BROADCAST TELECOMMUNICATION MANUAL
Vol.1

Telecomponents
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Dear readers,

with this small manual I wanted to insert the most important concepts necessary to understand the telecommunications systems over the air and in particular, the systems used in the radio and television broadcasting sector.

This manual does not intend to replace the fundamental texts of other authors in which the technical concepts are illustrated in greater detail and to which we refer, but is intended to be a handbook for understanding and building radio and television systems.

The contents included in this manual come from various excellent authors and have been verified in the field, in fact, Telecomponents (my company) has been working since 1975 in the broadcast sector and, through its experience, has been able to verify the real application and truthfulness in the field technical concepts.

Enjoy the reading

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Electromagnetic Waves: e/m radiation

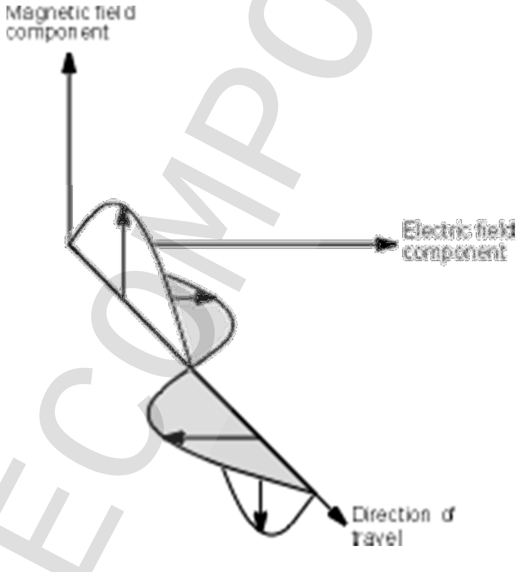
Electromagnetic waves or E/M radiation are the basic wave type that are used for radio waves, light and many more forms of radiation.

Radio signals exist as a form of electromagnetic wave. This is the same form of radiation as light, ultra-violet, infra-red, etc., differing only in the wavelength or frequency of the radiation.

Electromagnetic radiation can travel through many forms of medium. Air and free space form ideal media. However conductive media like metals form a barrier through which they do not travel. There are also some media through which they can travel but are attenuated.

Electromagnetic waves – e/m radiation basics

Electromagnetic waves or e/m radiation has two constituents. The radiation is made from electric and magnetic components that are inseparable. The planes of the fields are at right angles to each other and to the direction in which the wave is travelling.



An electromagnetic wave

It is useful to see where the different elements of the wave emanate from to gain a more complete understanding of electromagnetic waves. The electric component of the wave results from the voltage changes that occur as the antenna element is excited by the alternating waveform. The lines of force in the electric field run along the same axis as the antenna, but spreading out as they move away from it. This electric field is measured in terms of the change of potential over a given distance, e.g. volts per meter, and this is known as the field strength. This measure is often used in measuring the intensity of an electromagnetic wave at a particular point. The other component, namely the magnetic field is at right angles to the electric field and hence it is at right angles to the plane of the antenna. It is generated as a result of the current flow in the antenna.

Like other forms of electromagnetic wave, radio signals can be reflected, refracted and undergo diffraction. In fact some of the first experiments with radio waves proved these facts, and they were used to establish a link between radio waves and light rays.

Electromagnetic wave wavelength, frequency & velocity

There are a number of basic properties of electromagnetic waves, or any repetitive waves for that matter that are particularly important.

Frequency, wavelength and speed are three key parameters for any electromagnetic wave.

- ***E/m wave speed:*** Radio waves travel at the same speed as light. For most practical purposes the speed is taken to be 300 000 000 meters per second although a more exact value is 299 792 500 meters per second. Although exceedingly fast, they still take a finite time to travel over a given distance. With modern radio techniques, the time for a signal to propagate over a certain distance needs to be taken into account. Radar for example uses the fact that signals take a certain time to travel to determine the distance of a target. Other applications such as mobile phones also need to take account of the time taken for signals to travel to ensure that the critical timings in the system are not disrupted and that signals do not overlap.
- ***E/m wave wavelength:*** This is the distance between a given point on one cycle and the same point on the next cycle as shown. The easiest points to choose are the peaks as these are the easiest to locate. The wavelength was used in the early days of radio or wireless to determine the position of a signal on the dial of a set. Although it is not used for this purpose today, it is nevertheless an important feature of any radio signal or for that matter any electromagnetic wave. The position of a signal on the dial of a radio set or its position within the radio spectrum is now determined by its frequency as this provides a more accurate and convenient method for determining the properties of the signal.
- ***Frequency :*** This is the number of times a particular point on the wave moves up and down in a given time (normally a second). The unit of frequency is the Hertz and it is equal to one cycle per second. This unit is named after the German scientist who discovered radio waves. The frequencies used in radio are usually very high. Accordingly the prefixes kilo, Mega, and Giga are often seen. 1 kHz is 1000 Hz, 1 MHz is a million Hertz, and 1 GHz is a thousand million Hertz i.e. 1000 MHz. Originally the unit of frequency was not given a name and cycles per second (c/s) were used. Some older books may show these units together with their prefixes: kc/s; Mc/s etc. for higher frequencies.

Frequency to Wavelength Conversion

Although wavelength was used as a measure for signals, frequencies are used exclusively today. It is very easy to relate the frequency and wavelength as they are linked by the speed of light as shown:

$$\lambda=cf$$

Where

λ = the wavelength in meters
f = frequency in Hertz
c = speed of radio waves (light) taken as 300 000 000 meters per second for all practical purposes.

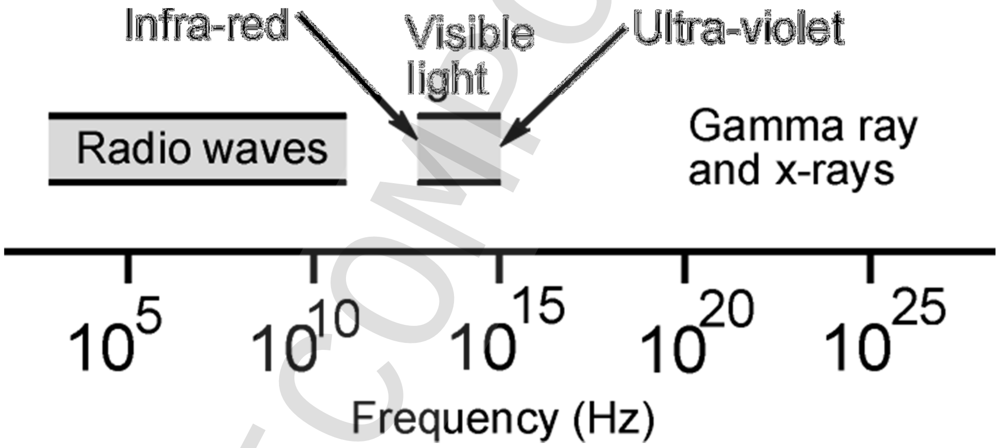
Electromagnetic waves are the key to radio and wireless communications. The fact that they can travel over vast distances as well as being reflected, refracted and diffracted means that they have been used for many years as the basis for radio communications over all distances from a few centimeters to many hundreds of thousands or millions of miles.

The Radio Spectrum: VLF, LF, MF, HF, VHF, UHF .

An overview of the different areas of the radio spectrum the types of radio transmissions or broadcasts that they contain

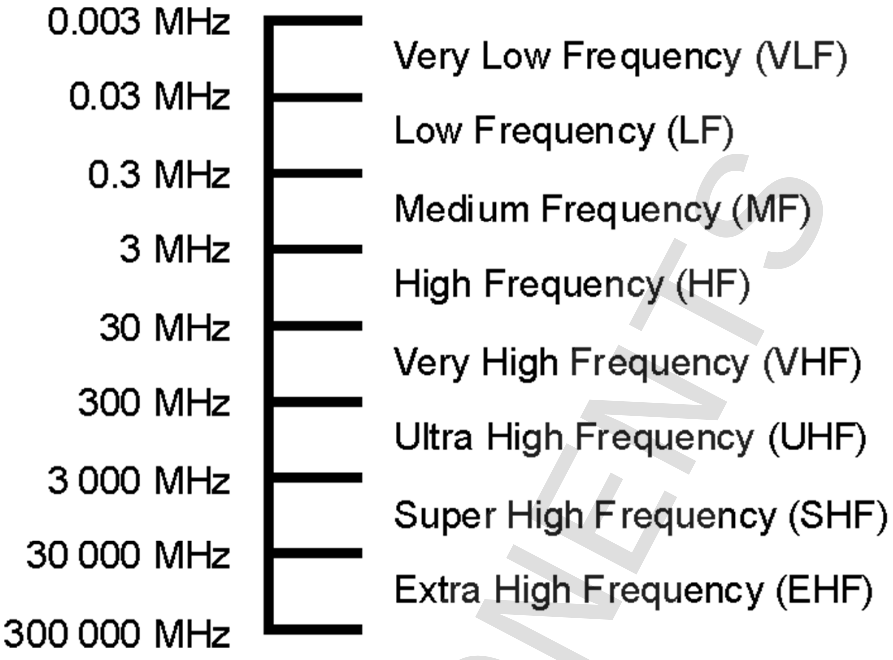
Radio waves are one form of electromagnetic radiation. They have the lowest frequency, and hence the longest wavelengths. Above the radio spectrum, other forms of radiation can be found. These include infra red radiation, light, ultraviolet and a number of other forms of radiation. Although they have different names, and they are often thought of as different entities, they are all forms of electromagnetic wave. The only fundamental difference is the wavelength / frequency. As a result of this difference they act in slightly different ways, and they may be used for different purposes. For example infra-red radiation may be used for heating, while light is used for illuminating areas and visibly seeing things. Nevertheless they are all fundamentally the same.

The different types of electromagnetic wave and their relative frequencies and wavelengths may be displayed on what is often termed the electromagnetic spectrum. This covers radio waves at the lower end with the lowest frequencies and longest wavelengths to infra-red, light and ultraviolet radiation and extending further up in frequency to radiation such as gamma and x-rays.



Electro-magnetic wave spectrum

While the whole of the electromagnetic wave spectrum covers a huge range of frequencies, radio waves themselves extend over a very large range as well. Again it is useful to be able to easily refer to different sections of the spectrum. To achieve this different designations are given to different areas. The frequencies that are covered are split into sections that vary by a factor of ten, e.g. from 3 MHz to 30 MHz. Each section is allocated a name such as high frequency and these areas are abbreviated to give terms like HF, VHF and so forth that are often used. Often talk is heard of VHF FM, or UHF television. The VHF and UHF refer to the areas of the radio spectrum where these transmissions take place



The radio spectrum

It can be seen from the diagram that transmissions in the long wave broadcast band which extends from 140.5 to 283.5 kHz available in some parts of the world falls into the low frequency or LF portion of the spectrum. There are also a number of other types of transmission which are made here. For example there are a number of navigational beacons which transmit on frequencies around 100 kHz or less.

Moving up in frequency, the medium wave broadcast band falls into the medium frequency or MF portion of the spectrum. Above this broadcast band is often where the lowest frequency short wave bands start. Here there is an amateur radio band together with allocations for maritime communications.

Between 3 and 30 MHz is the high frequency or HF portion. Within this frequency range lie the real short wave bands. Signals from all over the world can be heard. Broadcasters, radio amateurs and a host of others use them.

Moving up further the very high frequency or VHF part of the spectrum is encountered. This contains a large number of mobile users. "Radio Taxis" and the like have allocations here, as do the familiar VHF FM broadcasts.

In the ultra high frequency or UHF part of the spectrum most of the terrestrial television stations are located. In addition to these there are more mobile users including the increasingly popular cellular telephones.

Above this in the super high frequency or SHF and extremely high frequency or EHF portions of the spectrum there are many uses for the radio spectrum. They are being used increasingly for commercial satellite and point to point communications.

Polarization of electromagnetic waves

- and their importance in radio wave propagation

The polarization of electromagnetic waves often has a significant effect on the way in which radio wave propagate. While it is important to match the polarization of the transmitting and receiving antennas, the choice of polarization is also important for the signal propagation.

What is polarization

The polarization of an electromagnetic wave indicates the plane in which it is vibrating. As electromagnetic waves consist of an electric and a magnetic field vibrating at right angles to each other it is necessary to adopt a convention to determine the polarization of the signal. For this purpose the plane of the electric field is used.

Vertical and horizontal polarizations are the most straightforward forms and they fall into a category known as linear polarization. Here the wave can be thought of as vibrating in one plane, i.e. up and down, or side to side. This form of polarization is the most commonly used, and the most straightforward.

However this is not the only form as it is possible to generate waveforms that have circular polarization. Circular polarization can be visualized by imagining a signal propagating from an antenna that is rotating. The tip of the electric field vector can be seen to trace out a helix or corkscrew as it travels away from the antenna. Circular polarization can be either right or left handed dependent upon the direction of rotation as seen from the transmitting antenna.

It is also possible to obtain elliptical polarization. This occurs when there is a combination of both linear and circular polarization. Again this can be visualized by imagining the tip of the electric field tracing out an elliptically shaped corkscrew.

Importance for propagation

For many terrestrial applications it is found that once a signal has been transmitted then its polarization will remain broadly the same. However reflections from objects in the path can change the polarization. As the received signal is the sum of the direct signal plus a number of reflected signals the overall polarization of the signal can change slightly although it usually remains broadly the same. When reflections take place from the ionosphere, then greater changes may occur.

In some applications there are performance differences between horizontal and vertical polarization. For example medium wave broadcast stations generally use vertical polarization because ground wave propagation over the earth is considerably better using vertical polarization, whereas horizontal polarization shows a marginal improvement for long distance communications using the ionosphere. Circular polarization is sometimes used for satellite communications as there are some advantages in terms of propagation and in overcoming the fading caused if the satellite is changing its orientation.

What is Radio Propagation: RF propagation

An understanding of what radio propagation is can be an essential tool for anybody involved or interested in radio technology.

Radio signals can travel over vast distances. However radio signals are affected by the medium in which they travel and this can affect the radio propagation or RF propagation and the distances over which the signals can propagate. Some radio signals can travel or propagate around the globe, whereas other radio signals may only propagate over much shorter distances.

Radio propagation, or the way in which radio signals travel can be an interesting topic to study. RF propagation is a particularly important topic for any radio communications system. The radio propagation will depend on many factors, and the choice of the radio frequency will determine many aspects of radio propagation for the radio communications system.

Accordingly it is often necessary to have a good understanding of what is radio propagation, its principles, and the different forms to understand how a radio communications system will work, and to choose the best radio frequencies.

Radio propagation definition

Radio propagation is the way radio waves travel or propagate when they are transmitted from one point to another and affected by the medium in which they travel and in particular the way they propagate around the Earth in various parts of the atmosphere.

Factors affecting radio propagation

There are many factors that affect the way in which radio signals or radio waves propagate. These are determined by the medium through which the radio waves travel and the various objects that may appear in the path. The properties of the path by which the radio signals will propagate governs the level and quality of the received signal.

Reflection, refraction and diffraction may occur. The resultant radio signal may also be a combination of several signals that have travelled by different paths. These may add together or subtract from one another, and in addition to this the signals travelling via different paths may be delayed causing distorting of the resultant signal. It is therefore very important to know the likely radio propagation characteristics that are likely to prevail.

The distances over which radio signals may propagate varies considerably. For some radio communications applications only a short range may be needed. For example a Wi-Fi link may only need to be established over a distance of a few meters. On the other hand a short wave broadcast station, or a satellite link would need the radio waves to travel over much greater distances. Even for these last two examples of the short wave broadcast station and the satellite link, the radio propagation characteristics would be completely different, the signals reaching their final destinations having been affected in very different ways by the media through which the signals have travelled.

Types of radio propagation

There are a number of categories into which different types of RF propagation can be placed. These relate to the effects of the media through which the signals propagate.

- ***Free space propagation:*** Here the radio waves travel in free space, or away from other objects which influence the way in which they travel. It is only the distance from the source which affects the way in which the signal strength reduces. This type of radio propagation is encountered with radio communications systems including satellites where the signals travel up to the satellite from the ground and back down again. Typically there is little influence from elements such as the atmosphere, etc.

- ***Ground wave propagation:*** When signals travel via the ground wave they are modified by the ground or terrain over which they travel. They also tend to follow the Earth's curvature. Signals heard on the medium wave band during the day use this form of RF propagation.
- ***Ionospheric propagation:*** Here the radio signals are modified and influenced by a region high in the earth's atmosphere known as the ionosphere. This form of radio propagation is used by radio communications systems that transmit on the HF or short wave bands. Using this form of propagation, stations may be heard from the other side of the globe dependent upon many factors including the radio frequencies used, the time of day, and a variety of other factors.
- ***Tropospheric propagation:*** Here the signals are influenced by the variations of refractive index in the troposphere just above the earth's surface. Tropospheric radio propagation is often the means by which signals at VHF and above are heard over extended distances.
- In addition to these main categories, radio signals may also be affected in slightly different ways. Sometimes these may be considered as sub-categories, or they may be quite interesting on their own.

Some of these other types of niche forms of radio propagation include:

- ***Sporadic E:*** This form of propagation is often heard on the VHF FM band, typically in summer and it can cause disruption to services as distant stations are heard.
- ***Meteor scatter communications:*** As the name indicates, this form of radio propagation uses the ionised trails left by meteors as they enter the earth's atmosphere. When data is not required instantly, it is an ideal form of communications for distances around 1500km or so for commercial applications. Radio amateurs also use it, especially when meteor showers are present.
- ***Transequatorial propagation, TEP:*** Transequatorial propagation occurs under some distinct conditions and enables signals to propagate under circumstances when normal ionospheric propagation paths would not be anticipated.
- ***Near Vertical Incidence Skywave, NVIS:*** This form of propagation launches skywaves at a high angle and they are returned to Earth relatively close by. It provides local coverage in hilly terrain.
- ***Auroral backscatter:*** The aurora borealis (Northern Lights) and Aurora Australis (Southern Lights) are indicators of solar activity which can disrupt normal ionospheric propagation. This type of propagation is rarely used for commercial communications as it is not predictable but radio amateurs often take advantage of it.
- ***Moonbounce EME:*** When high power transmissions are directed towards the moon, feint reflections can be heard if the antennas have sufficient gain. This form of propagation can enable radio amateurs to communicate globally at frequencies of 140 MHz and above, effectively using the Moon as a giant reflector satellite.

In addition to these categories, many short range wireless or radio communications systems have RF propagation scenarios that do not fit neatly into these categories. Wi-Fi systems, for example, may be considered to have a form of free space radio propagation, but there will be will be very heavily modified because of multiple reflections, refractions and diffractions. Despite these complications it is still possible to generate rough guidelines and models for these radio propagation scenarios.

RF propagation summary

There are many radio propagation scenarios in real life. Often signals may travel by several means, radio waves travelling using one type of radio propagation interacting with another. However to build up an understanding of how a radio signal reaches a receiver, it is necessary to have a good understanding of all the possible methods of radio propagation. By understanding these, the interactions can be better understood along with the performance of any radio communications systems that are used.

Radio Signal Path Loss

The intensity of radio waves and all electromagnetic waves diminishes with distance – there are many reasons for this which affect radio propagation.

Radio path loss is key factor in the design of any radio communications system or wireless communication system.

It is a fact that any radio signal will suffer attenuation when it travels from the transmitter to the receiver. A variety of different phenomena give rise to this radio path loss.

Understanding what causes radio path loss enables any system to be designed to perform to its best despite the various issues affecting it.

How does radio path loss affect systems

The radio signal path loss will determine many elements of the radio communications system or wireless communication system in particular the transmitter power, and the antennas, especially their gain, height and general location. This is true for whatever frequency is used.

To be able to plan the system, it is necessary to understand the reasons for radio path loss, and to be able to determine the levels of the signal loss for a given radio path.

The radio path loss can often be determined mathematically and these calculations are often undertaken when preparing coverage or system design activities. These depend on a knowledge of the signal propagation properties.

Accordingly, radio path loss calculations are used in many radio and wireless survey tools for determining signal strength at various locations. These wireless survey tools are being increasingly used to help determine what radio signal strengths will be, before installing the equipment. For cellular operators radio coverage surveys are important because the investment in a macrocell base station is high. Also, wireless survey tools provide a very valuable service for applications such as installing wireless LAN systems in large offices and other centers because they enable problems to be solved before installation, enabling costs to be considerably reduced. Accordingly there is an increasing importance being placed onto wireless survey tools and software.

Radio path loss basics

The signal path loss is essentially the reduction in power density of an electromagnetic wave or signal as it propagates through the environment in which it is travelling. This affects all radio communication, broadcast and wireless communication systems

There are many reasons for the radio path loss that may occur:

- ***Free space loss:*** The free space loss occurs as the signal travels through space without any other effects attenuating the signal it will still diminish as it spreads out. This can be thought of as the radio communications signal spreading out as an ever increasing sphere. As the signal has to cover a wider area, conservation of energy tells us that the energy in any given area will reduce as the area covered becomes larger.

- ***Diffraction:*** radio signal path loss due diffraction occurs when an object appears in the path. The signal can diffract around the object, but losses occur. The loss is higher the more rounded the object. Radio signals tend to diffract better around sharp edges, i.e. edges that are sharp with respect to the wavelength.
- ***Multipath:*** In a real terrestrial environment, signals will be reflected and they will reach the receiver via a number of different paths. These signals may add or subtract from each other depending upon the relative phases of the signals. If the receiver is moved the scenario will change and the overall received signal will be found vary with position. Mobile receivers (e.g. cellular telecommunications phones) will be subject to this effect which is known as Rayleigh fading.
- ***Absorption losses:*** Absorption losses occur if the radio signal passes into a medium which is not totally transparent to radio signals. There are many reasons for this which include:

    - _Buildings, walls, etc:_ When radio signals pass through dense materials such was walls, buildings or even furniture within a building, they suffer attenuation. It is particularly applicable to cellular communications – in buildings, houses, etc signals are considerably reduced. The radio signal attenuation is more pronounced for the higher frequency mobile bands., e.g. 2.2 GHz as opposed to 800 / 900 MHz.
    - _Atmospheric moisture:_ At high microwave frequencies radio path loss increases as a result of precipitation or even moisture in the air. The radio signal path loss may vary according to the weather conditions. However this typically only has a noticeable effect further into the microwave region.
    - _Vegetation:_ In dense forest it is found that signals even at lower frequencies are considerably reduced. This illustrates that vegetation can introduce considerable levels of radio path loss. Trees and foliage can attenuate radio signals, particularly when wet.
- ***Terrain:*** The terrain over which signals travel will have a significant effect on the signal. Obviously hills which obstruct the path will considerably attenuate the signal, often making reception impossible. Additionally at low frequencies the composition of the earth will have a marked effect. For example on the Long Wave band, it is found that signals travel best over more conductive terrain, e.g. sea paths or over areas that are marshy or damp. Dry sandy terrain gives higher levels of attenuation.
- ***Atmosphere:*** The atmosphere can affect radio signal paths.
    - _Ionosphere:_ At lower frequencies, especially below 30 - 50MHz, the ionosphere has a significant effect, reflecting (or more correctly refracting) them back to Earth. However when passing through some regions, especially the D region and to a lesser extent the E region, signals can suffer attenuation rather than reflection / refraction. This can introduce a significant radio path loss.
    - _Troposphere:_ At frequencies above 50 MHz and more the troposphere has a major effect, refracting the signals back to earth as a result of changing refractive index. For UHF broadcast this can extend coverage to approximately a third beyond the horizon. The refraction can sometimes mean that signal that would normally reach a certain area may be refracted away from it.

