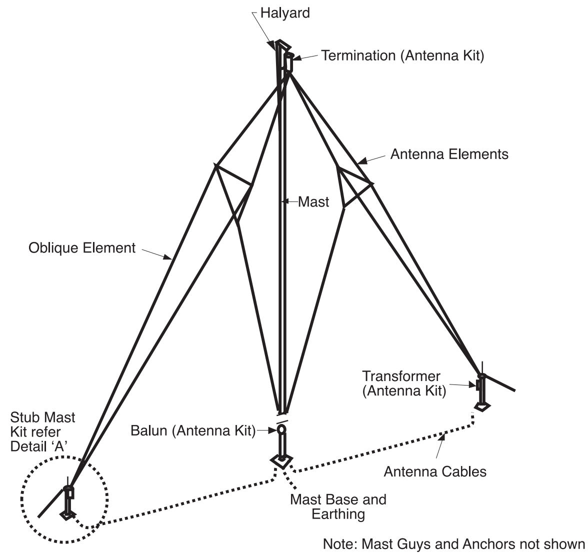

Fig 16 Cable-Fed Delta Antenna (DC Series)

Two dual wing deltas can be mounted on one mast to enable two transmitters to operate simultaneously and independently. The isolation between the two antennas is greater than 30dB.

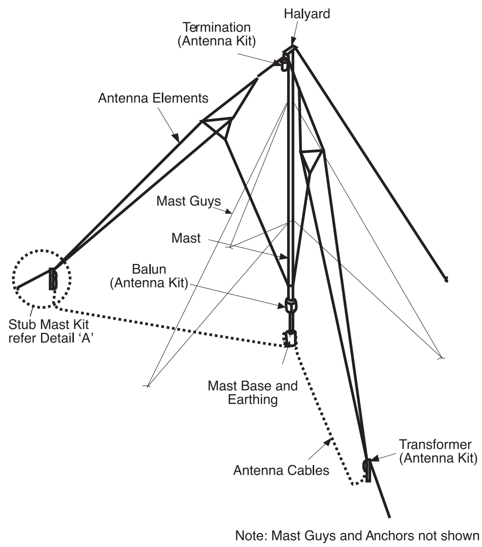

Fig 17 Directional Delta Antenna (DDC Series)

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To enhance the radiation in a particular direction, the two arms of a delta antenna can be moved around the mast as shown in Fig. 17. This model is known as a directional delta and extends the range of communication to up to 1600km or more. It is available to cover 2-30MHz and 3-30MHz and power ratings are from 1kW Av. to 4kW PEP.

The tandem delta (Fig. 18) is specifically designed for high grade short to medium distance circuits for communications and HF broadcasting. The tandem delta does not have a resistive termination at its apex. It is actually two delta antennas. One delta is terminated in another and so nearly 100% of the energy is radiated, giving the tandem delta a 2dB to 4dB gain over the standard delta. Power ratings are up to 80kW PEP.

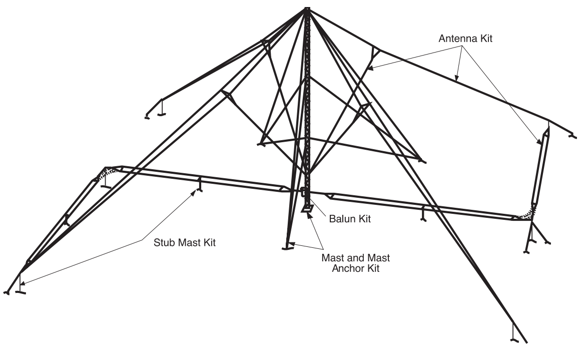

Fig 18 Tandem Delta Antenna (TDG Series)

Log-periodic Antennas

Wide-band antennas incorporating another principle are log-periodic antennas. These are of particular interest for high performance HF communication systems. They comprise an array of tapered dipoles with tapered spacing between adjacent dipoles where the tapering is constant (i.e. the ratio of adjacent dipole length and adjacent spacing is constant) in each model. The log-periodic dipole antenna is a resonant antenna. However, due to the tapered configuration, it is resonant at any operating frequency. Actually only three, four or five dipoles (the so called “active region”), which are close to resonance, operate at the incidental frequency.