These reasons represent some of the major elements causing signal path loss for any radio system.

Predicting radio path loss

One of the key reasons for understanding the various elements affecting radio signal path loss is to be able to predict the loss for a given path, or to predict the coverage that may be achieved for a particular base station, broadcast station, etc.

Although prediction or assessment can be fairly accurate for the free space scenarios, for real life terrestrial applications it is not easy as there are many factors to take into consideration, and it is not always possible to gain accurate assessments of the effects they will have.

Despite this there are wireless survey tools and radio coverage prediction software programmes that are available to predict radio path loss and estimate coverage. A variety of methods are used to undertake this.

Free space path loss varies in strength as an inverse square law, i.e. $1/(\text{range})^2$, or 20 dB per decade increase in range. This calculation is very simple to implement, but real life terrestrial calculations of signal path loss are far more involved. To show how a real life situation can alter the calculations, often mobile phone operators may

modify the inverse square law to 1/(range)^n where n may vary between 3.5 to 5 as a result of the buildings and other obstructions between the mobile phone and the base station.
Most path loss predictions are made using techniques outlined below:

- ***Statistical methods:*** Statistical methods of predicting signal path loss rely on measured and averaged losses for typical types of radio links. These figures are entered into the prediction model which is able to calculate the figures based around the data. A variety of models can be used dependent upon the application. This type of approach is normally used for planning cellular networks, estimating the coverage of PMR (Private Mobile Radio) links and for broadcast coverage planning.
- ***Deterministic approach:*** This approach to radio signal path loss and coverage prediction utilises the basic physical laws as the basis for the calculations. These methods need to take into consideration all the elements within a given area and although they tend to give more accurate results, they require much additional data and computational power. In view of their complexity, they tend to be used for short range links where the amount of required data falls within acceptable limits.

These wireless survey tools and radio coverage software packages are growing in their capabilities. However it is still necessary to have a good understanding of radio propagation so that the correct figures can be entered and the results interpreted satisfactorily.

For any given radio transmission, the radio path loss is likely to be caused by a number of different factors. This often makes accurate radio path loss calculations difficult. However even if they are not as accurate as might be always liked, the radio path loss calculations enable equipment to be designed to meet the requirements.

Free Space Path Loss: details & calculator

The simplest scenario for radio signal propagation is free space propagation model when a signal travels in free space.

The way the signal propagates and the path loss incurred provide a foundation for more complicated propagation models.

Although in most cases the free space propagation model details the way in which a radio signal travels in free space, when it is not under the influence of the many other external elements that affect propagation.

Free space propagation basics

The free space propagation model is the simplest scenario for the propagation of radio signals. Here they are considered to travel outwards from the point where they are radiated by the antenna.

The way in which they propagate can be likened to the ripples of waves on a pond that travel outwards from the point where a stone is dropped into a pond.

As the ripples move outwards their level reduces until they finally disappear to the eye.

In the case of radio signal propagation, the waves spread out in three dimensions rather than the two dimensions of the pond example.

Free space propagation signal level

It can be shown that the level of the signal falls as it moves away from the point where it has been radiated.

Signals reduce in intensity as they travel from the transmitter

The rate at which it falls is proportional to the inverse of the square of the distance.

$$\text{Signal level}=kd2$$

Where:

k = constant
d = distance from the transmitter

As a simple example this means that the signal level of a transmission will be a quarter of the strength at 2 meters distance that it is at 1 metre distance.

Where a radio signal comes under the influence of other factors, the basic formula can be altered to take account of this.

The exponent is altered to represent more accurately the real life scenario. In environments like the internals of buildings such as buildings, stadiums and other indoor environments, the path loss exponent can reach values in the range of 4 to 6. Many mobile phone operators base their calculations on a terrestrial signal reduction around the inverse of the distance to the power 4. However tunnels can act as a form of waveguide and they can result in a path loss exponent values of less than 2.

Free space path loss calculation

It is possible to calculate the path loss between a transmitter and a receiver. The path loss proportional to the square of the distance between the transmitter and receiver as seen above and also to the square of the frequency in use.

The free space path loss can be expressed in terms of either the wavelength or the frequency. Both equations are given below:

In terms of wavelength

$$\mathbf{FSPL=(4\pi d\lambda)2}$$

In terms of frequency

$$\mathbf{FSPL=(4\pi dfc)2}$$

Where:

FSPL = Free space path loss
d = distance from the transmitter to the receiver (meters)
λ = signal wavelength (meters)
f = signal frequency (Hz)
c = speed of light (meters per second)

Free space loss formula frequency dependency

The free space loss equations above seem to indicate that the loss is frequency or wavelength dependent. In reality the attenuation resulting from the distance travelled in space is not frequency or wavelength dependent and is constant.

Looking at the free space path loss equations it is possible to see that the result is dependent upon two effects:

- The first results from the spreading out of the energy as the sphere over which the energy is spread increases in area. This is described by the inverse square law.
- The second effect results from the antenna aperture change and this is dependent upon physical size and the wavelength being used. This affects the way in which any antenna can pick up signals and it results in this element being frequency dependent.

Even though one element of the equation for free space path loss is non-frequency dependent, the other is and this results in the overall equation having a wavelength or frequency dependence.

Free space path loss equation in decibel(dB)

It is normally more convenient to be able to express the path loss in terms of a direct loss in decibels. In this way it is possible to calculate elements including the expected signal, etc.

The equation below shows the path loss for a free space propagation application. It can also be used when calculating or estimating other paths as well.

$$\mathbf{FSPL(dB)=20\log(d)+20\log(f)+32.44}$$

Where:
d = distance of the receiver from the transmitter (km)
f = signal frequency (MHz)

It is worth noting that the equation above does not include antenna gains and feeder losses. It is for two isotropic antennas, i.e. ones that radiate equally in all directions.

It is possible to add the antenna gains into the equation

$$\mathbf{F=20\log(d)+20\log(f)+32.44-Gtx-Grx}$$

Where:
Gtx = overall transmitter antenna gain including feeder losses
Grx = overall receiver antenna gain including feeder losses

Radio Link Budget: details & formula

The radio link budget is a summary of transmitter power levels, system losses & gains.

Where:
P_{RX} = received power (dBm)
P_{TX} = transmitter output power (dBm)
G_{TX} = transmitter antenna gain (dBi)
G_{RX} = receiver antenna gain (dBi)
L_{TX} = transmit feeder and associated losses (feeder, connectors, etc.) (dB)
L_{FS} = free space loss or path loss (dB)
L_{P} = miscellaneous signal propagation losses (these include fading margin, polarization mismatch, losses associated with medium through which signal is travelling, other losses...) (dB)
L_{RX} = receiver feeder and associated losses (feeder, connectors, etc.) (d)B

NB for the sake of visibility, the losses in the link budget equation is shown with a negative sign e.g. LTX or LFS, etc. When entering the figures into the radio link budget formula, the figure should be entered as the modulus of the loss. In this way they will be subtracted and not added to the figure.

Antenna gain & radio link budget

The basic link budget equation where no levels of antenna gain are included assumes that the power spreads out equally in all directions from the source, i.e. from an isotropic source, an antenna that radiates equally in all directions.

This assumption is good for many theoretical calculations, but in reality all antennas radiate more in some directions than others. In addition to this it is often necessary to use antennas with gain to enable interference from other directions to be reduced at the receiver, and at the transmitter to focus the available transmitter power in the required direction.

In view of this it is necessary to accommodate these gains into the link budget equation as they have been in the equation above because they will affect the signal levels - increasing them by levels of the antenna gain, assuming the gain is in the direction of the required link. When quoting gain levels for antennas it is necessary to ensure they are gains when compared to an isotropic source, i.e. the basic type of antenna assumed in the equation when no gain levels are incorporated. The gain figures relative to an isotropic source are quoted as dBi, i.e. dB relative to an isotropic source. Often gain levels given for an antenna may be the gain relative to a dipole where the figures may be quoted as dBd, i.e. dB relative to a dipole. However a dipole has gain relative to an isotropic source, so the dipole gain of 2.1 dBi needs to be accommodated if figures relative to a dipole are quoted for an antenna gain.

Link budget calculations are an essential step in the design of a radio communications system. The link budget calculation enables the losses and gains to be seen, and devising a link budget enables the apportionment of losses, gains and power levels to be made if changes need to be made to enable the radio communications system to meet its operational requirements. Only by performing a link budget analysis is this possible.

Radio Wave Reflection

Like other forms of electromagnetic wave, radio signals can be reflected by certain surfaces.

It is possible for radio waves to be reflected in the same way as light waves. As both light and radio waves are forms of electromagnetic waves, they are both subject to the same basic laws and principles.

Visual examples of light reflection are everywhere from specific mirrors to flat reflective surfaces like glass, polished metal and the like.

So too, radio waves can experience reflection.

Radio wave reflection

When a radio wave or in fact any electromagnetic wave encounters a change in medium, some or all of it may propagate into the new medium and the remainder is reflected. The part that enters the new medium is called the transmitted wave and the other the reflected wave.

The rules that govern the reflection of radio waves are simple and are the same as those that govern light waves.

Propagation of reflected & refracted waves

When a reflection occurs it can be seen that the angle of incidence, θ1 is the same for the incident ray as for the reflected ray.

Additionally there is normally some loss, as a result of absorption, or signal passing into the medium.

Reflective medium

Conducting media provide the optimum surfaces for reflecting radio waves. Metal surfaces, and other conducting areas provide the best reflections. It is noticeable that for HF ionospheric propagation, when signals are returned to earth and are reflected back again by the Earth's surface, areas of good conductivity provide the best reflections. Desert areas give poor reflected signals, but the sea is much better and the differences are very noticeable despite the variations in the ionosphere and overall propagation path.

SURFACE	CONDUCTIVITY (SIEMENS)
Dry ground & desert	0.001
Average ground	0.005
Fresh water	0.01
Wet ground	0.02

SURFACE	CONDUCTIVITY (SIEMENS)
Sea water	5

Multiple reflections

In real transmission paths, radio waves are often reflected by a variety of different surfaces. Although ionospheric reflections are actually caused by refraction, they can often be considered as reflections. Also for shorter range signals like mobile phone or other VHF / UHF communications the signals undergo many reflections.

These multiple reflections lead to the signal arriving at the receiver via several paths. Radio wave reflections normally give rise to multi-path effects.

The multiple reflections and multi-path effects give rise to distortion of the signal and fading.

When a signal arrives by two paths, one is longer than the other and will take longer to arrive than the other. This can mean that the signals either add together if they are in phase, or they can tend to cancel each other out. This results in fading of anything moves of changes, or dead spots in certain areas if the reflective surfaces are fixed.

Additionally the delays in some signal paths can give rise to distortion of the modulation. For audio the signal can literally sound distorted dependent upon the type of modulation used – frequency modulation the audio can become very broken when multiple signals are received. For digital signals, it can result in data becoming corrupt as the data from one path may be delayed compared to the other and the receiver not being able to distinguish where data bits start and stop.

Radio Wave Refraction

Like other forms of electromagnetic wave, radio signals can be refracted when the refractive index of the medium through which they are passing changes.

It is possible for radio waves to be refracted in the same way as light waves. As both light and radio waves are forms of electromagnetic waves, they are both subject to the same basic laws and principles.

The concept of refraction is generally illustrated in terms of light. On a hot day the surface of the ground can be heated and this causes air to rise. Hot air and the colder air have slightly different values of refractive index and this causes the light to bend. With the movement of the rising air the surface of the ground appears to shimmer.

Refraction of radio waves

In just the same way that light waves are refracted, so too radio waves can undergo refraction.

The classic case for refraction occurs at the boundary of two media. At the boundary, some of the electromagnetic waves will be reflected, and some will enter the new medium and be refracted.

Propagation of reflected & refracted waves

This is best illustrated by placing a straight stick through the surface of a still pond where both the reflection and the refracted waves can be seen.

Radio wave refraction follows exactly the same effects as it does for light.

The basic law for radio wave refraction and light wave refraction is known as Snells Law which states:

$$\eta 1\sin(\theta 1)=\eta 2\sin(\theta 2)$$

Gradual changes in refractive index

Rather than a sudden boundary to two different media, radio waves will often be refracted by areas where the refractive index gradually changes.

This may happen as the radio waves propagate through the atmosphere where small changes in refractive index occur.

Typically it is found that the refractive index of the air is higher close to the earth's surface, falling slightly with height.

In this case the radio waves are refracted towards the area of higher refractive index. This extends the range over which they can travel.

Refraction of radio waves in ionized regions

Radio waves are also refracted in regions of ionization such as the ionosphere.

The ionosphere is a region in the upper atmosphere where there is a large concentration of ions and free electrons, primarily as a result of the effect of the Sun's radiation on the upper reaches of the atmosphere.

The electrons in the ionosphere are excited by the radio waves and are set in motion by them as a result they tend to re-radiate the signal. As the signal is travelling in an area where the density of electrons is increasing, the further it progresses into the region, the signal is refracted away from the area of higher electron density. In the case of signals below about 30 MHz, this refraction is often sufficient to bend them back to earth. In effect it appears that the region has "reflected" the signal.

The tendency for this "reflection" is dependent upon the frequency and the angle of incidence. As the frequency increases, it is found that the amount of refraction decreases until a frequency is reached where the signals pass through the region and on to the next. Eventually a point is reached where the signal passes through the E layer on to the next layer above it.

The state of the ionosphere is constantly changing, so the degrees of refraction that are encountered will vary continually.

More information about HF band ionospheric propagation can be found in out HF ionospheric propagation pages.

Radio Wave Diffraction

Like other forms of electromagnetic wave, radio signals can be diffracted when they travel past sharp corners.

Electromagnetic waves can be diffracted when they meet a sharp obstacle.

As radio waves are a form of electromagnetic wave, it means that they can also be diffracted.

Radio wave diffraction

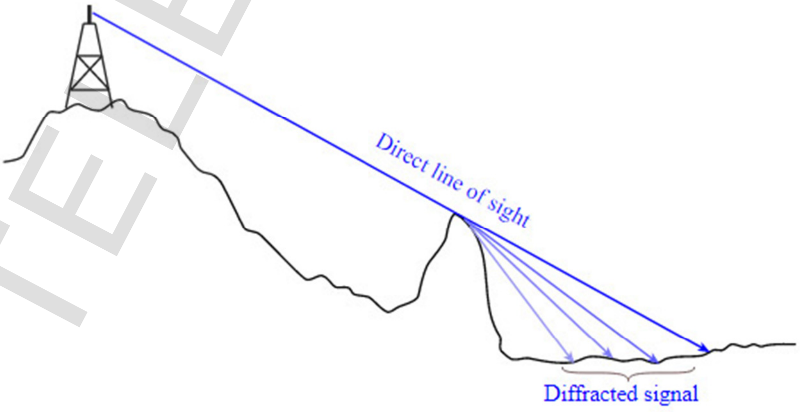
As radio waves undergo diffraction it means that a signal from a transmitter may be received from a transmitter even though it may be "shaded" by a large object between them.

To understand how this happens it is necessary to look at Huygen's Principle. This states that each point on a spherical wave front can be considered as a source of a secondary wave front.

Even though there will be a shadow zone immediately behind the obstacle, the signal will diffract around the obstacle and start to fill the void. It is found that diffraction is more pronounced when the obstacle becomes sharper and more like a "knife edge".

For a radio signal the definition of a knife edge depends upon the frequency, and hence the wavelength of the signal.

For low frequency signals a mountain ridge may provide a sufficiently sharp edge. A more rounded hill will not produce such a marked effect. It is also found that low frequency signals diffract more markedly than higher frequency ones. It is for this reason that signals on the long wave band are able to provide coverage even in hilly or mountainous terrain where signals at VHF and higher would not.



Radio wave diffraction

The effect may also be important for very high frequency signals where items of furniture in the home may have a sufficiently sharp edge to enable diffraction to be seen. This may give slightly better coverage to items like mobile phones or for Wi-Fi systems.

Multipath Propagation

Multipath radio propagation affects virtually all wireless signals: it can give rise to interference or it can be used to increase improve performance with techniques like MIMO.

Multipath propagation is a fact of life in any terrestrial radio scenario. While the direct or line of sight path is often the main wanted signal, a radio receiver will receive different versions of the same signal that have travelled from the transmitter via many different paths.

Multipath propagation basics

The vast number of different signal paths arise from the fact that signals are reflections from buildings, mountains or other reflective surfaces including water, etc. that may be adjacent to the main path. Additionally other effects such as ionospheric reflections give rise to multipath propagation as does tropospheric ducting.

The antennas used for transmission and reception have an effect on the number of paths that the signal can take. Non-directive antennas will radiate the signal in all directions, whereas directive ones will focus the power in one direction reducing the strength of reflected signals away from the main beam.

The multipath propagation resulting from the variety of signal paths that may exist between the transmitter and receiver can give rise to interference in a variety of ways including distortion of the signal, loss of data and multipath fading.

At other times, the variety of signal paths arising from the multipath propagation can be used to advantage. Schemes such as MIMO use multipath propagation to increase the capacity of the channels they use or seek to improve the signal to noise ratio.

Multipath fading

Signals are received in a terrestrial environment, i.e. where reflections are present and signals arrive at the receiver from the transmitter via a variety of paths. The overall signal received is the sum of all the signals appearing at the antenna. Sometimes these will be in phase with the main signal and will add to it, increasing its strength. At other times they will interfere with each other. This will result in the overall signal strength being reduced.

- ***Multipath fading:*** Multipath fading can be detected on many signals across the frequency spectrum from the HF bands right up to microwaves and beyond. It can cause signals to rise and fall in strength.
- ***Rayleigh fading:*** Rayleigh fading is the name given to the form of fading that is often experienced in an environment where there is a large number of reflections present.

Interference caused by multipath propagation

Multipath propagation can give rise to interference that can reduce the signal to noise ratio and reduce bit error rates for digital signals. One cause of a degradation of the signal quality is the multipath fading already described. However there are other ways in which multipath propagation can degrade the signal and affect its integrity.

One of the ways which is particularly obvious when driving in a car and listening to an FM radio. At certain points the signal will become distorted and appear to break up. This arises from the fact that the signal is frequency modulated and at any given time, the frequency of the received signal provides the instantaneous voltage for the audio output. If multipath propagation occurs, then two or more signals will appear at the receiver. One is the direct or line of sight signal, and another is a reflected signal. As these will arrive at different times because of the different path lengths, they will have different frequencies, caused by the fact that the two signals have been transmitted by the transmitter at slightly different times. Accordingly when the two signals are received together, distortion can arise if they have similar signal strength levels.

Another form of multipath propagation interference that arises when digital transmissions are used is known as Inter Symbol Interference, ISI. This arises when the delay caused by the extended path length of the reflected signal. If the delay is significant proportion of a symbol, then the receiver may receive the direct signal which indicates one part of the symbol or one state, and another signal which is indicating another logical state. If this occurs, then the data can be corrupted.

One way of overcoming this is to transmit the data at a rate the signal is sampled, only when all the reflections have arrived and the data is stable. This naturally limits the rate at which data can be transmitted, but ensures that data is not corrupted and the bit error rate is minimised. To calculate this the delay time needs to be calculated using estimates of the maximum delays that are likely to be encountered from reflections.

Using the latest signal processing techniques, a variety of methods can be used to overcome the problems with multipath propagation and the possibilities of interference.

Multipath Fading

Multipath fading occurs when signals reach a receiver via many paths & their relative strengths & phases change.

Multipath fading affects most forms of radio communications links in one form or another.

Multipath fading can affect signals on frequencies from the LF portion of the spectrum and below right up into the microwave portion of the spectrum.

Multipath fading occurs in any environment where there is multipath propagation and the paths change for some reason. This will change not only their relative strengths but also their phases, as the path lengths will change.

Multipath fading may also cause distortion to the radio signal. As the various paths that can be taken by the signals vary in length, the signal transmitted at a particular instance will arrive at the receiver over a spread of times. This can cause problems with phase distortion and inter-symbol interference when data transmissions are made. As a result, it may be necessary to incorporate features within the radio communications system that enables the effects of these problems to be minimised.

Multipath fading basics

Multipath fading is a feature that needs to be taken into account when designing or developing a radio communications system. In any terrestrial radio communications system, the signal will reach the receiver not only via the direct path, but also as a result of reflections from objects such as buildings, hills, ground, water, etc that are adjacent to the main path.

The overall signal at the radio receiver is a summation of the variety of signals being received. As they all have different path lengths, the signals will add and subtract from the total dependent upon their relative phases.

At times there will be changes in the relative path lengths. This could result from either the radio transmitter or receiver moving, or any of the objects that provides a reflective surface moving. This will result in the phases of the signals arriving at the receiver changing, and in turn this will result in the signal strength varying as a result of the different way in which the signals will sum together. It is this that causes the fading that is present on many signals.

Selective and flat fading

Multipath fading can affect radio communications channels in two main ways. This can given the way in which the effects of the multipath fading are mitigated.

- ***Flat fading:*** This form of multipath fading affects all the frequencies across a given channel either equally or almost equally. When flat multipath fading is experienced, the signal will just change in amplitude, rising and falling over a period of time, or with movement from one position to another.
- ***Selective fading:*** Selective fading occurs when the multipath fading affects different frequencies across the channel to different degrees. It will mean that the phases and amplitudes of the signal will vary across the channel. Sometimes relatively deep nulls may be experienced, and this can give rise to some reception problems. Simply maintaining the overall amplitude of the received signal will not overcome the effects of selective fading, and some form of equalization may be needed. Some digital signal formats, e.g. OFDM are able to spread the data over a wide channel so that only a portion of the data is lost by any nulls. This can be reconstituted using forward error correction techniques and in this way it can mitigate the effects of selective multipath fading.

  Selective multipath fading occurs because even though the path length will be change by the same physical length (e.g. the same number of meters, yards, miles, etc) this represents a different proportion of a wavelength. Accordingly the phase will change across the bandwidth used.

  Selective fading can occur over many frequencies. It can often be noticed when medium wave broadcast stations are received in the evening via ground wave and skywave. The phases of the signals received via the two means of propagation change with time and this causes the overall received signal to change. As the multipath fading is very dependent on path length, it is found that it affects the frequencies over even the bandwidth of an AM broadcast signal to be affected differently and distortion results.

  Selective multipath fading is also experienced at higher frequencies, and with high data rate signals becoming commonplace wider bandwidths are needed. As a result nulls and peaks may occur across the bandwidth of a single signal.

Cell phone signal fading

Mobile phone communications are subject to multipath fading. There are a variety of reasons for this.

- ***Mobile user is moving:***, The first is that the mobile station or user is likely to be moving, and as a result the path lengths of all the signals being received are changing. The second is that many objects around may also be moving. Automobiles and even people will cause reflections that will have a significant effect on the received signal. Accordingly multipath fading has a major bearing on cellular telecommunications.

- ***Other objects moving:*** Often the multipath fading that affects cellular phones is known as fast fading because it occurs over a relatively short distance. Slow fading occurs as a cell phone moves behind an obstruction and the signal slowly fades out.

The fast signal variations caused by multipath fading can be detected even over a short distance. Assume a frequency of 2 GHz (e.g. a typical approximate frequency value for many phones). The wavelength can be calculated as:

$$\lambda=cf$$

$$\lambda=3\cdot1082\cdot109$$

$$\lambda=0.15meters$$

Where:

c = speed of light in meters per second
f = frequency in Hertz

To move from a signal being in phase to a signal being out of phase is equivalent to increasing the path length by half a wavelength or 0.075m, or 7.5 cms. This example looks at a very simplified example. In reality the situation is far more complicated with signals being received via many paths. However it does give an indication of the distances involved to change from an in-phase to an out of phase situation.

Ionospheric fading

Short wave radio communications is renowned for its fading. Signals that are reflected via the ionosphere, vary considerably in signal strength. These variations in strength are primarily caused by multipath fading.

When signals are propagated via the ionosphere it is possible for the energy to be propagated from the transmitter to the receiver via very many different paths. Simple diagrams show a single ray or path that the signal takes. In reality the profile of the electron density of the ionosphere (it is the electron density profile that causes the signals to be refracted) is not smooth and as a result any signals entering the ionosphere will be scattered and will take multiple paths to reach a particular receiver. With changes in the ionosphere causing the path lengths to change, this will result in the phases changing and the overall summation at the receiver changing.

The changes in the ionosphere arise from a number of factors. One is that the levels of ionisation vary, although these changes normally occur relatively slowly, but nevertheless have an effect. In addition to this there are winds or air movements in the ionosphere. As the levels of ionisation are not constant, any air movement will cause changes in the profile of the electron density in the ionosphere. In turn this will affect the path lengths.

It is for this reason that signals on the short wave bands are constantly changing in strength.

Tropospheric fading

Many signals using frequencies at VHF and above are affected by the troposphere. The signal is refracted as a result of the changes in refractive index occurring, especially within the first kilometers above the ground. This can cause signals to travel beyond the line of sight. In fact for broadcast applications a figure of 4/3 of the visual line of sight is used for the radio horizon. However under some circumstances relatively abrupt changes in refractive index occurring as a result of weather conditions can cause the distances over which signals travel to be increased. Signals may then be "ducted" by the ionosphere over distances up to a few hundred kilometers.

When signals are ducted in this way, they will be subject to multipath fading. Here, heat rising from the Earth's surface will ensure that the path is always changing and signals will vary in strength. Typically these changes may be relatively slow with signals falling and rising in strength over a period of a number of minutes.

Multipath radio fading is factor that appears on most signals to a greater or lesser degree. As radio signals tend to reach a receiver via multiple paths regardless of how good the path appears to be there are always likely to be reflections from other objects. The only exception is in outer space where there are very few significant objects that are likely to cause major issues.

In view of the fact that signals take multiple paths and there is always likely to be some movement causing path lengths to change and signal strengths to vary, multipath fading will be an issue in many instances.

Rayleigh Fading

Rayleigh fading is the name given to the form of fading that is often experienced in an environment where there is a large number of reflections present.

The Rayleigh fading model uses a statistical approach to analyse the propagation, and can be used in a number of environments.

The Rayleigh fading model is ideally suited to situations where there are large numbers of signal paths and reflections. Typical scenarios include cellular telecommunications where there are large number of reflections from buildings and the like and also HF ionospheric communications where the uneven nature of the ionosphere means that the overall signal can arrive having taken many different paths.

The Rayleigh fading model is also appropriate for for tropospheric radio propagation because, again there are many reflection points and the signal may follow a variety of different paths.

Rayleigh fading definition

The Rayleigh fading model may be defined as follow:

- ***Rayleigh fading model:*** Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium (also called a communications channel) will vary randomly, or fade, according to a Rayleigh distribution — the radial component of the sum of two uncorrelated Gaussian random variables.

Rayleigh radio signal fading basics

The Rayleigh fading model is particularly useful in scenarios where the signal may be considered to be scattered between the transmitter and receiver. In this form of scenario there is no single signal path that dominates and a statistical approach is required to the analysis of the overall nature of the radio communications channel.

Rayleigh fading is a model that can be used to describe the form of fading that occurs when multipath propagation exists. In any terrestrial environment a radio signal will travel via a number of different paths from the transmitter to the receiver. The most obvious path is the direct, or line of sight path.

However there will be very many objects around the direct path. These objects may serve to reflect, refract, etc the signal. As a result of this, there are many other paths by which the signal may reach the receiver.

When the signals reach the receiver, the overall signal is a combination of all the signals that have reached the receiver via the multitude of different paths that are available. These signals will all sum together, the phase of the signal being important. Dependent upon the way in which these signals sum together, the signal will vary in strength. If they were all in phase with each other they would all add together. However this is not normally the case, as some will be in phase and others out of phase, depending upon the various path lengths, and therefore some will tend to add to the overall signal, whereas others will subtract.

As there is often movement of the transmitter or the receiver this can cause the path lengths to change and accordingly the signal level will vary. Additionally if any of the objects being used for reflection or refraction of any part of the signal moves, then this too will cause variation. This occurs because some of the path lengths will change and in turn this will mean their relative phases will change, giving rise to a change in the summation of all the received signals.

The Rayleigh fading model can be used to analyse radio signal propagation on a statistical basis. It operates best under conditions when there is no dominant signal (e.g. direct line of sight signal), and in many instances cellular telephones being used in a dense urban environment fall into this category. Other examples where no dominant path generally exists are for ionospheric propagation where the signal reaches the receiver via a huge number of individual paths. Propagation using tropospheric ducting also exhibits the same patterns. Accordingly all these examples are ideal for the use of the Rayleigh fading or propagation model.

Radio Wave Propagation & Atmosphere

- overview of radio signals and radio-wave propagation and how different areas of the atmosphere affect radio communications.

The various effects like reflection, refraction, diffraction, etc all come together in a real way as radio signals propagate through the atmosphere. The signals are affected by a variety of factors enabling signals to be detected near and far dependent upon a variety of factors.

The way that radio signals propagate, or travel from the radio transmitter to the radio receiver is of great importance when planning a radio communications network or system.

In many instances, terrestrial radio propagation is governed to a great degree by the regions of the atmosphere through which the signals pass. Without the action of the atmosphere it would not be possible for radio communications signals to travel around the globe on the short wave bands, or travel greater than only the line of sight distance at higher frequencies.

In fact the way in which the atmosphere affects radio communications is of tremendous importance for anyone associated with radio communications, whether they are for two way radio communications links, mobile radio communications, radio broadcasting, point to point radio communications or any other radio.

In view of the importance of the atmosphere to radio communications, an overview of its make-up is given here.

Atmospheric layers

The atmosphere can be split up into a variety of different layers according to their properties.

Although there are is a number of different ways of classifying the different atmospheric regions - typically different scientific displaces may have their own nomenclature as a result of their interest in different properties.

The lowest area in the meteorological system is referred to as the Troposphere. This extends to altitudes of around 10km above the Earth's surface. Above this is the Stratosphere that extends from altitudes around 10 to 50km. Above this at altitudes between 50 and 80 km is the Mesosphere and above this is the Themosphere: named because of the dramatic rise in temperatures here.

From the viewpoint of radio propagation, there are two main areas of interest:

- ***Troposphere:*** As a very approximate rule of thumb, this area of the atmosphere tends to affect signals more above 30 MHz or so.
- ***Ionosphere:*** The ionosphere is the area that enables signals on the short wave bands to traverse major distances. It crosses over the meteorological boundaries and extends from altitudes around 60 km to 700 km. The region gains its name because the air in this region becomes ionised by radiation primarily from the sun. Free electrons in this region have affect radio signals and may be able to refract them back to Earth dependent upon a variety of factors.

Troposphere

The lowest of the layers of the atmosphere is called the troposphere. The troposphere extends from ground level to an altitude of 10 km.

It is within the tropospheric region that what we term the weather, occurs. Low clouds occur at altitudes of up to 2 km and medium level clouds extend to about 4 km. The highest clouds are found at altitudes up to 10 km whereas modern jet airliners fly above this at altitudes of up to 12 km.

Within this region of the atmosphere there is generally a steady fall in temperature with height. This affects radio propagation because it affects the refractive index of the air. This plays a dominant role in radio signal propagation and the radio communications applications that use tropospheric radio-wave propagation. This depends on the temperature, pressure and humidity. When radio communications signals are affected this often occurs at altitudes up to 2 km.

The ionosphere

The ionosphere is the area that is traditionally thought of as providing the means by which long distance communications can be made. It has a major effect on what are normally thought of as the short wave bands, providing a means by which signals appear to be reflected back to earth from layers high above the ground.

The ionosphere has a high level of free electrons and ions - hence the name ionosphere. It is found that the level of electrons sharply increases at altitudes of around 30 km, but it is not until altitudes of around 60km are reached that the free electrons are sufficiently dense to significantly affect radio signals.

The ionisation occurs as a result of radiation, mainly from the sun, striking molecules of air with sufficient energy to release electrons and leave positive ions.

Obviously when ions and free electrons meet, then they are likely to recombine, so a state of dynamic equilibrium is set up, but the higher the level of radiation, the more electrons will be freed.

Much of the ionisation is caused by ultraviolet light. As it reaches the higher reaches of the atmosphere it will be at its strongest, but as it hits molecules in there upper reaches where the air is very thin, it will ionise much of the gas. In doing this, the intensity of the radiation is reduced

At the lower levels of the ionosphere, the intensity of the ultraviolet light his much reduced and more penetrating radiation including x-rays and cosmic rays gives rise to much of the ionisation.

As a result of many factors it is found that the level of free electrons varies over the ionosphere and there are areas that affect radio signals more than others. These are often referred to as layers, but are possibly more correctly thought of a regions as they are quite indistinct in many respects. These layers are given designations D, E, and F1 and F2.

Description of ionospheric regions

- ***D region:*** The D layer or D region is the lowest of the regions that affects radio signals. It exists at altitudes between about 60 and 90 km. It is present during the day when radiation is being received from the sun, but because of the density of molecules at this altitude, free electrons and ions quickly recombine after sunset when there is no radiation to retain the ionization levels. The main effect of the D region is to attenuate signals that pass through it, although the level of attenuation decreases with increasing frequency. Accordingly its effects are very obvious on the medium wave broadcast band - during the day when the D region is present, few signals are heard beyond that provided by ground wave coverage. At night when the region is not present, signals are reflected from higher layers and signals are heard from much further afield.
- ***E region:*** Above the D region, the next region is the E region or E layer. This exists at an altitude of between 100 and 125 km. The main effect of this region is to reflect radio signals although they still undergo some attenuation.

  In view of its altitude and the density of the air, electrons and positive ions recombine relatively quickly. This means that after sunset when the source of radiation is removed, the layer reduces in strength very considerably although some residual ionisation does remain.

- ***F region:*** The F region or F layer is higher than both the D and E regions and it the most important region for long distance HF communications. During the day it often splits into two regions known as the F_1 and F_2 regions, the F_1 layer being the lower of the two.

  At night these two regions merge as a result of the reduction in level of radiation to give one region called the F region. The altitudes of the F regions vary considerably. Time of day, season and the state of the sun all have **major** effects on the F region. As a result any figures for altitude are very variable and the following figures should only be used as a very rough guide. Typical summer altitudes for the F_1 region may be approximately 300 km with the F_2 layer at about 400 km or even higher. Winter figures may see the altitudes reduced to about 200 km and 300 km. Night time altitudes may be around 250 to 300 km.

  Like the D and E regions, the level of ionization fort he F region falls at night, but in view of the much lower air density, the ions and electrons combine much more slowly and the F layer decays much more slowly. As a result it is able to support radio communications at night, although changes are experienced because of the lessening of the ionization levels.

The way in which the various regions in the atmosphere affect radiowave propagation and radio communications is a fascinating study. There are very many factors that influence radio propagation and the resulting radio communications links that can be established. Predicting the ways in which this occurs is complicated and difficult, however it is possible to gain a good idea of the likely radio communications conditions using some simple indicators. Further pages in this section of the website detail many of these aspects.

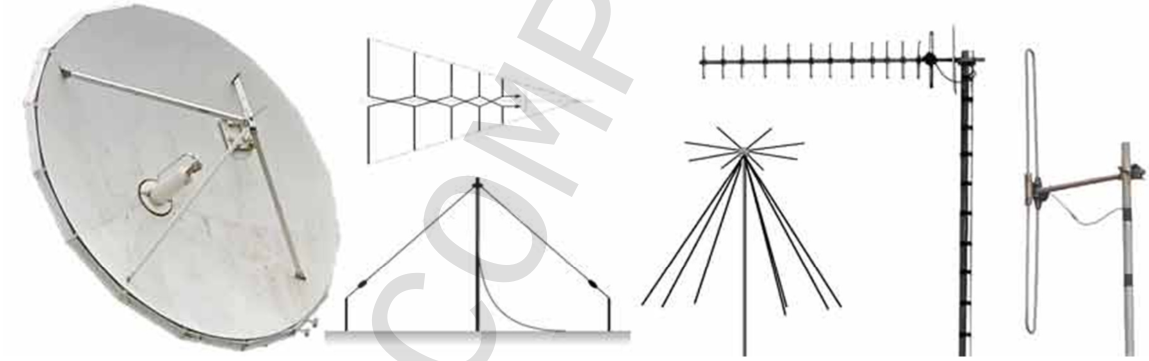
Antenna Theory: aerial basics

Radio antennas or aerials are essential to the operation of any radio system - understanding how they work and the basic theory is key to installing, optimizing and designing antennas.

Radio antennas are a key element of any radio communications broadcast or wireless system. An antenna is required to radiate and receive the signals and therefore their performance is key to the operation of the overall radio system.

If the radio antenna performance is poor, then it will limit the performance of the overall radio communications system, or whatever wireless system is using it. As such, maximising the performance of the antenna is very important. An understanding of basic radio antenna theory will help the maximum be gained from any aerial system.

In depth antenna theory can become quite complicated, but a qualitative and simplified theoretical explanation help help in understanding what is actually happening, how the radio antennas work, and how they can be optimized. This can be key when setting up a radio communications system or link.

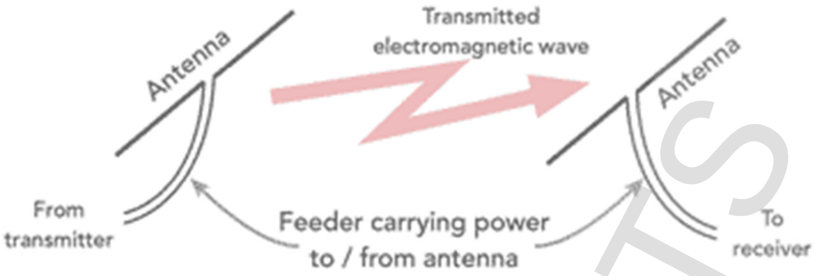


How does an antenna work

The purpose of a radio antenna is to convert the power applied to it in the form of a radio frequency alternating current signal into an electromagnetic wave.

This electromagnetic wave is able to travel through the space between the transmitting radio antenna and a receiving antenna. At the receiving end the electromagnetic wave is converted from the electromagnetic wave back into a radio frequency signal that can be applied to the input of a radio receiver.

In this way a radio antenna is able have power applied to it from which a signal int he form of an electromagnetic wave is launched. Similarly when an electromagnetic wave is incident upon an antenna it is converted from the electromagnetic wave into a radio frequency signal that can be carried to the input of the receiving equipment.



The basic theory about the way in which antennas work can be explained using Maxwell's equations. They detail the way that as the current or charges move along the antenna they produce electromagnetic waves.

Looking at how an antenna works from a more qualitative approach, it is possible to visualise a point charge that is oscillating in line with the radio frequency signal.

As a result of the oscillation of the charge the resultant electric field will also change and this changing electric field will generate a displacement current.

In turn, as a result of Ampere's Law, this current will generate a magnetic field.

In view of the fact that the oscillation of the charge, creates the varying electric field and then a magnetic field, they all vary together.

Applying Faraday's law, a changing magnetic field will created an electric field. In turn, this electric field will again create a magnetic field and the process repeats. These waves of electric and magnetic fields constitute electromagnetic waves that propagate outwards from the original point charge.

The energy of the original oscillating point charge is converted into the energy for the electromagnetic wave - in other words the power entering the antenna is converted into the energy of the electromagnetic waves.

It can also be seen that it is the current component of the signal on the antenna that gives rise to the radiated electromagnetic waves.

Transmitter & receive reciprocity

One of the key aspects about any radio antenna is whether it will receive and transmit in the same way. Any passive antenna, i.e. one that does not use an embedded electronic circuit such as an active antenna will work in the same way transmitting and receiving.

It will have the same gain, the same directional pattern, polarization, the same impedance and other aspects for both transmitting and receiving.

Often it is easier to visualize factors like the gain, and directional pattern using the image of a transmitted signal, but the antenna will have the same gain and directional pattern, etc when receiving as well.

Key antenna theory topics

There are several basic topics that are common to all radio antenna types and which form part of the basic antenna theory.

- ***Polarization:*** Radio antennas are sensitive to polarization. In just the same way that electromagnetic waves can be polarized, so too are antennas. It will be seen that some antennas have their elements in a vertical fashion and others are horizontal. This is to accommodate vertical and horizontally polarized electromagnetic waves.

  Vertical and horizontally polarized antennas receive electromagnetic waves having the same polarization - the polarization of an electromagnetic eave is defined by the plane in which the electric field is contained. If the polarization of a wave is not aligned, then the signal level will be reduced - cross polarized antennas will not receive any signals transmitted by the other. It is therefore important to ensure that the polarization of antennas in a radio communications system are the same.

  Apart from linear polarization, electromagnetic waves can also be polarized in a circular fashion - there are obviously two directions, i.e. clockwise and anticlockwise. Similar to linear polarization, the circularly polarized antennas must have the same direction of polarization to recieve signals transmitted by the other.

- ***Resonance & bandwidth:*** Resonance and bandwidth are key issues for antenna theory. Essentially the bandwidth of an antenna is the band of frequencies over which the antenna will operate within its specification. Although this may seem like a vague definition, it is actually the one that is the most useful as there are often different criteria for different antennas in different scenarios.

  Two aspects of antenna performance may limit the bandwidth. One is the reflected power, and the other is the gain.

  As many antennas are operated as resonant antennas, there is only a limited band over which they can operate. Outside these limits the level of reflected power increases and they may not be able to operate as effectively.

  The other common limitation is the gain. Many antennas like the Yagi, commonly used as a TV antenna. These antennas operate well within their given bandwidth. Outside this the directional patter will change and they will not be as effective.

  The bandwidth of antennas can be important. For some applications a very wide bandwidth is required. For example, television antennas often need to have a wide bandwidth - not only do the transmissions occupy a reasonably wide bandwidth, but more importantly the different television signals can be be spaced over a wide band, and the antenna will need to be able to receive them. For other applications, for example various wireless systems, the system may operate on a single frequency using a narrow band transmission, and for these applications antenna bandwidth can be narrow.
- ***Gain & directivity:*** Antennas do not radiate equally in all directions - only an isotropic source radiates equally in all directions and this is a theoretical entity only . In some directions practical antennas exhibit gain where the available power is focused in a particular direction, and they have a directional pattern. Antenna theory for directivity and gain is important in many areas whether for various wireless systems, radio communications or broadcasting.
- ***Feed impedance & matching:*** The input connection to an antenna presents an impedance to the feeder to which it is connected. For optimum power transfer source and load should be matched. Accordingly antenna theory associated with the feed impedance is important for the optimum operation of the antenna.

  There are many factors associated with feed impedance and there are various methods of ensuring that a good feed and matcha re obtained for any particular antenna to ensure its performance is optimized.

Although radio antenna theory may appear to be daunting, a working understanding of how antennas work, and some of the key concepts is very useful. It can be invaluable when setting up a radio communications system or link or even for installing broadcast receiving antennas, or radio antennas for any one of a number of applications.

Antenna Polarization

Radio antennas are sensitive to the polarization of electromagnetic wave and this is an important aspect of their operation.

Antenna polarization is an important factor when designing and erecting radio antennas or even incorporating them into small wireless or mobile communications systems. Some antennas are vertically polarized, others horizontal, and yet other antenna types have different forms of polarization.

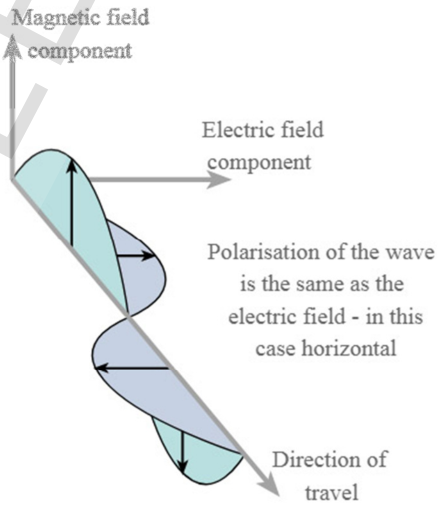
When designing an antenna, deciding on a particular form of antenna, it is important to understand which way it needs to be polarized. Radio antennas with a particular polarization will not be effective receiving electromagnetic wave signals with a different polarization.

That said, many wireless and mobile phone systems may rely on the fact that there are likely to be many reflections between the transmitter and the receiver and these will tend to mean that a signal will have a particular polarization when it reaches the receiver. Nevertheless, the polarization of the antenna is still important.

Antenna polarization basics

For the electromagnetic wave the polarization is effectively the plane in which the electric wave vibrates. This is important when looking at antennas because they are sensitive to polarization, and generally only receive or transmit a signal with a particular polarization.

For most antennas it is very easy to determine the polarization. It is simply in the same plane as the elements of the antenna. So a vertical antenna (i.e. one with vertical elements) will receive vertically polarized signals best and similarly a horizontal antenna will receive horizontally polarized signals.



An electromagnetic wave

It is important to match the polarization of the RF antenna to that of the incoming signal. In this way the maximum signal is obtained. If the RF antenna polarization does not match that of the signal there is a corresponding decrease in the level of the signal. It is reduced by a factor of cosine of the angle between the polarization of the RF antenna and the signal.

Accordingly the polarization of the antennas located in free space is very important, and obviously they should be in exactly the same plane to provide the optimum signal. If they were at right angles to one another (i.e. cross-polarized) then in theory no signal would be received.

For terrestrial radio communications applications it is found that once a signal has been transmitted then its polarization will remain broadly the same. However reflections from objects in the path can change the polarization. As the received signal is the sum of the direct signal plus a number of reflected signals the overall polarization of the signal can change slightly although it remains broadly the same.

Polarization categories

Different types of electromagnetic wave polarization propagate in slightly different ways under some circumstances.

This means that for some forms of broadcasting, radio communications or for some wireless systems, different forms of polarization may be used.

In general the advantages and disadvantages of the various forms of polarization are relatively subtle, but form some forms of broadcasting, wireless links of for radio communications or mobile communications systems these small differences can make a large difference.

There are several categories of polarization, and within each type there are several sub categories. Along with this the relevant antennas have corresponding polarizations.

- ***Linear polarization:*** Linear polarization is the most common form of antenna polarization. It is characterized by the fact that all of the radiation is in one plane - hence the term linear:
  - *Horizontal polarization:* This form of antenna polarization has horizontal elements. It picks up and radiates horizontally polarized signals, i.e. electromagnetic waves with the electric field in the horizontal plane.
  - *Vertical polarization:* This form of antenna is typified by the vertical elements within the antenna. It could be a single vertical element. One of the reasons for using vertical polarization is that antennas comprising of a single vertical element can radiate equally around it in the horizontal plane. Typically vertically polarized antennas have what is termed a low angle of radiation enabling a large proportion of their power to be radiated at an angle close to the earth's surface. Vertically polarized antennas are also very convenient for use with automobiles.
  - *Slant polarization:* This is a form of radio antenna polarization that is at an angle to the horizontal or vertical planes. In this way both vertical and horizontally polarized antennas are able to receive the signal.
- ***Circular polarization:*** This has a number of benefits for areas such as satellite applications where it helps overcome the effects of propagation anomalies, ground reflections and the effects of the spin that occur on many satellites. Circular polarization is a little more difficult to visualise than linear polarization. However it can be imagined by visualising a signal propagating from an RF antenna that is rotating. The tip of the electric field vector will then be seen to trace out a helix or corkscrew as it travels away from the antenna.
  - *Right hand circular polarization:* In this form of polarization the vector rotates in a right handed fashion.
  - *Left hand circular polarization :* In this form of polarization the vector rotates in a left handed fashion, i.e. opposite to right handed.