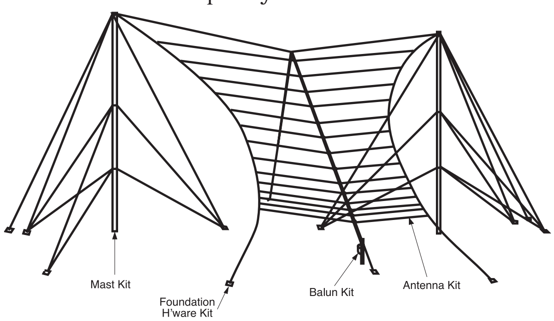

Fig 19 Horizontal Log Periodic Dipole Antenna (HLP Series)

The horizontal log periodic dipole array (Fig. 19) is for medium to long distance communication. It is available with a wide range of take off angles and gains. Power ratings are from 1 to 20kW Av. and frequency ranges are from 2-30MHz. No ground screen is required.

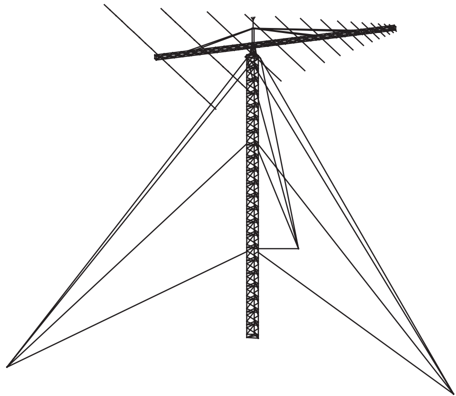

Fig 20 Rotatable Log Periodic Dipole Antenna (HLO Series)

A rotatable version of the horizontally polarized log periodic antenna is shown in Fig 20. This antenna can be used to achieve high quality transmission with some flexibility in selection of the transmission direction. The antenna is available in 4-30 MHz and 6-30 MHz versions with power ratings up to 10kW Av, 40KW PEP.

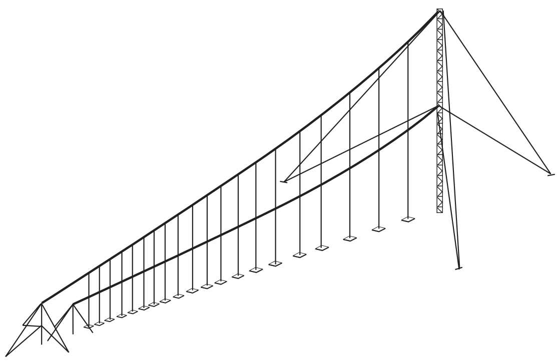

Fig 21 Vertical Log Periodic Dipole Antenna (VLP Series)

The vertically polarized version shown in Fig 21 provides a very low take-off angle for radiation that is ideal for long distance communication. Power ratings are from 1 to 20kW AV, 40kW PEP and frequency ranges are from 3.5-30MHz. For optimum performance, the low angle radiation can be enhanced by extending a ground screen for several wavelengths in front of the antenna.

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The electronically steerable log periodic dipole rosette (Fig. 22) is designed for shore-ship or ground-air communications. Four separate antennas share a common mast and operators can achieve full 360 degree coverage by switching power to the appropriate antenna. These antennas provide maximum opportunity to optimize circuit performance in the selected directions.

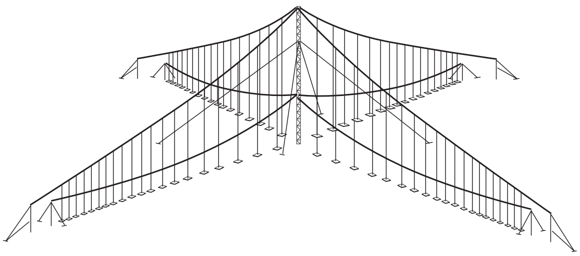

Fig 22 Vertical Log Periodic Dipole Rosette Antenna (VLPR Series)

Ground Screens

Ground screens have two main purposes:

- They form an essential part of vertically polarized monopole antenna systems (WM series, for example) by providing a return path for the current being fed to the monopole. In this application they are referred to as impedance stabilization ground screens, and typically extend radially for one-quarter wavelength at the lowest frequency of operation. They can be placed on the surface of the ground, or buried slightly below the surface, for convenience. Although not strictly required to stabilize impedance for other antenna types, they can improve the efficiency of vertical dipoles, and certain other antennas, by reducing ground losses.
- They can enhance the low angle radiation of vertically polarized antennas. Unfortunately, to be effective for this purpose, very large ground screens are required. These usually consist of grids or mesh of wires and typically extend 10 to 20 wavelengths in the required transmission direction. It usually requires a performance / cost trade-off analysis to determine if there is a need for such a screen. Note that the impedance stabilization ground screens are usually much too small to perform this function.

Conclusion

As can be seen, RFS manufactures a wide range of broadband antennas. Selecting the right antenna is crucial if the operational objectives of the system are to be realized. RFS can offer advice to ensure that the antenna selection is tailored to suit your individual requirements.