- ***Mixed polarization:*** Another form of polarization is known as elliptical polarization. It occurs when there is a mix of linear and circular polarization. This can be visualised as before by the tip of the electric field vector tracing out an elliptically shaped corkscrew.

It is possible for linearly polarized antennas to receive circularly polarized signals and vice versa. The strength will be equal whether the linearly polarized antenna is mounted vertically, horizontally or in any other plane but directed towards the arriving signal.

There will be some degradation because the signal level will be 3 dB less than if a circularly polarized antenna of the same sense was used. The same situation exists when a circularly polarized antenna receives a linearly polarized signal.

Applications for different types of antenna polarization

Different types of polarization are used in different applications to enable their advantages to be used. Accordingly different forms of polarization are used for different applications:

- ***General radio communications:*** Linear polarization is by far the most widely used for most radio communications applications as the radio antennas are generally simpler and more straightforward.
- ***Mobile phones and short range wireless communications:*** In recent years there has been a phenomenal amount of growth in the use of mobile phone and short range wireless communications. Everything from cellular communications to Wi-Fi and a host of other standards that enable short range wireless communications to be achieved.

  Normally linear polarization is used for these devices because linearly polarized antennas are easier to fabricate in these devices, and hence the base stations need to have a similar polarization. Although vertical polarization is often used, many items like Wi-Fi routers have adjustable antennas. Also the fact that these communications often have signal paths that may reflect from a variety of surfaces, the polarization that reaches the receiver can be relatively random, and therefore it can be less of an issue.
- ***Mobile two way radio communications:*** There are many traditional mobile two way radio communication systems still in use for everything from the emergency services to a host of private mobile radio applications where radio transceivers are located in vehicles.

  Vertical polarization is often used for these mobile two way radio communications. This is because many vertically polarized radio antenna designs have an omni-directional radiation pattern and it means that the antennas do not have to be re-orientated as positions as always happens for mobile radio communications as the vehicle moves.
- ***Long distance HF ionospheric communications:*** Both vertical and horizontal polarization are used:

  - *Horizontal polarization:* Wire antennas are widely used for HF communications. These tend to be more easily erected using two poles leaving he wire antenna to be suspended between the two. In this way the antenna is horizontally polarized.

    For large multi-element antenna arrays, mechanical constraints mean that they can be mounted in a horizontal plane more easily than in the vertical plane. This is because the RF antenna elements are at right angles to the vertical tower of pole on which they are mounted and therefore by using an antenna with horizontal elements there is less physical and electrical interference between the two.
  - *Vertical polarization:* Antennas consisting of a single vertical element are widely used. The vertically polarized antenna provides a low angle of radiation which enables it to provide good long distance transmission and reception.

- ***Medium wave broadcasting:*** Medium wave broadcast stations generally use vertical polarization because ground wave propagation over the earth is considerably better using vertical polarization, whereas horizontal polarization shows a marginal improvement for long distance communications using the ionosphere.

A typical medium wave broadcast transmitter antenna used for relatively local coverage using ground wave propagation

A vertically polarized antenna has the advantage that it will radiate equally in all directions parallel to the Earth and this has advantages for coverage. Additionally a vertical antenna only requires the vertical element - a horizontally polarized antenna would need two supports.

- ***Satellite communications:*** Circular polarization is sometimes used for satellite radio communications as there are some advantages in terms of propagation and in overcoming the fading caused if the satellite is changing its orientation.

As can be seen, each form of radio antenna polarization has its own advantages which can be utilised to effect in particular instances. Selecting the right form of polarization can provide some advantages, and therefore can be quite important.

Antenna Resonance & Bandwidth

Radio antennas have a certain bandwidth over which they can work, and most operate in a resonant mode.

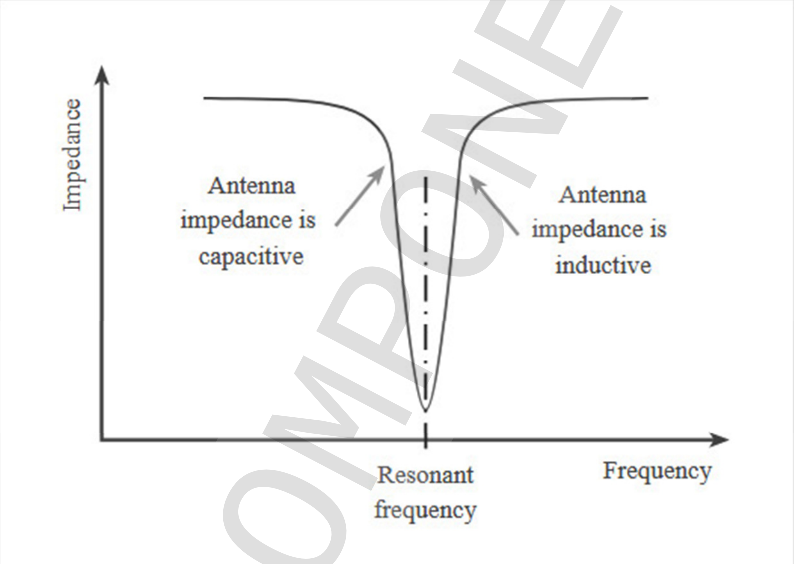
Radio antennas have a bandwidth over which they can operate effectively; even wideband antennas. Many antennas operate in a resonant mode and this gives them a relatively narrow bandwidth over which they are able to provide excellent performance.

Antenna resonance and bandwidth are two properties for antennas that are closely linked.

Whether the radio antenna is used for broadcasting, TV and radio reception, WLAN, cellular telecommunications, PMR, amateur radio, or any other application, the performance of the antenna is paramount. In this the antenna resonant frequency and the antenna bandwidth are of great importance.

Antenna resonance

A radio antenna is a form of tuned circuit consisting of inductance and capacitance, and as a result it has a resonant frequency. This is the frequency where the capacitive and inductive reactances cancel each other out. At this point the antenna appears purely resistive, the resistance being a combination of the loss resistance and the radiation resistance.



Variation of impedance of antenna

The capacitance and inductance of an RF antenna are determined by its physical properties and the environment where it is located. The major feature of the antenna design is its dimensions. It is found that the larger the antenna or more strictly the antenna elements, the lower the resonant frequency. For example antennas for UHF terrestrial television have relatively small elements, while those for VHF broadcast sound FM have larger elements indicating a lower frequency. Antennas for short wave applications are larger still.

Antenna bandwidth

An antenna bandwidth is governed by whether it is able to operate within the parameters required for that particular application. In some scenarios impedance may be an issue, in others it may be gain, or beamwidth. In this way there are several ways in which the performance of an antenna bandwidth can be judged.

In most cases, antenna are operated around the resonant point. This means that there is only a limited bandwidth over which an RF antenna design can operate efficiently. Outside this the levels of reactance rise to levels that may be too high for satisfactory operation. Other characteristics of the antenna may also be impaired away from the center operating frequency.

The antenna bandwidth is particularly important where radio transmitters are concerned as damage may occur to the transmitter if the antenna is operated outside its operating range and the radio transmitter is not adequately protected. In addition to this the signal radiated by the RF antenna may be less for a number of reasons.

For receiving purposes the performance of the antenna is less critical in some respects. It can be operated outside its normal bandwidth without any fear of damage to the set. Even a random length of wire will pick up signals, and it may be possible to receive several distant stations. However for the best reception it is necessary to ensure that the performance of the RF antenna design is optimum.

Impedance bandwidth

One major feature of an radio antenna that does change with frequency is its impedance. This in turn can cause the amount of reflected power to increase. If the radio antenna is used for transmitting it may be that beyond a given level of reflected power damage may be caused to either the transmitter or the feeder, and this is quite likely to be a factor which limits the operating bandwidth of an antenna. Today most transmitters have some form of SWR protection circuit that prevents damage by reducing the output power to an acceptable level as the levels of reflected power increase. This in turn means that the efficiency of the station is reduced outside a given bandwidth. As far as receiving is concerned the impedance changes of the antenna are not as critical as they will mean that the signal transfer from the antenna itself to the feeder is reduced and in turn the efficiency will fall. For amateur operation the frequencies below which a maximum SWR figure of 1.5:1 is produced is often taken as the acceptable bandwidth.

In order to increase the bandwidth of an antenna there are a number of measures that can be taken. One is the use of thicker conductors. Another is the actual type of antenna used. For example a folded dipole has a wider bandwidth than a non-folded one. In fact looking at a standard television antenna it is possible to see both of these features included.

Radiation pattern

Another feature of an antenna that changes with frequency is its radiation pattern. In the case of a beam it is particularly noticeable. In particular the front to back ratio will fall off rapidly outside a given bandwidth, and so will the gain. In an antenna such as a Yagi this is caused by a reduction in the currents in the parasitic elements as the frequency of operation is moved away from resonance. For beam antennas such as the Yagi the radiation pattern bandwidth is defined as the frequency range over which the gain of the main lobe is within 1 dB of its maximum.

For many beam antennas, especially high gain ones it will be found that the impedance bandwidth is wider than the radiation pattern bandwidth, although the two parameters are inter-related in many respects.

Antenna bandwidth is a key issue for any radio antenna. Whilst most antennas are operated in a resonant mode, many others are not. Whatever the radio antenna, it has a limited band over which it can operate effectively and within the parameters set out for it.

Radio Antenna Directivity, Gain & Polar Diagrams

Gain & directivity are two key factors for antennas. The two figures and linked and are important for all radio antenna systems..

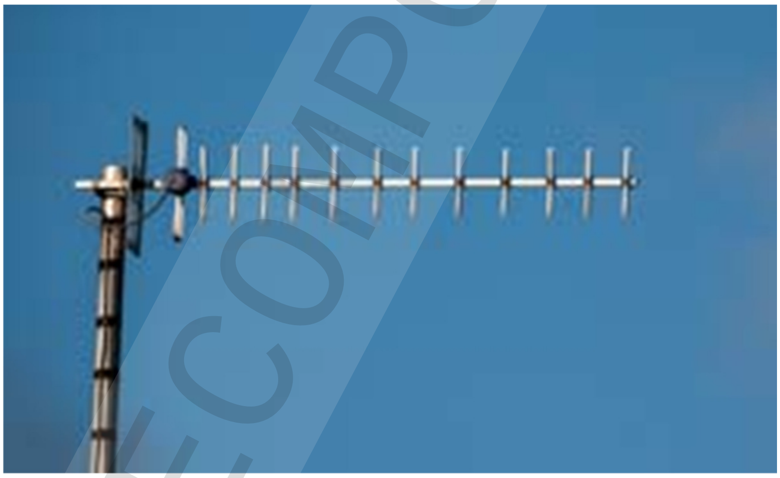
Radio antennas or aerials do not radiate equally in all directions – any real radio antenna design will radiate more in some directions than others.

The actual pattern of the radiation from the antenna is dependent upon the type of antenna design, its size, the environment and many other factors.

This directional pattern or radiation pattern as it is often called, can be used to ensure that the power radiated is focussed in the desired directions, or for a receiver, the maximum sensitivity is in the desired direction.

Antenna directivity basics

It is normal to refer to the directional patterns and gain in terms of the transmitted signal. It is often easier to visualise the radio antenna is terms of its radiated power, however the antenna performs in an exactly equivalent manner for reception, having identical figures and specifications.



Typical directional antenna used for television reception

In order to visualize the way in which a radio antenna radiates a diagram known as a polar diagram is used. This is normally a two dimensional plot around an antenna showing the intensity of the radiation at each point for a particular plane.

Normally the scale that is used is logarithmic so that the differences can be conveniently seen on the plot. Although the radiation pattern of the antenna varies in three dimensions, it is normal to make a plot in a particular plane, normally either horizontal or vertical as these are the two that are most used, and it simplifies the measurements and presentation.

Radio antenna designs are often categorized by the type of polar diagram they exhibit. For example an omni-directional antenna design is one which radiates equally (or approximately equally) in all directions in the plane of interest. An antenna design that radiates equally in all directions in all planes is called an isotropic antenna. As already mentioned it is not possible to produce one of these in reality, but it is useful as a theoretical reference for some measurements. Other RF antennas exhibit highly directional patterns and these may be utilized in a number of applications. The Yagi antenna is an example of a directive antenna and possibly it is most widely used for television reception.

Radio antenna beamwidth

There are a number of key features that can be seen from this polar diagram. The first is that there is a main beam or lobe and a number of minor lobes. It is often useful to define the beam-width of an RF antenna. This is taken to be angle between the two points where the power falls to half its maximum level, and as a result it is sometimes called the half power beam-width.

Radio antenna gain

A radio antenna radiates a given amount of power. This is the power dissipated in the radiation resistance of the Radio antenna. An isotropic radiator will distribute this equally in all directions. For an antenna with a directional pattern, less power will be radiated in some directions and more in others. The fact that more power is radiated in given directions implies that it can be considered to have a gain.

The gain can be defined as a ratio of the signal transmitted in the "maximum" direction to that of a standard or reference antenna. This may sometimes be called the "forward gain". The figure that is obtained is then normally expressed in decibels (dB). In theory the standard antenna could be almost anything but two types are generally used. The most common type is a simple dipole as it is easily available and it is the basis of many other types of antenna. In this case the gain is often expressed as dBd i.e. gain expressed in decibels over a dipole. However a dipole does not radiated equally in all directions in all planes and so an isotropic source is sometimes used. In this case the gain may be specified in dBi i.e. gain in decibels over an isotropic source.

The main drawback with using an isotropic source (antenna dBi) as a reference is that it is not possible to realise them in practice and so that figures using it can only be theoretical. However it is possible to relate the two gains as a dipole has a gain of 2.1 dB over an isotropic source i.e. 2.1 dBi. In other words, figures expressed as gain over an isotropic source will be 2.1 dB higher than those relative to a dipole.

When choosing an antenna and looking at the gain specifications, be sure to check whether the gain is relative to a dipole or an isotropic source, i.e. the antenna dBi figure of the antenna dBd figure.

Apart from the forward gain of an antenna another parameter which is important is the front to back ratio. This is expressed in decibels and as the name implies it is the ratio of the maximum signal in the forward direction to the signal in the opposite direction.

Polar diagram of a Yagi antenna showing front to pack ratio

This figure is normally expressed in decibels. It is found that the design of an antenna can be adjusted to give either maximum forward gain of the optimum front to back ratio as the two do not normally coincide exactly. For most VHF and UHF operation the design is normally optimized for the optimum forward gain as this gives the maximum radiated signal in the required direction.

$$\text{FB ratio (dB)}=10\log10(\text{FB})$$

Where:

F = power in forward direction
B = power in back direction

Radio antenna gain / beamwidth balance

There are several parameters that need to be balanced when adjusting an antenna design. It may appear that seeking a high forward gain is the main requirement, but it is worth remembering that as the forward gain increases, so t e beamwidth narrows. Very narrow beamwidth antennas required accurate setting, and they must also be able to maintain their setting and not be blown about by the wind, etc.

An additional factor to remember is that as directional antenna designs have many interacting elements to them, the maximum forward gain may not correspond to other parameters like the maximum front to back ratio. When developing an antenna, it is necessary to ensure that the design meets the actual operational requirements rather then just a theoretical specification.

Antenna Feed Impedance

The feed impedance of an antenna is a key element associated with its performance. To achieve the maximum efficient, its feeder must have the same impedance.

A radio antenna is like any other form of RF load or signal source. It has a load or source impedance.

In order to obtain the optimum performance the antenna feeder must be matched to antenna to ensure the maximum power transfer.

Accordingly it important to understand the feed impedance of any antenna so that the best performance can be obtained.

Antenna feed impedance basics

This impedance is known as the antenna feed impedance. It is a complex impedance and it is made up from several constituents: resistance, capacitance and inductance.

The feed impedance of the antenna results from a number of factors including the size and shape of the RF antenna, the frequency of operation and its environment. The impedance seen is normally complex, i.e. consisting of resistive elements as well as reactive ones.

Antenna feed impedance resistive elements

The resistive elements are made up from two constituents. These add together to form the sum of the total resistive elements.

- ***Loss resistance:*** The loss resistance arises from the actual resistance of the elements in the RF antenna, and power dissipated in this manner is lost as heat. Although it may appear that the "DC" resistance is low, at higher frequencies the skin effect is in evidence and only the surface areas of the conductor are used. As a result the effective resistance is higher than would be measured at DC. It is proportional to the circumference of the conductor and to the square root of the frequency.

  The resistance can become particularly significant in high current sections of an RF antenna where the effective resistance is low. Accordingly to reduce the effect of the loss resistance it is necessary to ensure the use of very low resistance conductors.
- ***Radiation resistance:*** The other resistive element of the impedance is the "radiation resistance". This can be thought of as virtual resistor. It arises from the fact that power is "dissipated" when it is radiated from the RF

antenna. The aim is to "dissipate" as much power in this way as possible. The actual value for the radiation resistance varies from one type of antenna to another, and from one design to another. It is dependent upon a variety of factors. However a typical half wave dipole operating in free space has a radiation resistance of around 73 Ohms.

Antenna reactive elements

There are also reactive elements to the feed impedance. These arise from the fact that the antenna elements act as tuned circuits that possess inductance and capacitance. At resonance where most antennas are operated the inductance and capacitance cancel one another out to leave only the resistance of the combined radiation resistance and loss resistance. However either side of resonance the feed impedance quickly becomes either inductive (if operated above the resonant frequency) or capacitive (if operated below the resonant frequency).

Efficiency

It is naturally important to ensure that the proportion of the power dissipated in the loss resistance is as low as possible, leaving the highest proportion to be dissipated in the radiation resistance as a radiated signal. The proportion of the power dissipated in the radiation resistance divided by the power applied to the antenna is the efficiency.

A variety of means can be employed to ensure that the efficiency remains as high as possible. These include the use of optimum materials for the conductors to ensure low values of resistance, large circumference conductors to ensure large surface area to overcome the skin effect, and not using designs where very high currents and low feed impedance values are present. Other constraints may require that not all these requirements can be met, but by using engineering judgement it is normally possible to obtain a suitable compromise.

It can be seen that the antenna feed impedance is particularly important when considering any RF antenna design. However by maximising the energy transfer by matching the feeder to the antenna feed impedance the antenna design can be optimised and the best performance obtained.

Difference between dBu, dBm, dBuV, and other field intensity units?

There is a great deal of confusion when engineers, technicians, and equipment salespersons talk about units of antenna gain and field strength. This FAQ discusses units of gain and field intensity and explains how to convert between some of these units when appropriate.

Units of Antenna Gain

While field strength at any location is independent of antenna gain, received voltage at the receiver is not. Therefore, let us first consider antenna gain.

Gain may be expressed as either a power multiplier or in dB. Antenna gain stated in dB is referenced to either isotropic or a half-wave dipole. The microwave industry has universally established the convention of reporting antenna gain in dBi (referenced to isotropic). The land mobile industry has almost universally expressed antenna gain as dBd (referenced to a half-wave dipole rather than isotropic.) When a manufacturer lists a gain as dB, you may generally assume that the referenced gain is dBd. Broadcast antenna manufacturers commonly refer to a multiplier gain where the antenna input power is multiplied by this gain to yield the effective radiated power.

The simplest antenna is an isotropic radiator. This is a theoretical antenna that radiates the same level of energy in all directions when power is applied to the antenna. Even though this type of an antenna cannot actually be constructed, the use of the concept provides a uniform standard against which the performance of all manufactured antennas can be calibrated and compared.

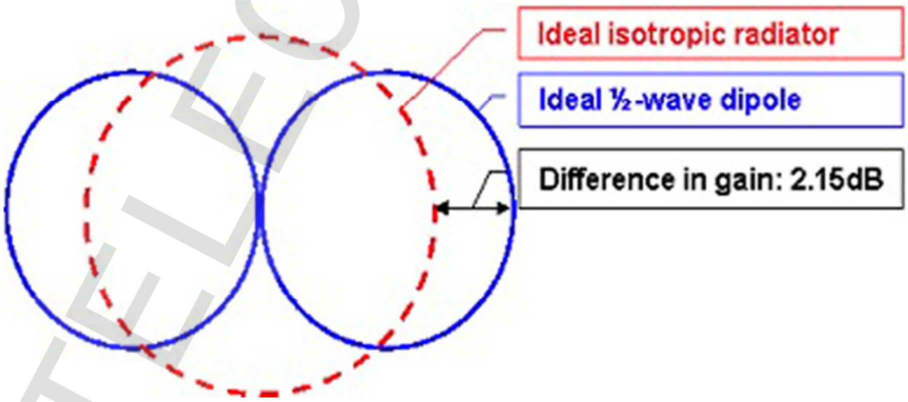


Figure 1 Half wave dipole vs isotropic antenna

An antenna which can be easily built is a half-wavelength dipole. A half-wavelength dipole antenna has a gain of 2.15 dB greater than an isotropic antenna. The dipole concentrates the energy in certain directions, so that the radiation in those directions is greater than the radiation from an isotropic source with the same input power.

Therefore, the gain of an antenna referenced to an isotropic radiator is the gain referenced to a half-wavelength dipole plus 2.15 dB:

(1) GdBi = GdBd + 2.15

As shown in Figure 1 (and Figure 2) a directional antenna (including a half-wave dipole) can be considered to concentrate the available energy fed into the antenna, focusing the energy radiated from the antenna into the desired direction. The energy radiated in the desired direction(s) is increased by reducing the energy radiated in some other direction(s).

For example, a collinear array of four dipole antennas will typically have a gain of 6 dBd. This same antenna will have a gain of 8.15 dBi (referenced to isotropic).

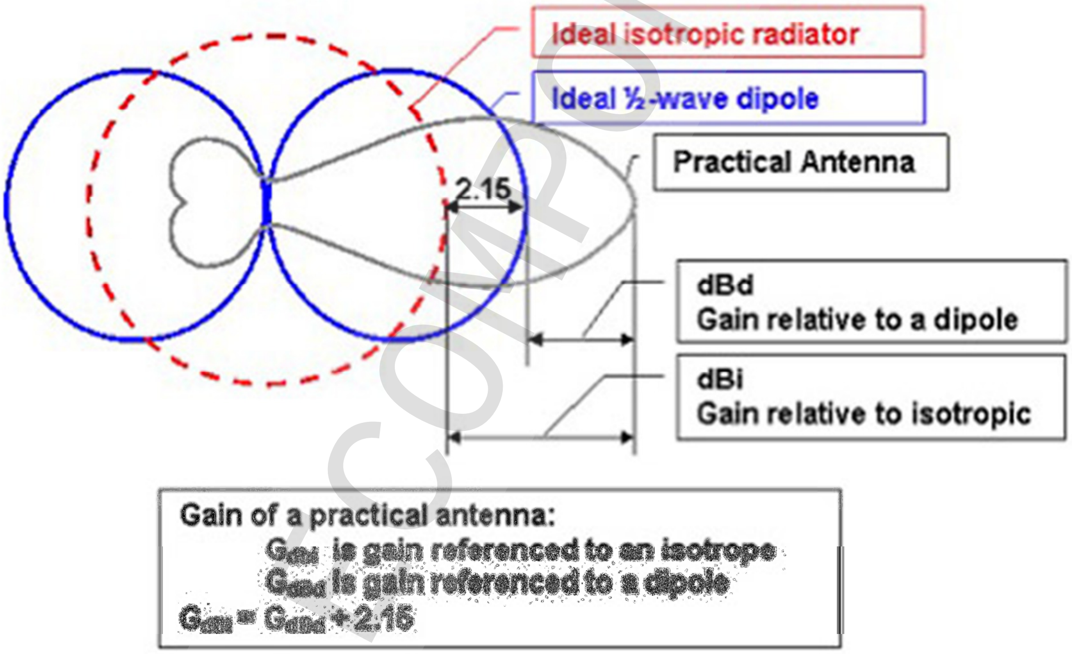


Figure 2 Gain in dBd vs dBi

Directional antenna patterns are sometimes plotted as gain in dB above a half-wave dipole. Other patterns are shown as a relative field voltage. These are directly transferable as long as one knows the absolute gain in dBd or dBi of the major lobe of the antenna. The equation is as follows:

(2) G(dB) = Gm(dBd) + 20 log Rv

WHERE:

- G is the gain in dB on a particular azimuth
- Gm is the maximum power gain in dB referenced to a half-wave dipole
- Rv is the relative field voltage for the particular azimuth

To convert the gain value (in dB) on a particular azimuth to a relative field value, use the following equation:

$$(3)\ Rv = 10(G - Gm)/20$$

When the maximum effective radiated power and the relative field voltage on a particular azimuth are known, the effective radiated power on that particular azimuth is calculated from the following equation:

$$(4)\ Rp = P\ (Rv)2$$

WHERE:

- Rp is the effective radiated power on a particular azimuth (in watts, kW, etc.)
- P is the effective radiated power in the major lobe (max) in the horizontal plane (in W, kW, etc.)

Units of Field Intensity

There is also a great deal of confusion in the vocabulary for field strength (also called field intensity). Values are commonly expressed in dBu, dBµV, and dBm. Each unit has both merit and common usage in certain disciplines in the radio communications industry. However, the widespread confusion about how they relate to one another causes both frustration and misunderstandings about system design and actual performance. The following terms will be discussed at length.

- dBu is E (electric field intensity) always in decibels above one microvolt/meter (dBµV/m)
- dBµV (using the Greek letter µ ["mu"] instead of u) is voltage expressed in dB above one microvolt into a specific load impedance; in land mobile and broadcast this is commonly 50 ohms.
- dBm is a power level expressed in dB above one milliwatt

Electric Field Intensity

The electric field intensity unit dBu is the unit used extensively by the Federal Communications Commission when referring to field strength. True electric field strength is always expressed in some relative value of volts/meter – never in volts or milliwatts. Electric field intensity is independent of frequency, receiving antenna gain, receiving antenna impedance and receiving transmission line loss. Therefore, this measure can be used as an absolute measure for describing service areas and comparing different transmitting facilities independent of the many variables introduced by different receiver configurations.

When a path has unobstructed line of sight and no obstructions fall within 0.5 of the first Fresnel zone, which would introduce additional attenuation, the received electric field strength will approximate that of free space and may be calculated from the following equation:

(5) $E(dB\mu V/m) = 106.92 + ERP(dBk) - 20 \log d(km)$

WHERE:

- ERP is expressed in dB above 1 kW
- d is distance expressed in kilometers

Received Voltage and Power

Although calculations of electric field strength are independent of the receiver characteristics mentioned above, predictions of voltage and received power supplied to the input of a receiver must carefully take each of these factors into account. Correlation between electric field strength and voltage applied to the receiver input is impossible unless all of the above listed information is known and considered in the system design.

When the exact same conditions (path, frequency, effective radiated power, etc.) are applied to identical circumstances, the following equations will allow the system designer to translate between the various systems with complete confidence.

Field strength as a function of received voltage, receiving antenna gain and frequency when applied to an antenna whose impedance is 50 ohms can be expressed as:

(6) $E(dB\mu V/m) = E(dB\mu V) - Gr(dBi) + 20\log f(MHz) - 29.8$

Solved for received voltage this equation becomes:

(7) $E(dB\mu V) = E(dB\mu V/meter) + Gr(dBi) - 20\log f(MHz) + 29.8$

For Power and Voltage calculations into a 50 ohm load:

(8) $P(dBm) = E(dB\mu V) - 107$

Substituting the field value for the voltage from Eq. 7:

(9) $P(dBm) = E(dB\mu V/m) + Gr(dBi) - 20\log F(MHz) - 77.2$

Note the more general equation for values of impedance (Z) other than 50Ω is:

$$(8a)\ P(\mathrm{dBm}) = E\ (\mathrm{dB\mu V}) - 20\log(\sqrt{Z}) - 90$$

And substituting the field value for the voltage from Eq. 7:

$$(9a)\ P(\mathrm{dBm}) = E\ (\mathrm{dB\mu V/m}) + Gr(\mathrm{dBi}) - 20\log F(\mathrm{MHz}) - 20\log(\sqrt{Z}) - 60.2$$

WHERE:

- Gr is the isotropic gain of the receiving antenna
- Z is the system impedance in Ohms

When a “field strength contour” is plotted and identified in dBm or microvolts (dBµV), it is important to know these values of frequency and antenna gain. The user must understand that such “contours” are only valid for one frequency and the particular receiving antenna gain used for the prediction. There is also a fixed loss in the receiving antenna transmission line – often assumed to be lossless.

For these reasons, such “contours” are ambiguous as coverage predictions, when all receiving antenna gains and transmission line losses are not identical for all receivers. To determine the level of field strength necessary to adequately receive a transmitted signal, use Equation 6 above, taking into account the frequency, receiving antenna gain and required level of receiver voltage for the desired level of quieting in the receiver.

These predictions are for the voltage at the antenna terminals. Actual voltage and power levels at the receiver input must take into account the additional loss present in the receiving transmission line. This loss in signal is particularly critical at high frequencies when cables are long.

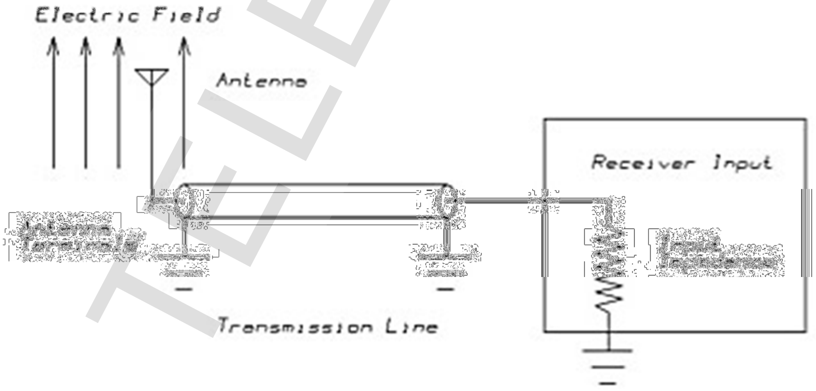


Figure 3 Electric Field and received voltage and power

Figure 3 summarizes the relationship between electric field strength and the voltage and power at the receiver input terminals.

The electric field strength (in dBu) is a function only of:

- Transmitter effective radiated power.
- Distance from the transmitter.
- Losses from terrain obstructions.

Since the electric field strength is independent of any receiver characteristics, it is a useful standard for computing coverage areas.

The electric field induces a voltage into the antenna, transferring power into the antenna. The voltage (dBµV) at the terminals of the antenna is a function of the gain of the antenna for the particular frequency under consideration. The power (dBm) available at the antenna terminals is also a function of the antenna impedance (usually 50 Ohms).

The transmission line (usually coaxial cable or waveguide) connects the antenna terminals to the receiver input terminals. The voltage and power at the receiver input terminals are reduced by the loss in this transmission line. Transmission line losses are a function of the size and type of the transmission line and the operating frequency. In addition, other losses affect the power transferred to the receiver input terminals. See “Typical Loss Values” in the Technical Reference section for more information about losses inside vehicles, losses due to body proximity with handheld receivers, etc.

Conclusion

The obvious conclusion from this information is that receiving systems with different antenna gains require significantly different electric field strength values for proper operation. A service area contour (in dBµV or dBm) computed for a mobile receiver with a high gain permanently mounted roof antenna can be misleading to users with low gain antenna hand-held units.

Based on the actual equipment proposed and the above equations, the system designer can now calculate the actual field strength necessary for any particular receiving system. Operating the receivers in areas where the field strength meets or exceeds the design level for the equipment can be expected to produce satisfactory system performance. The Field Intensity Grids technical reference section discusses the conversion of electric field intensity values (computed in dBu with TAP) to other units for plotting directly in dBm or dBµV.

How to convert dBm to watts

The power conversion of dBm to watts is given by the formula:
$P_{(W)} = 1W \cdot 10^{(P_{(dBm)} / 10)} / 1000 = 10^{((P_{(dBm)} - 30) / 10)}$

Example

Convert 43dBm to watts:
$P_{(W)} = 1W \cdot 10^{(43dBm/ 10)} / 1000 = 19.9526W$

How to convert watts to dBm

The power $P_{(dBm)}$ in dBm is equal to 10 times the base 10 logarithm of 1000 times the power $P_{(W)}$ in watts (W) divided by 1 watt (W):
$P_{(dBm)} = 10 \cdot \log_{10}(1000 \cdot P_{(W)} / 1W) = 10 \cdot \log_{10}(P_{(W)} / 1W) + 30$
so
1W = 30dBm

Example
Convert 20 watts to dBm:
$P_{(dBm)} = 10 \cdot \log_{10}(1000 \cdot 20W) = 43.0103dBm$

How to convert dBm to dbmV, dBV,DbuV (50 ohm)

dBmV= dBm + 47 dB

dBV= dBm – 13 dB

dBuV=dBm + 107 dB

How to convert dBm to dbmV, dBV,DbuV (75 ohm)

dBmV= dBm – 48.75 dB

dBV= dBm – 11.25 dB

dBuV=dBm + 108.75 dB

Conversion table dBm to

microwatt(uW), milliwatt(mW), Watt , Kilowatt(KW), Megawatt(MW)

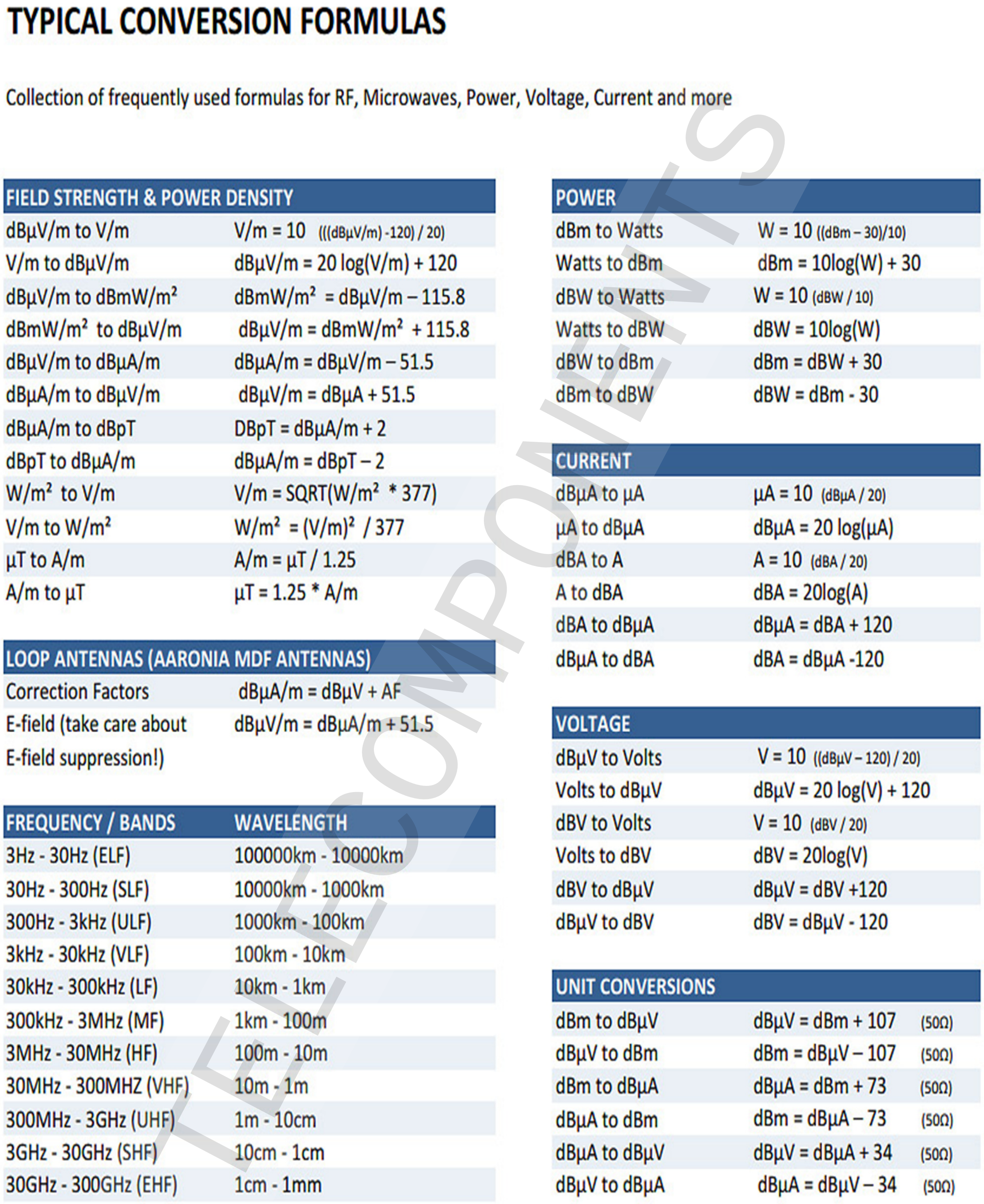
Power (dBm)	Power	Power (dBm)	Power
-60 dbm	0.001uW	10 dBm	10 mW
-50 dbm	0.01uW	20 dBm	100 mW
-40 dbm	0.1uW	30 dBm	1 W
-30 dBm	0.001 mW (1uW)	40 dBm	10 W
-20 dBm	0.01 mW	50 dBm	100 W
-10 dBm	0.1mW	60 dBm	1000 W (1 KW)
0 dBm	0.001 W (1 mW)	70 dBm	10 KW
1 dBm	1.2589 mW	80 dBm	100 KW
2 dBm	1.5849 mW	90 dBm	1000 KW (1 MW)
3 dBm	1.9953 mW	100 dBm	10 MW
4 dBm	2.5119 mW	110 dBm	100 MW
5 dBm	3.1628 mW	120 dBm	1000 MW
6 dBm	3.9811 mW		
7 dBm	5.0119 mW		
8 dBm	6.3096 mW		
9 dBm	7.9433 mW		

Watt to dBm conversion table

Power (mW)	Power (dBm)
0 W	not defined
0^+ W	-∞ dBm
01 W	-20 dBm
0.0001 W	-10 dBm
0.001 W	0 dBm
0.01 W	10 dBm
0.1 W	20 dBm
1 W	30 dBm
10 W	40 dBm
100 W	50 dBm
1000 W	60 dBm
10000 W	70 dBm
100000 W	80 dBm
1000000 W	90 dBm

dbm /millivolts / milliWatts conversion table

DBM	MILLIWATTS	VOLTAGE MILLIVOLTS (P-P)	VOLTAGE MILLIVOLTS (RMS)		DBM	WATTS	VOLTAGE MV (P-P)	VOLTAGE MV (RMS)
-30	0.0010	20	7.1		30	1.00	20	7.10
-28	0.0016	25.2	8.9		32	1.58	25.2	8.94
-26	0.0025	31.7	11.2		34	2.51	31.7	11.3
-24	0.0040	40.0	14.2		36	3.98	40.0	14.1
-22	0.0063	50.2	17.8		38	6.31	50.2	17.8
-20	0.010	63.2	22.4		40	10.0	63.2	22.4
-18	0.016	79.6	28.2		42	15.9	79.6	28.2
-16	0.025	100	35.5		44	25.1	100	35.5
-14	0.040	126	44.7		46	39.8	126	44.7
-12	0.063	159	56.4		48	63.1	159	56.4
-10	0.100	200	71.0		50	100	200	71.0
-8	0.16	252	89.4		52	159	252	89.4
-6	0.25	317	112		54	251	317	112
-4	0.40	399	142		56	398	399	142
-2	0.63	502	178		58	631	502	178
0	1.00	0.632	0.224		60	1000	632	224
2	1.58	0.796	282		62	1585	796	282
4	2.51	4.00	1.42					
6	3.98	1.26	0.45					
8	6.31	1.59	0.56					
10	10	2.00	0.71					
12	15.8	2.52	0.89					
14	25.1	3.17	1.12					
16	39.8	3.99	1.41					
18	63.1	5.02	1.78					
20	100	6.32	2.24					
22	158	7.95	2.82					
24	25.1	10.0	3.55					
26	398	12.6	4.48					
28	631	15.9	5.64					
30	1000	20.0	7.10					
32	1585	25.2	8.94					
34	2510	31.7	11.2					



TYPICAL CONVERSION FORMULAS

Collection of frequently used formulas for RF, Microwaves, Power, Voltage, Current and more

FIELD STRENGTH & POWER DENSITY

dBµV/m to V/m	$V/m = 10^{(((dB\mu V/m) - 120) / 20)}$
V/m to dBµV/m	dBµV/m = 20 log(V/m) + 120
dBµV/m to $dBmW/m^2$	$dBmW/m^2$ = dBµV/m – 115.8
$dBmW/m^2$ to dBµV/m	dBµV/m = $dBmW/m^2$ + 115.8
dBµV/m to dBµA/m	dBµA/m = dBµV/m – 51.5
dBµA/m to dBµV/m	dBµV/m = dBµA + 51.5
dBµA/m to dBpT	DBpT = dBµA/m + 2
dBpT to dBµA/m	dBµA/m = dBpT – 2
W/m^2 to V/m	V/m = SQRT(W/m^2 * 377)
V/m to W/m^2	$W/m^2 = (V/m)^2 / 377$
µT to A/m	A/m = µT / 1.25
A/m to µT	µT = 1.25 * A/m

LOOP ANTENNAS (AARONIA MDF ANTENNAS)

Correction Factors	dBµA/m = dBµV + AF
E-field (take care about E-field suppression!)	dBµV/m = dBµA/m + 51.5

FREQUENCY / BANDS	WAVELENGTH
3Hz - 30Hz (ELF)	100000km - 10000km
30Hz - 300Hz (SLF)	10000km - 1000km
300Hz - 3kHz (ULF)	1000km - 100km
3kHz - 30kHz (VLF)	100km - 10km
30kHz - 300kHz (LF)	10km - 1km
300kHz - 3MHz (MF)	1km - 100m
3MHz - 30MHz (HF)	100m - 10m
30MHz - 300MHZ (VHF)	10m - 1m
300MHz - 3GHz (UHF)	1m - 10cm
3GHz - 30GHz (SHF)	10cm - 1cm
30GHz - 300GHz (EHF)	1cm - 1mm

POWER

dBm to Watts	$W = 10^{((dBm - 30)/10)}$
Watts to dBm	dBm = 10log(W) + 30
dBW to Watts	$W = 10^{(dBW / 10)}$
Watts to dBW	dBW = 10log(W)
dBW to dBm	dBm = dBW + 30
dBm to dBW	dBW = dBm - 30

CURRENT

dBµA to µA	$\mu A = 10^{(dB\mu A / 20)}$
µA to dBµA	dBµA = 20 log(µA)
dBA to A	$A = 10^{(dBA / 20)}$
A to dBA	dBA = 20log(A)
dBA to dBµA	dBµA = dBA + 120
dBµA to dBA	dBA = dBµA -120

VOLTAGE

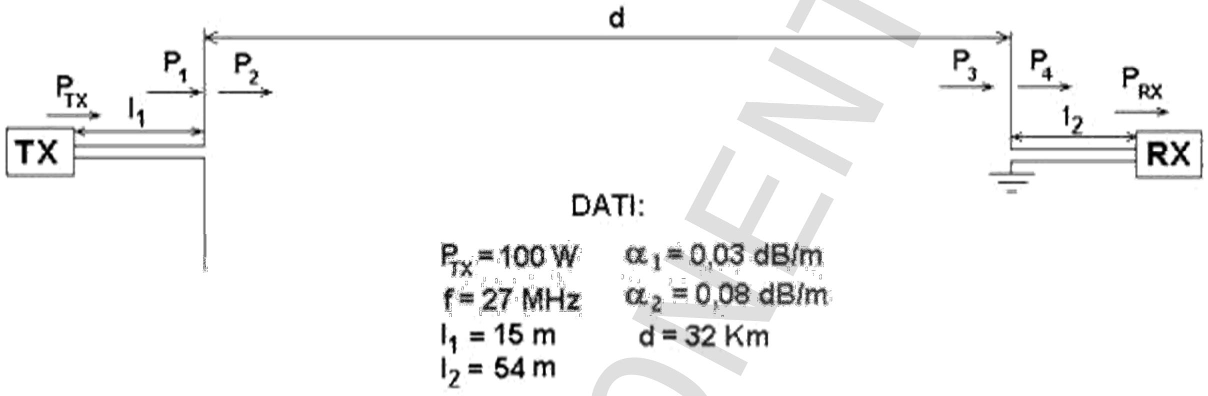
dBµV to Volts	$V = 10^{((dB\mu V - 120) / 20)}$
Volts to dBµV	dBµV = 20 log(V) + 120
dBV to Volts	$V = 10^{(dBV / 20)}$
Volts to dBV	dBV = 20log(V)
dBV to dBµV	dBµV = dBV +120
dBµV to dBV	dBV = dBµV - 120

UNIT CONVERSIONS

dBm to dBµV	dBµV = dBm + 107	(50Ω)
dBµV to dBm	dBm = dBµV – 107	(50Ω)
dBm to dBµA	dBµA = dBm + 73	(50Ω)
dBµA to dBm	dBm = dBµA – 73	(50Ω)
dBµA to dBµV	dBµV = dBµA + 34	(50Ω)
dBµV to dBµA	dBµA = dBµV – 34	(50Ω)

AIR TRANSMISSION BETWEEN TWO ANTENNAS(Example)

We want to determine the power at the input of the RX receiver, knowing the power supplied by the TX transmitter, according to the diagram shown in the figure, assuming antennas, cables, transmitter and receiver adapted to each other and the efficiency of each of the two antennas by 96%.



DATI:

$P_{TX} = 100\ W$ $\alpha_1 = 0,03\ dB/m$
$f = 27\ MHz$ $\alpha_2 = 0,08\ dB/m$
$l_1 = 15\ m$ $d = 32\ Km$
$l_2 = 54\ m$

Also determine the lengths of the transmitter antenna, of the Hertzian type, and of the receiver, of the Marconian type

Let's first calculate the wavelength ▯:

$$\lambda = \frac{c}{f} = \frac{3 \cdot 10^8}{27 \cdot 10^6} = 11,1\ m$$

The Ptx power, supplied by the generator, is attenuated by cable l1 which has total attenuation in dB:

$$\alpha_{1tot} = \alpha_1 \cdot l_1 = 0,03 \cdot 15 = 0,45\ dB$$

and it reduces to the value of P1 that can be obtained from the definition of attenuation in decibels:

$$\alpha_{1TOT} = 10 \log_{10} \frac{P_{TX}}{P_1}$$

Substituting the known or calculated values, we obtain:

$$0,45 = 10 \log_{10} \frac{100}{P_1}$$

Dividing the first and second members by 10 we have:

$$0{,}045 = \log_{10} \frac{100}{P_1}$$

From this expression, passing from logarithms to numbers, we obtain:

$$10^{0{,}045} = \frac{100}{P_1}$$

from which making the inverse formula, we obtain:

$$P_1 = \frac{100}{10^{0{,}045}} = 90{,}2\ W$$

This power is fed into the antenna which loses 4% due to the Joule effect and transmits 96%, that is:

$$P_{j\,1} = 0{,}04 \cdot 90{,}2 = 3{,}61\ W$$

$$P_2 = 0{,}96 \cdot 90{,}2 = 86{,}6\ W$$

At this point we must take into account the gain of the Marconian antenna, the gain of the Hertzian one, and the attenuation of the free space, as indicated by the fundamental transmission formula:

$$P_3 = \frac{P_2 \cdot G_{TX} \cdot G_{RX}}{A_{SL}}$$

We recall the values of the two gains and the formula for attenuating free space:

$$G_{TX} = 1{,}65$$

$$G_{RX} = 3{,}3$$

$$A_{SL} = \left(\frac{4 \cdot \pi \cdot d}{\lambda}\right)^2 = \left(\frac{4 \cdot \pi \cdot 32.000}{11{,}1}\right)^2 = 1{,}31 \cdot 10^9$$

Substituting the values found, the power arriving at the receiving antenna P2 is obtained from the fundamental formula of the transmission:

$$P_3 = \frac{P_2 \cdot G_{TX} \cdot G_{RX}}{A_{SL}} = \frac{86{,}6 \cdot 1{,}65 \cdot 3{,}3}{1{,}31 \cdot 10^9} = 359 \cdot 10^{-9} W = 359\ nW$$

Here too, part of the signal turns into heat on the antenna, and part enters the cable l2:

$$P_{j2} = 0{,}04 \cdot 359 \cdot 10^{-9} = 14{,}4 \cdot 10^{-9} W = 14{,}4\ nW$$

$$P_4 = 0{,}96 \cdot 359 \cdot 10^{-9} = 345 \cdot 10^{-9} W = 345\ nW$$

At this point the signal is attenuated by the reception cable which has total attenuation:

$$\alpha_{2TOT} = \alpha_2 \cdot l_2 = 0{,}08 \cdot 54 = 4{,}32\ dB$$

To calculate the TRX power that arrives at the receiver, write the decibel attenuation formula:

$$\alpha_{2TOT} = 10 \log_{10} \frac{P_4}{P_{RX}}$$

Substituting the known or calculated values, we obtain:

$$4{,}32 = 10 \log_{10} \frac{345 \cdot 10^{-9}}{P_{RX}}$$

Dividing the first and second members by 10 we have:

$$0{,}432 = \log_{10} \frac{345 \cdot 10^{-9}}{P_{RX}}$$

From this expression, passing from logarithms to numbers, we obtain:

$$10^{0,432} = \frac{345 \cdot 10^{-9}}{P_{RX}}$$

from which making the inverse formula, we obtain:

$$P_{RX} = \frac{345 \cdot 10^{-9}}{10^{0,432}} = 128 \cdot 10^{-9} W = 128\ nW$$

The lengths of the two antennas, in first approximation, are given by the formulas:

$$l_1 = \frac{\lambda}{2} = \frac{11,1}{2} = 5,55\ m$$
$$l_2 = \frac{\lambda}{4} = \frac{11,1}{4} = 2,78\ m$$

If, on the other hand, you want to take into account the effect of the edges and the lower speed of the signal on the antenna compared to the free space, then you can calculate the more precise formula:

$$l_1' = 0,95\frac{\lambda}{2} = 0,95\frac{11,1}{2} = 5,27\ m$$
$$l_2' = 0,95\frac{\lambda}{4} = 0,95\frac{11,1}{4} = 2,64\ m$$

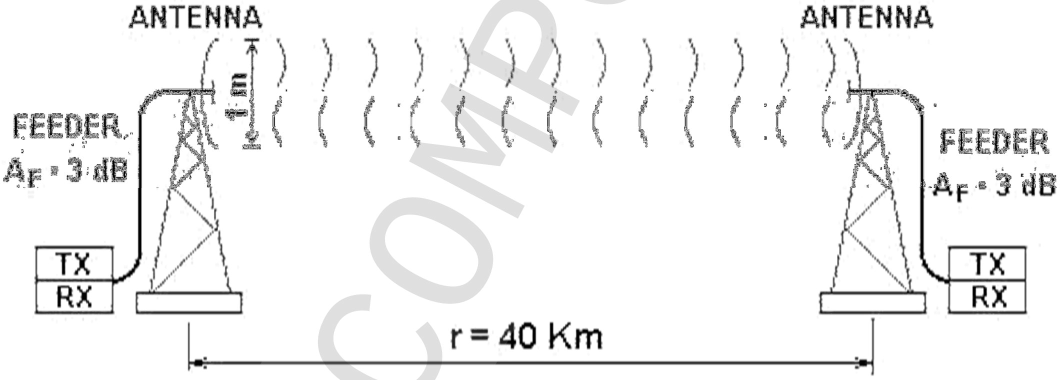
****

FREQUENCY MODULATION RADIO LINK TRANSMISSION (Example)

A radio link operating in FM at a frequency with this data:

- Frequency Link: **2.3 GHz**
- Distance**: 40 km**
- Band Modulation B = **1 MHz**
- Frequency deviation of **Df = 4 MHz**.
- Transmitter Power: **10 W**
- Overall attenuation of the feeder(wavguide)= **3 dB.**
- Antenna Tx parabolic Diameter **D: 1 m**
- Antenna Rx parabolic Diameter **D: 1 m**
- The receiver is characterized by a band equal to that of the modulated signal, and by a noise figure equal to: **F (dB) = 8 dB.**

We want evaluate the connection quality, if you want an availability time equal to 99%, corresponding to a fading margin of 18 dB, with an S/N ratio in reception, equal to a minimum of 30 dB.



We want to verify the S / N reception ratio is not less than 30 dB.

We therefore calculate both S, i.e. the signal strength in reception, and N, i.e. the noise power in reception.

CALCULATION OF S AT THE ENTRANCE TO THE RECEIVER.

Based on the general transmission formula, the receiving power is:

$$P_R = P_T \cdot G_T \cdot G_R \cdot \left(\frac{\lambda}{4\pi r}\right)^2 = \frac{P_T \cdot G_T \cdot G_R}{\left(\frac{4\pi r}{\lambda}\right)^2}$$

This expression, calling the parenthesis in the denominator attenuation of the free space:

$$A_{SL} = \left(\frac{4\pi r}{\lambda}\right)^2$$

it is much more often calculated using dB for gains and attenuation, and dBm for powers.

$$P_R(dB_m) = P_T(dB_m) + G_T(dB) + G_R(dB) - A_{SL}(dB)$$

However, remember that the two feeders have an attenuation of:

$$A_F(dB) = 3\ dB$$

each, and that a power margin of:

$$M_F(dB) = 18\ dB$$

to compensate for fading fluctuations, the power required in reception must be:

$$P_R(dB_m) = P_T(dB_m) + G_T(dB) + G_R(dB) - A_{SL}(dB) - 2A_F(dB) - M_F(dB)$$

To calculate the attenuation of the free space, and to calculate the antenna gains, you must first calculate the wavelength l:

$$\lambda = \frac{c}{f} = \frac{3 \cdot 10^8}{2{,}3 \cdot 10^9} = 0{,}13\ m$$

Let's now calculate the gain of the two satellite dishes and the **attenuation of the free space**:

$$G_T(dB) = G_R(dB) = 10\log_{10} 0{,}55\left(\frac{\pi \cdot D}{\lambda}\right)^2 = 10\log_{10} 0{,}55\left(\frac{\pi \cdot 1}{0{,}13}\right)^2 = 25\ dB$$

$$A_{SL}(dB) = 10\log_{10}\left(\frac{4\pi r}{\lambda}\right)^2 = 10\log_{10}\left(\frac{4\pi \cdot 40.000}{0{,}13}\right)^2 = 132\ dB$$

Let's calculate the transmission power in dBm:

$$P_T(dB_m) = 10\log_{10}\frac{10}{10^{-3}} = 40\ dB_m$$

Now replacing all the values given or calculated, we finally find the receiving power in dBm:

$$P_R(dB_m) = P_T(dB_m) + G_T(dB) + G_R(dB) - A_{SL}(dB) - 2A_F(dB) - M_F(dB) =$$

$$= 40 + 25 + 25 - 132 - 3 - 3 - 18 = -66\ dB_m$$

CALCULATION OF THE NOISE POWER N.

Reception noise is given by the formula:

$$N = F \cdot K \cdot T \cdot B$$

K is the Boltzmann constant and holds:

$$K = 1{,}38 \cdot 10^{-23}\ W/K^{\circ} \cdot Hz$$

T is the temperature in degrees Kelvin of the receiver, i.e. the ambient temperature, and holds:

$$T = 273^{\circ} + 20^{\circ} = 293^{\circ}K$$

B is the useful band of the demodulator which, being tuned to an FM modulated signal, must be, according to Carson's formula:

$$B = 2 \cdot (f_m + \Delta f) = 2 \cdot (1 + 4) \cdot 10^6 = 10\ MHz$$

F is the noise figure of the demodulator and is:

F(dB) = 8 dB

Let's calculate F in the normal way:

$$8\ dB = 10\log_{10} F$$

Dividing first and second members by 10:

$$0{,}8 = \log_{10} F$$

Going from logarithms to numbers:

$$10^{0{,}8} = F$$

From which:

F= 6,31

Let's finally calculate the value of the noise power N in dBm:

$$N(dB_m) = 10\log_{10}\frac{F\cdot K\cdot T\cdot B}{10^{-3}} = 10\log_{10}\frac{6{,}31\cdot 1{,}38\cdot 10^{-23}\cdot 293\cdot 10\cdot 10^{6}}{10^{-3}} = -96\ dB_m$$

The value of the **signal /noise** ratio that is obtained is then:

$$S/N(dB) = -66\ dB_m - (-96\ dB_m) = 30\ dB$$

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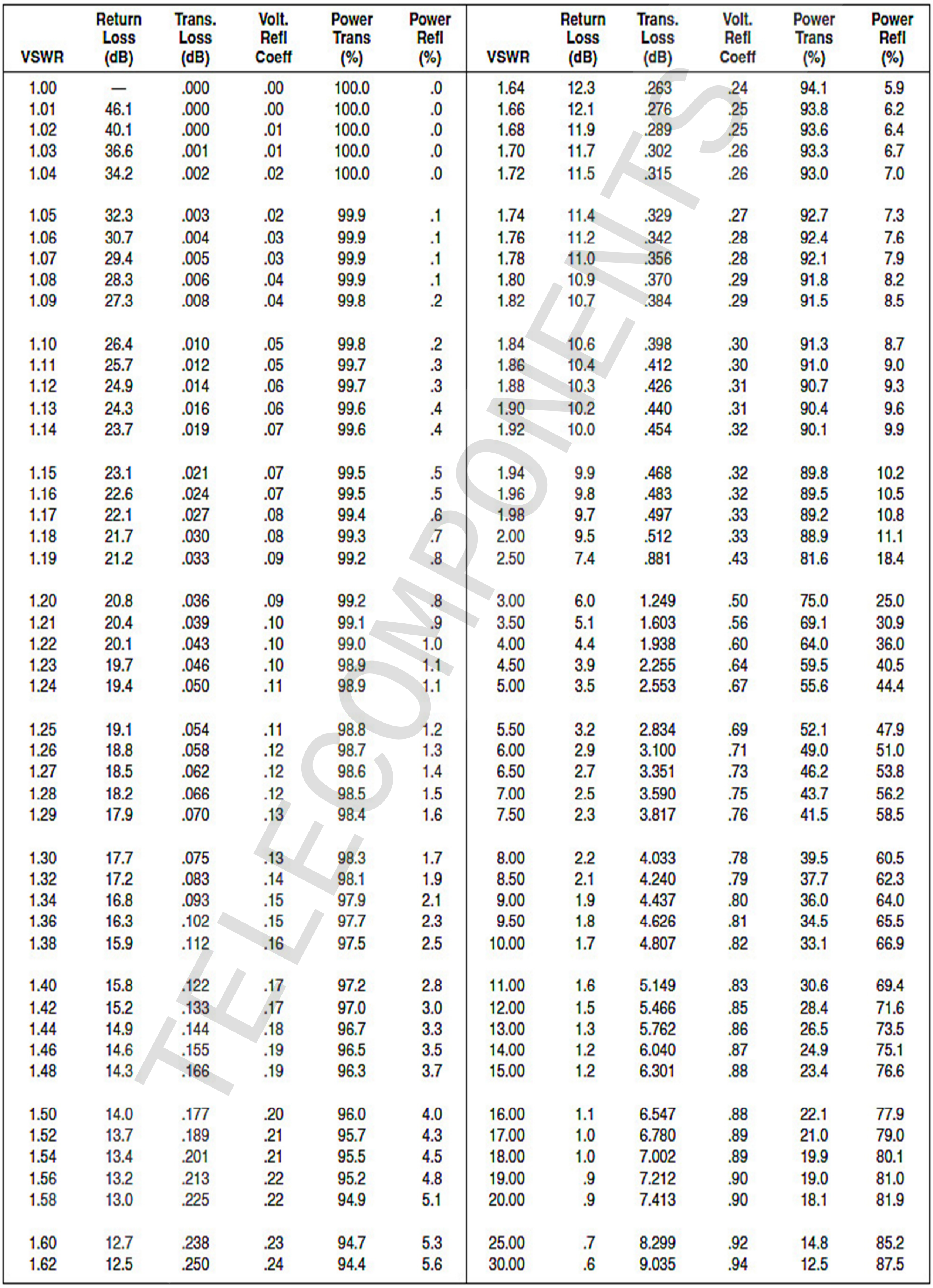
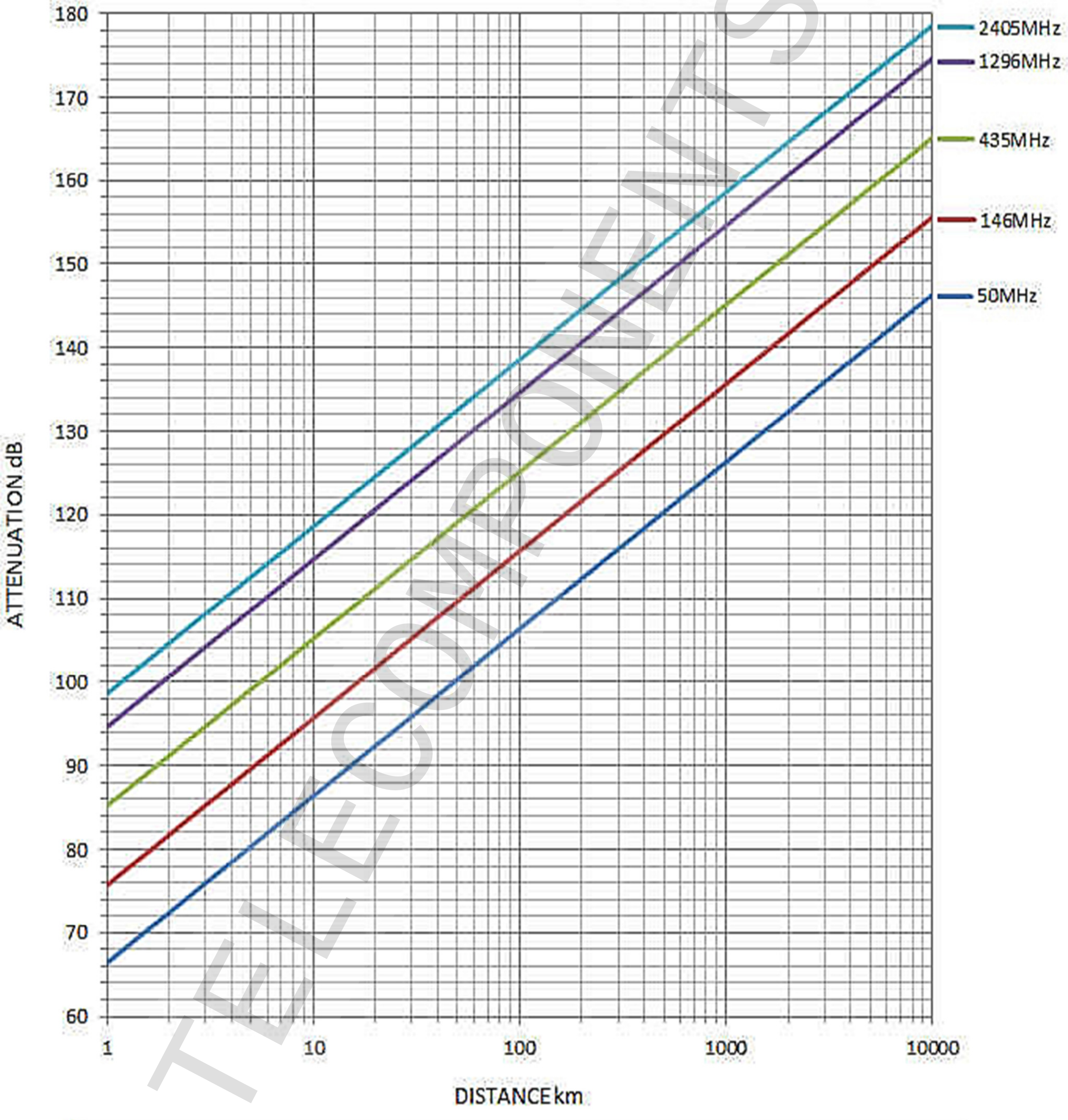
VSWR TO RETURN LOSS - %



VSWR	Return Loss (dB)	Trans. Loss (dB)	Volt. Refl Coeff	Power Trans (%)	Power Refl (%)	VSWR	Return Loss (dB)	Trans. Loss (dB)	Volt. Refl Coeff	Power Trans (%)	Power Refl (%)
1.00	—	.000	.00	100.0	.0	1.64	12.3	.263	.24	94.1	5.9
1.01	46.1	.000	.00	100.0	.0	1.66	12.1	.276	.25	93.8	6.2
1.02	40.1	.000	.01	100.0	.0	1.68	11.9	.289	.25	93.6	6.4
1.03	36.6	.001	.01	100.0	.0	1.70	11.7	.302	.26	93.3	6.7
1.04	34.2	.002	.02	100.0	.0	1.72	11.5	.315	.26	93.0	7.0
1.05	32.3	.003	.02	99.9	.1	1.74	11.4	.329	.27	92.7	7.3
1.06	30.7	.004	.03	99.9	.1	1.76	11.2	.342	.28	92.4	7.6
1.07	29.4	.005	.03	99.9	.1	1.78	11.0	.356	.28	92.1	7.9
1.08	28.3	.006	.04	99.9	.1	1.80	10.9	.370	.29	91.8	8.2
1.09	27.3	.008	.04	99.8	.2	1.82	10.7	.384	.29	91.5	8.5
1.10	26.4	.010	.05	99.8	.2	1.84	10.6	.398	.30	91.3	8.7
1.11	25.7	.012	.05	99.7	.3	1.86	10.4	.412	.30	91.0	9.0
1.12	24.9	.014	.06	99.7	.3	1.88	10.3	.426	.31	90.7	9.3
1.13	24.3	.016	.06	99.6	.4	1.90	10.2	.440	.31	90.4	9.6
1.14	23.7	.019	.07	99.6	.4	1.92	10.0	.454	.32	90.1	9.9
1.15	23.1	.021	.07	99.5	.5	1.94	9.9	.468	.32	89.8	10.2
1.16	22.6	.024	.07	99.5	.5	1.96	9.8	.483	.32	89.5	10.5
1.17	22.1	.027	.08	99.4	.6	1.98	9.7	.497	.33	89.2	10.8
1.18	21.7	.030	.08	99.3	.7	2.00	9.5	.512	.33	88.9	11.1
1.19	21.2	.033	.09	99.2	.8	2.50	7.4	.881	.43	81.6	18.4
1.20	20.8	.036	.09	99.2	.8	3.00	6.0	1.249	.50	75.0	25.0
1.21	20.4	.039	.10	99.1	.9	3.50	5.1	1.603	.56	69.1	30.9
1.22	20.1	.043	.10	99.0	1.0	4.00	4.4	1.938	.60	64.0	36.0
1.23	19.7	.046	.10	98.9	1.1	4.50	3.9	2.255	.64	59.5	40.5
1.24	19.4	.050	.11	98.9	1.1	5.00	3.5	2.553	.67	55.6	44.4
1.25	19.1	.054	.11	98.8	1.2	5.50	3.2	2.834	.69	52.1	47.9
1.26	18.8	.058	.12	98.7	1.3	6.00	2.9	3.100	.71	49.0	51.0
1.27	18.5	.062	.12	98.6	1.4	6.50	2.7	3.351	.73	46.2	53.8
1.28	18.2	.066	.12	98.5	1.5	7.00	2.5	3.590	.75	43.7	56.2
1.29	17.9	.070	.13	98.4	1.6	7.50	2.3	3.817	.76	41.5	58.5
1.30	17.7	.075	.13	98.3	1.7	8.00	2.2	4.033	.78	39.5	60.5
1.32	17.2	.083	.14	98.1	1.9	8.50	2.1	4.240	.79	37.7	62.3
1.34	16.8	.093	.15	97.9	2.1	9.00	1.9	4.437	.80	36.0	64.0
1.36	16.3	.102	.15	97.7	2.3	9.50	1.8	4.626	.81	34.5	65.5
1.38	15.9	.112	.16	97.5	2.5	10.00	1.7	4.807	.82	33.1	66.9
1.40	15.8	.122	.17	97.2	2.8	11.00	1.6	5.149	.83	30.6	69.4
1.42	15.2	.133	.17	97.0	3.0	12.00	1.5	5.466	.85	28.4	71.6
1.44	14.9	.144	.18	96.7	3.3	13.00	1.3	5.762	.86	26.5	73.5
1.46	14.6	.155	.19	96.5	3.5	14.00	1.2	6.040	.87	24.9	75.1
1.48	14.3	.166	.19	96.3	3.7	15.00	1.2	6.301	.88	23.4	76.6
1.50	14.0	.177	.20	96.0	4.0	16.00	1.1	6.547	.88	22.1	77.9
1.52	13.7	.189	.21	95.7	4.3	17.00	1.0	6.780	.89	21.0	79.0
1.54	13.4	.201	.21	95.5	4.5	18.00	1.0	7.002	.89	19.9	80.1
1.56	13.2	.213	.22	95.2	4.8	19.00	.9	7.212	.90	19.0	81.0
1.58	13.0	.225	.22	94.9	5.1	20.00	.9	7.413	.90	18.1	81.9
1.60	12.7	.238	.23	94.7	5.3	25.00	.7	8.299	.92	14.8	85.2
1.62	12.5	.250	.24	94.4	5.6	30.00	.6	9.035	.94	12.5	87.5

FREE SPACE PATH LOSS ATTENUATION (DB)



$$\mathrm{FSPL(dB)} = 20\log(d) + 20\log(f) + 32.44$$

Where:

d = distance of the receiver from the transmitter (km)
f = signal frequency (MHz)

TV Channels (PAL BG/DK DIGITAL DVBT)

Channel rasters In Poland there is used PAL DK standard, with continuous numbering (e.g. after S8 we have S9). We have also presented PAL BG channels used mostly in Western European countries. In this case - in some countries - there is a leap in numbering between S8 and S11.

It is an important information for some installers that may be surprised by this irregularity, e.g. when programming output channels of modulators. The tip - it is more convenient to measure and compare frequencies than channel numbers. Below we show tables containing information on the bands, frequency ranges, and channels used in European countries.

Band name	Frequency range [MHz]	Channels	Channel width	Frequency range [MHz]	Channels	Channel width
	D/K			B/G		
FM	87.5-108.0	UKF–FM	20.5	87.5-108.0	FM	20.5
Special channels (low band)	110-174	S01-S08 (S01-S08)	8	111-174	S02-S10	7
VHF III	174-230	K06-K12	8	174-230	CH05-CH12	7
Special channels (high band)	230-302	S09-S17 (S10-S18)	8	230-300	S11-S20	7
Special channels (hyperband)	302-470	S18-S38 (S19-S40)	8	302-446	S21-S38	8
UHF IV	470-606	K21-K37	8	470-606	CH21-CH37	8
UHF V	606-862	K38-K69	8	606-862	CH38-CH69	8

Note: In the following table, the BIII band has channel raster identical with B/G standard (channel width 7 MHz), adopted for DAB radio and DVB-T.

D/K (CCIR)					
Band	**Channel**	**Frequency range [MHz]**	**Center frequency [MHz]**	**Video carrier freq. [MHz]**	**Sound carrier freq. [MHz]**
Return channel (data)	-	4-30	-	-	-
	-	5-65	-	-	-
Return channel (TV)	R1	14.75-21.75	-	-	-
	R2	21.75-28.75	-	-	-
BI	C1	48.50 - 56.50	52.50	49.75	56.25
	C2	58.00 - 66.00	62.00	59.25	65.75
	C3	76.00 - 84.00	80.00	77.25	83.75
BII / FM	-	87.5-108	-	-	-
Cable band I	S1	110.00 - 118.00	114.00	111.25	117.25
	S2	118.00 - 126.00	122.00	119.25	125.75
	S3	126.00 - 134.00	130.00	127.25	133.75
	S4	134.00 - 142.00	138.00	135.25	141.75

	S5	142.00 - 150.00	146.00	143.25	149.75
	S6	150.00 - 158.00	154.00	151.25	157.75
	S7	158.00 - 166.00	162.00	159.25	165.75
	S8	166.00 - 174.00	170.00	167.25	173.75
BIII TV/DAB	E5	174.00 - 181.00	177.50	172.25	180.75
	E6	181.00 - 188.00	184.50	182.25	187.75
	E7	188.00 - 195.00	191.50	189.25	194.75
	E8	195.00 - 202.00	198.50	196.25	201.75
	E9	202.00 - 209.00	205.50	203.25	208.75
	E10	209.00 - 216.00	212.50	210.25	215.75
	E11	216.00 - 223.00	219.50	217.25	222.75
	E12	223.00 - 230.00	226.50	224.25	229.75
Cable band II	S9	230.00 - 238.00	234.00	231.25	237.75
	S10	238.00 - 246.00	242.00	239.25	245.75
	S11	246.00 - 254.00	250.00	247.25	253.75
	S12	254.00 - 262.00	258.00	255.25	261.75
	S13	262.00 - 270.00	266.00	263.25	269.75
	S14	270.00 - 278.00	274.00	271.25	277.75
	S15	278.00 - 286.00	282.00	279.25	285.75
	S16	286.00-294.00	290.00	287.25	293.75
	S17	294.00 - 302.00	298.00	295.25	301.75
	S18	302.00 - 310.00	306.00	303.25	309.75
	S19	310.00 - 318.00	314.00	311.25	317.75
	S20	318.00 - 326.00	322.00	319.25	325.75
	S21	326.00 - 334.00	326.00	327.25	333.75
	S22	334.00 - 342.00	338.00	335.25	341.75
	S23	342.00 - 350.00	346.00	343.25	349.75
	S24	350.00 - 358.00	354.00	351.25	357.75
	S25	358.00 - 366.00	362.00	359.25	365.75
	S26	366.00 - 374.00	370.00	367.25	373.75
	S27	374.00 - 382.00	378.00	375.25	381.75
	S28	382.00 - 390.00	386.00	383.25	389.75
	S29	390.00 - 398.00	394.00	391.25	397.75

	S30	398.00 - 406.00	402.00	399.25	405.75
	S31	406.00 - 414.00	410.00	407.25	413.75
	S32	414.00 - 422.00	418.00	415.25	421.75
	S33	422.00 - 430.00	426.00	423.25	429.75
	S34	430.00 - 438.00	434.00	431.25	437.75
	S35	438.00 - 446.00	442.00	439.25	445.75
	S36	446.00 - 454.00	450.00	447.25	453.75
	S37	454.00 - 462.00	458.00	455.25	461.75
	S38	462.00 - 470.00	466.00	463.25	469.75
			DVB-T	**Analog TV**	
BIV	C21	470.00 - 478.00	474.00	471.25	477.75
	C22	478.00 - 486.00	482.00	479.25	485.75
	C23	486.00 - 494.00	490.00	487.25	493.75
	C24	494.00 - 502.00	498.00	495.25	501.75
	C25	502.00 - 510.00	506.00	503.25	509.75
	C26	510.00 - 518.00	514.00	511.25	517.75
	C27	518.00 - 526.00	522.00	519.25	525.75
	C28	526.00 - 534.00	530.00	527.25	533.75
	C29	534.00 - 542.00	538.00	535.25	541.75
	C30	542.00 - 550.00	546.00	543.25	549.75
	C31	550.00 - 558.00	554.00	551.25	557.75
	C32	558.00 - 566.00	562.00	559.25	565.75
	C33	566.00 - 574.00	570.00	567.25	573.75
	C34	574.00 - 582.00	578.00	575.25	581.75
	C35	582.00 - 590.00	586.00	583.25	589.75
	C36	590.00 - 598.00	594.00	591.25	597.75
	C37	598.00 - 606.00	602.00	599.25	605.75
	C38	606.00 - 614.00	610.00	607.25	613.75
	C39	614.00 - 622.00	618.00	615.25	621.75
BV	C40	622.00 - 630.00	626.00	623.25	629.75
	C41	630.00 - 638.00	634.00	631.25	637.75
	C42	638.00 - 646.00	642.00	639.25	645.75
	C43	646.00 - 654.00	650.00	647.25	653.75

	C44	654.00 - 662.00	658.00	655.25	661.75
	C45	662.00 - 670.00	666.00	663.25	669.75
	C46	670.00 - 678.00	674.00	671.25	677.75
	C47	678.00 - 686.00	682.00	679.25	685.75
	C48	686.00 - 694.00	690.00	687.25	693.75
	C49	694.00 - 702.00	698.00	695.25	701.75
	C50	702.00 - 710.00	706.00	703.25	709.75
	C51	710.00 - 718.00	714.00	711.25	717.75
	C52	718.00 - 726.00	722.00	719.25	725.75
	C53	726.00 - 734.00	730.00	727.25	733.75
	C54	734.00 - 742.00	738.00	735.25	741.75
	C55	742.00 - 750.00	746.00	743.25	749.75
	C56	750.00 - 758.00	754.00	751.25	757.75
	C57	758.00 - 766.00	762.00	759.25	765.75
	C58	766.00 - 774.00	770.00	767.25	773.75
	C59	774.00 - 782.00	778.00	775.25	781.75
	C60	782.00 - 790.00	786.00	783.25	789.75
	C61	790.00 - 798.00	794.00	791.25	797.75
	C62	798.00 - 806.00	802.00	799.25	805.75
	C63	806.00 - 814.00	810.00	807.25	813.75
	C64	814.00 - 822.00	818.00	815.25	821.75
	C65	822.00 - 830.00	826.00	823.25	829.75
	C66	830.00 - 838.00	834.00	831.25	837.75
	C67	838.00 - 846.00	842.00	839.25	845.75
	C68	846.00 - 854.00	850.00	847.25	853.73
	C69	854.00 - 862.00	858.00	855.25	861.75

TV Channels (NTSC DIGITAL)

US Television Channels (MHz)					
Channel	**Band Limits**	**DTV Pilot**	**Analog Video**	**Analog Audio**	**Notes**
2	54-60	54.31	55.25	59.75	
3	60-66	60.31	61.25	65.75	
4	66-72	66.31	67.25	71.75	
5	76-82	76.31	77.25	81.75	
6	82-88	82.31	83.25	87.75	
7	174-180	174.31	175.25	179.75	
8	180-186	180.31	181.25	185.75	
9	186-192	186.31	187.25	191.75	
10	192-198	192.31	193.25	197.75	
11	198-204	198.31	199.25	203.75	
12	204-120	204.31	205.25	209.75	
13	210-216	210.31	211.25	215.75	
14	470-476	470.31	471.25	475.75	
15	476-482	476.31	477.25	481.75	
16	482-488	482.31	483.25	487.75	
17	488-494	488.31	489.25	493.75	
18	494-500	494.31	495.25	499.75	
19	500-506	500.31	501.25	505.75	
20	506-512	506.31	507.25	511.75	
21	512-518	512.31	513.25	517.75	
22	518-524	518.31	519.25	523.75	
23	524-530	524.31	525.25	529.75	
24	530-536	530.31	531.25	535.75	
25	536-542	536.31	537.25	541.75	
26	542-548	542.31	543.25	547.75	
27	548-554	548.31	549.25	553.75	
28	554-560	554.31	555.25	559.75	
29	560-566	560.31	561.25	565.75	

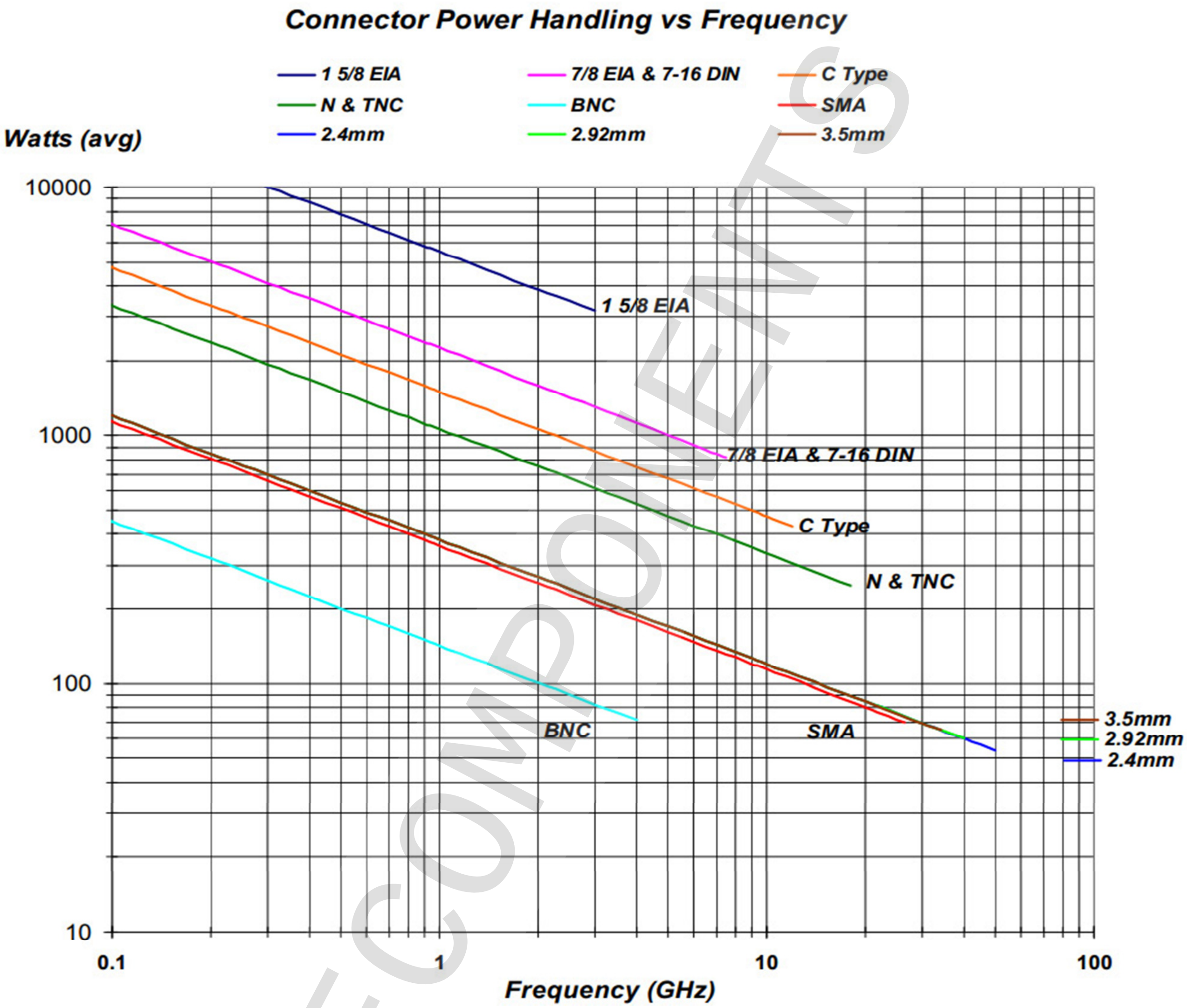
30	566-572	566.31	567.25	571.75	
31	572-578	572.31	573.25	577.75	
32	578-584	578.31	579.25	583.75	
33	584-590	584.31	585.25	589.75	
34	590-596	590.31	591.25	595.75	
35	596-602	596.31	597.25	601.75	
36	602-608	602.31	603.25	607.75	
37	608-614	608.31	609.25	613.75	
38	614-620	614.31	615.25	619.75	
39	620-626	620.31	621.25	625.75	
40	626-632	626.31	627.25	631.75	
41	632-638	632.31	633.25	637.75	
42	638-644	638.31	639.25	643.75	
43	644-650	644.31	645.25	649.75	
44	650-656	650.31	651.25	655.75	
45	656-662	656.31	657.25	661.75	
46	662-668	662.31	663.25	667.75	
47	668-674	668.31	669.25	673.75	
48	674-680	674.31	675.25	679.75	
49	680-686	680.31	681.25	685.75	
50	686-692	686.31	687.25	691.75	
51	692-698	692.31	693.25	697.75	
52	698-704	698.31	699.25	703.75	
53	704-710	704.31	705.25	709.75	
54	710-716	710.31	711.25	715.75	
55	716-722	716.31	717.25	721.75	
56	722-728	722.31	723.25	727.75	
57	728-734	728.31	729.25	733.75	
58	734-740	734.31	735.25	739.75	
59	740-746	740.31	741.25	745.75	
60	746-752	746.31	747.25	751.75	
61	752-758	752.31	753.25	757.75	

62	758-764	758.31	759.25	763.75	
63	764-770	764.31	765.25	769.75	
64	770-776	770.31	771.25	775.75	
65	776-782	776.31	777.25	781.75	
66	782-788	782.31	783.25	787.75	
67	788-794	788.31	789.25	793.75	
68	794-800	794.31	795.25	799.75	
69	800-806	800.31	801.25	805.75	
70	806-812	806.31	807.25	811.75	
71	812-818	812.31	813.25	817.75	
72	818-824	818.31	819.25	823.75	
73	824-830	824.31	825.25	829.75	
74	830-836	830.31	831.25	835.75	
75	836-842	836.31	837.25	841.75	
76	842-848	842.31	843.25	847.75	
77	848-854	848.31	849.25	853.75	
78	854-860	854.31	855.25	859.75	
79	860-866	860.31	861.25	865.75	
80	866-872	866.31	867.25	871.75	
81	872-878	872.31	873.25	877.75	
82	878-884	878.31	879.25	883.75	
83	884-890	884.31	885.25	889.75	

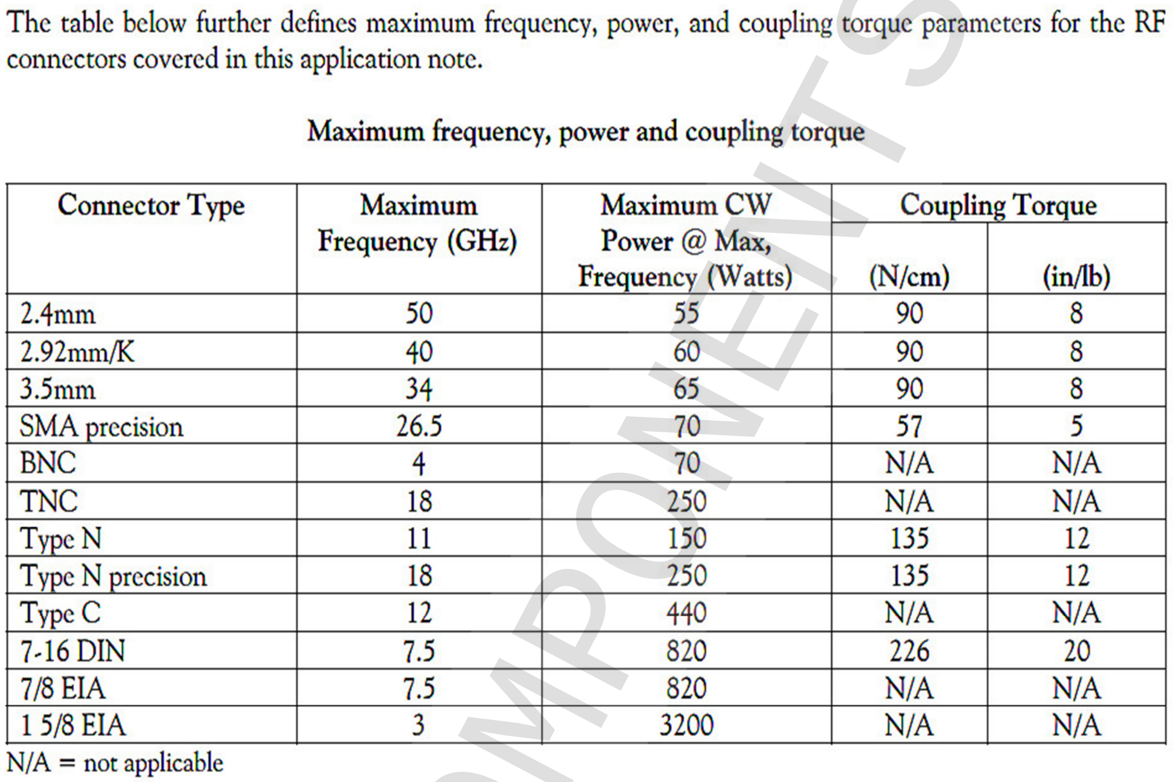
Notes

- **1**. 470-512 MHz (channels 14-20) - UHF-T band used for land mobile radio only within 50 miles of the following metropolitan areas:
- **2.** 608-614 MHz (channel 37) - Reserved for radio astronomy. Audio, video and pilot frequencies are for reference only.
- **3.** 698-746 MHz (channels 52-59) - Lower 700 MHz band. TV stations will vacate this band. Used by various wireless and broadband networks. Audio, video and pilot frequencies are for reference only.
- **4.** 746-806 MHz (channels 60-69) - Upper 700 MHz band. TV stations vacated this band in 2009. Used by public safety land mobile radio and various commercial and public safety broadband networks. Audio, video and pilot frequencies are for reference only.
- **5.** 806-890 MHz (channels 70-83) - 800 MHz band. TV stations vacated this band in the late 1970s. Used by land mobile radio and various wireless and broadband networks. Audio, video and pilot frequencies are for reference only.
- **6.** 614-698 MHz (channels 38-51) - 600 MHz band. The Broadcast Incentive Auction will require TV stations to vacate this band between April 2017 and July 2020. It will then be used by various wireless and broadband networks. Audio, video and pilot frequencies are for reference only.

Connector Power handling vs frequency



Maximum Frequency, power and coupling torque RF connectors



The table below further defines maximum frequency, power, and coupling torque parameters for the RF connectors covered in this application note.

Maximum frequency, power and coupling torque

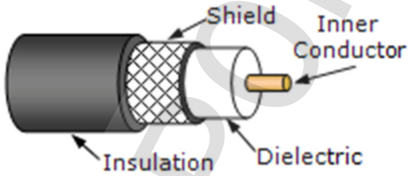
Connector Type	Maximum Frequency (GHz)	Maximum CW Power @ Max, Frequency (Watts)	Coupling Torque	
			(N/cm)	(in/lb)
2.4mm	50	55	90	8
2.92mm/K	40	60	90	8
3.5mm	34	65	90	8
SMA precision	26.5	70	57	5
BNC	4	70	N/A	N/A
TNC	18	250	N/A	N/A
Type N	11	150	135	12
Type N precision	18	250	135	12
Type C	12	440	N/A	N/A
7-16 DIN	7.5	820	226	20
7/8 EIA	7.5	820	N/A	N/A
1 5/8 EIA	3	3200	N/A	N/A

N/A = not applicable

Coaxial cable specification

Properties of Coaxial Cable Dielectrics
(c = speed of light in a vacuum)

Dielectric Type	Time Delay (ns/ft)	Propagation Velocity
Solid Polyethylene (PE)	1.54	0.659c
Foam Polyethylene (FE)	1.27	0.800c
Foam Polystyrene (FS)	1.12	0.910c
Air Space Polyethylene (ASP)	1.15-1.21	0.840c-0.880c
Solid Teflon (ST)	1.46	0.694c
Air Space Teflon (AST)	1.13-1.20	0.850c-0.900c



Properties of standard coaxial type cables have been very much standardized for many years. Unless you buy rogue stock from a supplier, if you abide by the manufacturer's application guidelines, there should not be any surprises. Do not make a bend of smaller recommended radius, do not expose the cable to excess temperatures, vibration, mechanical stress, or chemicals. Be absolutely certain to attach the coaxial cable into a properly designed connector, printed circuit board, or other type termination, paying careful attention to insulation and dielectric strip lengths, solder temperatures and dwell times, and shielding preparation. Do all that, and you will be assured a long lifetime from your cable system.

Properties of Popular Coaxial Cables

Note that attenuation values are given at 400 MHz, but can - and do - often have significantly different values at other frequencies. Always check with a coaxial cable vendor for values specific to the type you plan to use.

Type (/U)	MIL-C-17	Z_0(Ω)	Dielectric Type	Capacitance (pF/ft)	O.D. (in.)	dB/100 ft @400 MHz	Vmax (rms)	Shield
LMR-100A		50.0	FE	31	0.110	14	2,000	Braid+Foil
LMR-195		50.0	FE	25	0.195	7.0	3,000	Braid+Foil
LMR-200		50.0	FE	24	0.195	6.5	3,000	Braid+Foil
LMR-300		50.0	FE	24	0.300	4.0	5,000	Braid+Foil
LMR-400		50.0	FE	24	0.405	2.5	8,000	Braid+Foil
LMR-500		50.0	FE	24	0.500	2.0	8,000	Braid+Foil
LMR-600		50.0	FE	23	0.590	1.6	8,000	Braid+Foil
LMR-900		50.0	FE	23	0.870	1.1	8,000	Braid+Foil
LMR-1200		50.0	FE	23	1.200	0.8	8,000	Braid+Foil
RG-4		50.0	PE	31	0.226	11.7	1,900	Braid
RG-5		52.5	PE	29	0.332	7.0	3,000	Braid

RG-5A/B		50.0	PE	31	0.328	6.5	3,000	Braid
RG-6	/2-RG6	76.0	PE	20	0.332	7.4	2,700	Braid
RG-6A	/2-RG6	75.0	PE	21	0.332	6.5	2,700	Braid
RG-8		52.0	PE	30	0.405	6.0	4,000	Braid
9914 (RG-8)		50.0	PE	25	0.403	2.6	300	Braid+Foil
RG-8A		52.0	PE	30	0.405	4.5	5,000	Braid
RG-8X		50.0	PE	26	0.242	8.0	2,500	Braid
RG-9		51.0	PE	30	0.420	5.9	4,000	Braid
RG-9A		51.0	PE	30	0.420	6.1	4,000	Braid
RG-9B		50.0	PE	31	0.420	6.1	5,000	Braid
RG-10		52.0	PE	30	0.463	6.0	4,000	Braid
RG-10A		52.0	PE	30	0.463	6.0	5,000	Braid
RG-11	/6-RG11	75.0	PE	21	0.405	5.7	4,000	Braid
RG-11A	/6-RG11	75.0	PE	21	0.405	5.2	5,000	Braid
RG-12	/6-RG12	75.0	PE	21	0.463	5.7	4,000	Braid
RG-12A	/6-RG12	75.0	PE	21	0.463	5.2	5,000	Braid
RG-17A		52.0	PE	30	0.870	2.8	11,000	Braid
RG-22	/15-RG22	95.0	PE	16	0.405	10.5	1,000	Braid
RG-22A/B	/15-RG22	95.0	PE	16	0.420	10.5	1,000	Braid
RG-23/A	/16-RG23	125.0	PE	12	0.650	5.2	3,000	Braid
RG-24/A	/16-RG24	125.0	PE	12	0.708	5.2	3,000	Braid
RG-34	/24-RG34	71.0	PE	22	0.625	5.3	5,200	Braid
RG-34A	/24-RG34	75.0	PE	21	0.630	5.3	6,500	Braid
RG-35	/64-RG35	71.0	PE	22	0.928	2.8	10,000	Braid
RG-35A/B	/64-RG35	75.0	PE	21	0.928	2.8	10,000	Braid
RG-55B		53.5	PE	29	0.200	11.7	1,900	Braid
RG-58	/28-RG58	53.5	PE	29	0.195	11.7	1,900	Braid
RG-58A	/28-RG58	52.0	PE	30	0.195	13.2	1,900	Braid
RG-58B		53.5	PE	28	0.195	14.0	1,900	Braid
RG-58C	/28-RG58	50.0	PE	31	0.195	14.0	1,900	Braid
RG-59/A	/29-RG59	73.0	PE	21	0.242	10.5	2,300	Braid
RG-59B	/29-RG59	75.0	PE	21	0.242	9.0	2,300	Braid
RG-62/A/B	/30-RG62	93.0	ASP	14	0.242	8.0	750	Braid
RG-63/A/B	/31-RG63	125.0	ASP	10	0.405	5.5	1,000	Braid
RG-65/A	/34-RG65	950.0	ASP	44	0.405	16 @5MHz	1,000	Braid
RG-71/A/B	/90-RG71	93.0	ASP	14	0.245	8.0	750	Braid
RG-79/A/B	/31-RG79	125.0	ASP	10	0.436	5.5	1,000	Braid
RG-83		35.0	PE	44	0.405	9.0	2,000	Braid
RG-88		48.0		50	0.515	0.7 @1MHz	10,000	Braid
RG-108/A	/45-RG108	78.0	PE	20	0.235	2.8 @10MHz	1,000	Braid
RG-111/A	/15-RG111	95.0	PE	16	0.478	10.5	1,000	Braid
RG-114/A	/47-RG114	185.0	ASP	7	0.405	8.5	1,000	Braid
RG-119	/52-RG119	50.0	ST	30	0.465	3.8	6,000	Braid
RG-120	/52-RG120	50.0	ST	30	0.523	3.8	6,000	Braid

RG-122	/54-RG122	50.0	PE	31	0.160	18.0	1,900	Braid
RG-130	/56-RG130	95.0	PE	17	0.625	8.8	3,000	Braid
RG-131	/56-RG131	95.0	PE	17	0.683	8.8	3,000	Braid
RG-133/A	/100-RG133	95.0	PE	16	0.405	5.7	4,000	Braid
RG-141/A		50.0	ST	29	0.190	9.0	1,900	Braid
RG-142/A/B	/60-RG142	50.0	ST	29	0.195	9.0	1,900	Braid
RG-144	/62-RG144	75.0	ST	20	0.410	4.5	5,000	Braid
RG-164	/64-RG164	75.0	PE	21	0.870	2.8	10,000	Braid
RG-165	/65-RG165	50.0	ST	29	0.410	5.0	5,000	Braid
RG-166	/65-RG166	50.0	ST	29	0.460	5.0	5,000	Braid
RG-174		50.0		31	0.110	14.7		Braid
RG-177	/67-RG177	50.0	PE	31	0.895	2.8	11,000	Braid
RG-178/A/B	/93-RG178	50.0	ST	29	0.072	29.0	1,000	Braid
RG-179	/94-RG179	70.0	ST	21	0.100	21.0	1,200	Braid
RG-179A/B	/94-RG179	75.0	ST	20	0.100	21.0	1,200	Braid
RG-180	/95-RG180	93.0	ST	15	0.140	17.0	1,500	Braid
RG-180A/B	/95-RG180	95.0	ST	15	0.140	17.0	1,500	Braid
RG-210	/97-RG210	93.0	ASP	14	0.242	8.0	750	Braid
RG-211/A	/72-RG211	50.0	ST	29	0.730	2.3	7,000	Braid
RG-212	/73-RG212	50.0	PE	29	0.332	6.5	3,000	Braid
RG-213	/74-RG213	50.0	PE	31	0.405	5.5	5,000	Braid
RG-214	/75-RG214	50.0	PE	31	0.425	5.5	5,000	Dbl Braid
RG-215	/74-RG215	50.0	PE	31	0.463	5.5	5,000	Braid
RG-216	/77-RG216	75.0	PE	21	0.425	5.2	5,000	Braid
RG-217	/78-RG217	50.0	PE	31	0.545	4.3	7,000	Braid
RG-218	/79-RG218	50.0	PE	31	0.870	2.5	11,000	Braid
RG-219	/79-RG219	50.0	PE	31	0.928	2.5	11,000	Braid
RG-223	/84-RG223	50.0	PE	12	0.211	8.8	1,900	Dbl Braid
RG-302	/110-RG302	75.0	ST	20	0.201	8.0	2,300	Braid
RG-303	/111-RG303	50.0	ST	29	0.170	9.0	1,900	Braid
RG-304	/112-RG304	50.0	ST	29	0.280	6.0	3,000	Braid
RG-307/A	/116-RG307	75.0	80	17	0.270	7.5	1,000	Braid
RG-316	/113-RG316	50.0	ST	29	0.102	20.0	1,200	Braid
RG-391	/126-RG391	72.0		23	0.405	15.0	5,000	Braid
RG-392	/126-RG392	72.0		23	0.475	15.0	5,000	Braid
RG-393	/127-RG393	50.0	ST	29	0.390	5.0	5,000	Braid
RG-400	/128-RG400	50.0	ST	29	0.195	9.6	1,900	Braid
RG-401	/129-RG401	50.0	ST	29	0.250	4.6	3,000	Cu. S-R
RG-402	/130-RG402	50.0	ST	29	0.141	7.2	2,500	Cu. S-R
RG-403	/131-RG403	50.0	ST	29	0.116	29.0	2,500	Braid
RG-405	/133-RG405	50.0	ST	29	0.086	13.0	1,500	Cu. S-R

Corrugate Coaxial cables Specification

SCF14-50 Series
1/4" Superflexible Foam Coax

APPLICATIONS

OEM jumpers, BTS inter-cabinet connections, GPS lines, Riser-rated In-Building (JFN types)

GENERAL INFORMATION

Cable Type	Foam-Dielectric, Superflexible
Size	1/4"

STRUCTURE

Inner Conductor Material	Copper-Clad Aluminum Wire
Diameter Inner Conductor, mm (in)	1.9 (0.075)
Diameter Dielectric, mm (in)	4.3 (0.170)
Outer Conductor Material	Corrugated Copper
Diameter Copper Outer Conductor, mm (in)	6.5 (0.26)
Diameter over Jacket Nominal, mm (in)	7.8 (0.31)

MECHANICAL SPECIFICATIONS

Cable Weight, kg/m (lb/ft)	0.07 (0.05)
Minimum Bending Radius, Repeated Bends, mm (in)	25 (1.0)
Bending Moment, N•m (lb-ft)	0.7 (0.5)
Flat Plate Crush Strength, N/mm (lb/in)	18.4 (100)
Tensile Strength, N (lb)	600 (135)
Recommended / Maximum Clamp Spacing, m (ft)	0.20 / 0.20 (0.67 / 0.67)

ELECTRICAL SPECIFICATIONS

Impedance, ohm	50 +/- 1
Velocity, percent	82
Capacitance, pF/m (pF/ft)	82.0 (25.0)
Inductance, µH/m (µH/ft)	0.207 (0.063)
Maximum Frequency, GHz	20.4
Peak Power Rating, kW	5.5
RF Peak Voltage, volts	740
Jacket Spark, volt RMS	5000
Inner Conductor dc Resistance, ohm/1000 m (ohm/1000 ft)	10.40 (3.17)
Outer Conductor dc Resistance, ohm/1000 m (ohm/1000 ft)	6.60 (2.01)

See Installation, Operation and Storage Temperatures on page 16.

SCF14-50J/JFN ATTENUATION AND AVERAGE POWER

Frequency MHz	Attenuation dB/100 m	Attenuation dB/100 ft.	Average Power kW
0.5	0.401	0.122	5.50
1	0.568	0.173	5.50
1.5	0.696	0.212	5.50
2	0.804	0.245	5.50
10	1.81	0.550	3.66
20	2.56	0.781	2.58
30	3.15	0.960	2.10
50	4.08	1.24	1.62
88	5.45	1.66	1.21
100	5.82	1.77	1.14
108	6.06	1.85	1.09
150	7.17	2.19	0.922
174	7.75	2.36	0.854
200	8.33	2.54	0.794
300	10.3	3.13	0.643
400	12.0	3.65	0.553
450	12.7	3.88	0.519
500	13.5	4.10	0.491
512	13.6	4.15	0.485
600	14.8	4.52	0.446
700	16.1	4.91	0.411
800	17.3	5.27	0.382
824	17.6	5.35	0.376
894	18.4	5.60	0.360
900	18.4	5.62	0.359
925	18.7	5.70	0.354
960	19.1	5.81	0.347
1000	19.5	5.94	0.339
1250	22.0	6.71	0.300
1500	24.3	7.41	0.272
1700	26.1	7.94	0.254
1800	26.9	8.20	0.246
2000	28.5	8.69	0.232
2100	29.3	8.93	0.226
2200	30.1	9.17	0.220
2400	31.6	9.62	0.209
3000	35.8	10.9	0.185
3500	39.1	11.9	0.169
4000	42.2	12.9	0.157
5000	48.0	14.6	0.138
6000	53.4	16.3	0.124
7000	58.6	17.9	0.113
8000	63.4	19.3	0.104
9000	68.1	20.8	0.097
10000	72.6	22.1	0.091
12000	81.2	24.8	0.081
14000	89.4	27.2	0.074
16000	97.2	29.6	0.068
18000	104.7	31.9	0.063
20000	112	34.2	0.059
20400	113	34.6	0.058

Standard Conditions:
For attenuation: VSWR 1.0, cable temperature 20° C (68° F).
For average power: VSWR 1.0, ambient temperature 40° C (104°F), inner conductor temperature 100° C (212° F). No solar loading.

SCF38-50 Series
3/8" Superflexible Foam Coax

APPLICATIONS

OEM jumpers, BTS inter-cabinet connections, GPS lines, Riser-rated In-Building (JFN types)

GENERAL INFORMATION

Cable Type	Foam-Dielectric, Superflexible
Size	3/8"

STRUCTURE

Inner Conductor Material	Copper-Clad Aluminum Wire
Diameter Inner Conductor, mm (in)	2.6 (0.1)
Diameter Dielectric, mm (in)	6.3 (0.25)
Outer Conductor Material	Corrugated Copper
Diameter Copper Outer Conductor, mm (in)	9.1 (0.36)
Diameter over Jacket Nominal, mm (in)	10.2 (0.4)

MECHANICAL SPECIFICATIONS

Cable Weight, kg/m (lb/ft)	0.12 (0.08)
Minimum Bending Radius, Repeated Bends, mm (in)	25 (1.0)
Bending Moment, N•m (lb-ft)	1.4 (1.0)
Flat Plate Crush Strength, N/mm (lb/in)	18.4 (100)
Tensile Strength, N (lb)	600 (135)
Recommended / Maximum Clamp Spacing, m (ft)	0.25 / 0.25 (0.80 / 0.80)

ELECTRICAL SPECIFICATIONS

Impedance, ohm	50 +/- 1
Velocity, percent	82
Capacitance, pF/m (pF/ft)	82.0 (25.0)
Inductance, µH/m (µH/ft)	0.207 (0.063)
Maximum Frequency, GHz	13.4
Peak Power Rating, kW	11.9
RF Peak Voltage, volts	1090
Jacket Spark, volt RMS	5000
Inner Conductor dc Resistance, ohm/1000 m (ohm/1000 ft)	5.3 (1.62)
Outer Conductor dc Resistance, ohm/1000 m (ohm/1000 ft)	5.6 (1.71)

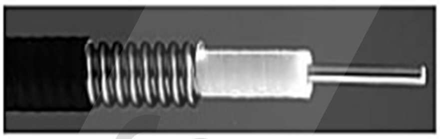
See Installation, Operation and Storage Temperatures on page 16.

SCF38-50J/JFN ATTENUATION AND AVERAGE POWER

Frequency MHz	Attenuation dB/100 m	Attenuation dB/100 ft.	Average Power kW
0.5	0.291	0.089	11.9
1	0.412	0.126	11.9
1.5	0.505	0.154	11.9
2	0.584	0.178	11.9
10	1.31	0.400	6.02
20	1.86	0.567	4.24
30	2.28	0.696	3.46
50	2.96	0.903	2.67
88	3.95	1.20	2.00
100	4.22	1.29	1.87
108	4.39	1.34	1.80
150	5.20	1.58	1.52
174	5.61	1.71	1.41
200	6.03	1.84	1.31
300	7.45	2.27	1.06
400	8.66	2.64	0.912
450	9.22	2.81	0.857
500	9.74	2.97	0.810
512	9.87	3.01	0.800
600	10.7	3.27	0.736
700	11.6	3.55	0.678
800	12.5	3.81	0.631
824	12.7	3.87	0.621
894	13.3	4.05	0.595
900	13.3	4.06	0.593
925	13.5	4.12	0.584
960	13.8	4.20	0.572
1000	14.1	4.30	0.560
1250	15.9	4.85	0.496
1500	17.6	5.36	0.449
1700	18.8	5.74	0.420
1800	19.4	5.92	0.407
2000	20.6	6.27	0.384
2100	21.1	6.45	0.373
2200	21.7	6.61	0.364
2400	22.8	6.94	0.347
3000	25.8	7.87	0.306
3500	28.2	8.59	0.280
4000	30.4	9.27	0.260
5000	34.6	10.5	0.228
6000	38.4	11.7	0.205
7000	42.1	12.8	0.188
8000	45.6	13.9	0.173
9000	48.9	14.9	0.161
10000	52.1	15.9	0.152
12000	58.2	17.7	0.136
13400	62.3	19.0	0.127

Standard Conditions:
For attenuation: VSWR 1.0, cable temperature 20° C (68° F).
For average power: VSWR 1.0, ambient temperature 40° C (104°F), inner conductor temperature 100° C (212° F). No solar loading.

SCF12-50 Series
1/2" Superflexible Foam Coax



APPLICATIONS

OEM jumpers, Main feed transitions to equipment, GPS lines, Riser-rated In-Building (JFN types)

GENERAL INFORMATION

Cable Type	Foam-Dielectric, Superflexible
Size	1/2"

STRUCTURE

Inner Conductor Material	Copper-Clad Aluminum Wire
Diameter Inner Conductor, mm (in)	3.6 (0.14)
Diameter Dielectric, mm (in)	8.3 (0.33)
Outer Conductor Material	Corrugated Copper
Diameter Copper Outer Conductor, mm (in)	12.3 (0.48)
Diameter over Jacket Nominal, mm (in)	13.7 (0.54)

MECHANICAL SPECIFICATIONS

Cable Weight, kg/m (lb/ft)	0.21 (0.14)
Minimum Bending Radius, Repeated Bends, mm (in)	32 (1.25)
Bending Moment, N•m (lb-ft)	1.8 (1.3)
Flat Plate Crush Strength, N/mm (lb/in)	20.4 (110)
Tensile Strength, N (lb)	650 (146)
Recommended / Maximum Clamp Spacing, m (ft)	0.30 / 0.30 (1.00 / 1.00)

ELECTRICAL SPECIFICATIONS

Impedance, ohm	50 +/- 1
Velocity, percent	82
Capacitance, pF/m (pF/ft)	82.0 (25.0)
Inductance, µH/m (µH/ft)	0.207 (0.063)
Maximum Frequency, GHz	11.7
Peak Power Rating, kW	20.5
RF Peak Voltage, volts	1430
Jacket Spark, volt RMS	5000
Inner Conductor dc Resistance, ohm/1000 m (ohm/1000 ft)	2.9 (0.88)
Outer Conductor dc Resistance, ohm/1000 m (ohm/1000 ft)	3.4 (1.04)

See Installation, Operation and Storage Temperatures on page 16.

SCF12-50J/JFN ATTENUATION AND AVERAGE POWER

Frequency MHz	Attenuation dB/100 m	Attenuation dB/100 ft.	Average Power kW
0.5	0.229	0.070	20.5
1	0.324	0.099	20.5
1.5	0.397	0.121	20.5
2	0.458	0.140	18.8
10	1.03	0.314	8.37
20	1.46	0.446	5.90
30	1.80	0.548	4.80
50	2.33	0.710	3.70
88	3.11	0.949	2.77
100	3.33	1.01	2.59
108	3.46	1.05	2.49
150	4.10	1.25	2.10
174	4.43	1.35	1.95
200	4.76	1.45	1.81
300	5.89	1.79	1.47
400	6.85	2.09	1.26
450	7.29	2.22	1.18
500	7.71	2.35	1.12
512	7.81	2.38	1.10
600	8.50	2.59	1.01
700	9.23	2.81	0.934
800	9.92	3.02	0.869
824	10.1	3.07	0.855
894	10.5	3.21	0.818
900	10.6	3.22	0.816
925	10.7	3.27	0.803
960	11.0	3.34	0.787
1000	11.2	3.41	0.770
1250	12.7	3.86	0.682
1500	14.0	4.26	0.616
1700	15.0	4.57	0.575
1800	15.5	4.72	0.557
2000	16.4	5.01	0.525
2100	16.9	5.15	0.511
2200	17.3	5.28	0.498
2400	18.2	5.55	0.474
3000	20.7	6.30	0.417
3500	22.6	6.88	0.382
4000	24.4	7.44	0.353
5000	27.8	8.48	0.310
6000	31.0	9.44	0.278
7000	34.0	10.4	0.254
8000	36.8	11.2	0.234
9000	39.6	12.1	0.218
10000	42.3	12.9	0.204
11700	46.6	14.2	0.185

Standard Conditions:
For attenuation: VSWR 1.0, ambient temperature 20° C (68° F).
For average power: VSWR 1.0, ambient temperature 40° C (104°F), inner conductor temperature 100° C (212° F). No solar loading.

UCF78-50A Series
7/8" Ultraflexible Foam Coax

APPLICATIONS

Main feed line, Riser-rated In-Building (JFN types)

GENERAL INFORMATION

Cable Type	Foam-Dielectric, Ultraflexible
Size	7/8"

STRUCTURE

Inner Conductor Material	Corrugated Copper Tube
Diameter Inner Conductor, mm (in)	9.42 (0.371)
Diameter Dielectric, mm (in)	21.1 (0.83)
Outer Conductor Material	Corrugated Copper
Diameter Copper Outer Conductor, mm (in)	24.89 (0.980)
Diameter over Jacket Nominal, mm (in)	27.48 (1.082)

MECHANICAL SPECIFICATIONS

Cable Weight, kg/m (lb/ft)	0.432 (0.290)
Minimum Bending Radius, Single Bend, mm (in)	90 (3.5)
Minimum Bending Radius, Repeated Bends, mm (in)	125 (5)
Bending Moment, N•m (lb-ft)	13.0 (9.6)
Flat Plate Crush Strength, N/mm (lb/in)	14.3 (80)
Recommended / Maximum Clamp Spacing, m (ft)	0.8 / 1.0 (2.75 / 3.25)

ELECTRICAL SPECIFICATIONS

Impedance, ohm	50 +/- 1
Velocity, percent	88
Capacitance, pF/m (pF/ft)	76 (23.2)
Inductance, µH/m (µH/ft)	0.190 (0.058)
Maximum Frequency, GHz	4.9
Peak Power Rating, kW	83
RF Peak Voltage, volts	2850
Jacket Spark, volt RMS	8000
Inner Conductor dc Resistance, ohm/1000 m (ohm/1000 ft)	2.82 (0.86)
Outer Conductor dc Resistance, ohm/1000 m (ohm/1000 ft)	1.04 (0.32)

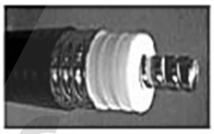
See Installation, Operation and Storage Temperatures on page 16.

UCF78-50JA/JFNA ATTENUATION AND AVERAGE POWER

Frequency MHz	Attenuation dB/100 m	Attenuation dB/100 ft.	Average Power kW
0.5	0.084	0.026	21.5
1.0	0.119	0.036	21.5
1.5	0.146	0.044	21.5
2.0	0.169	0.051	21.5
10	0.379	0.116	21.5
20	0.539	0.164	18.8
30	0.662	0.202	15.3
50	0.860	0.262	11.8
88	1.15	0.351	8.80
100	1.23	0.375	8.24
108	1.28	0.390	7.91
150	1.52	0.462	6.67
174	1.64	0.500	6.17
200	1.76	0.537	5.74
300	2.18	0.665	4.64
400	2.54	0.775	3.98
450	2.71	0.826	3.74
500	2.87	0.874	3.53
512	2.90	0.885	3.49
600	3.16	0.964	3.20
700	3.44	1.05	2.94
800	3.70	1.13	2.74
824	3.76	1.15	2.69
894	3.93	1.20	2.57
900	3.94	1.20	2.57
925	4.00	1.22	2.53
960	4.09	1.25	2.48
1000	4.18	1.27	2.42
1250	4.73	1.44	2.14
1500	5.24	1.60	1.93
1700	5.62	1.71	1.80
1800	5.81	1.77	1.74
2000	6.16	1.88	1.64
2100	6.34	1.93	1.60
2200	6.51	1.98	1.55
2400	6.84	2.09	1.48
3000	7.79	2.37	1.30
3500	8.52	2.60	1.19
4000	9.22	2.81	1.10
4900	10.4	3.17	0.972

Standard Conditions:
For attenuation: VSWR 1.0, cable temperature 20° C (68° F).
For average power: VSWR 1.0, ambient temperature 40° C (104°F), inner conductor temperature 100° C (212° F). No solar loading.

LCF158-50A Series
1-5/8" Low-Loss Foam Coax



APPLICATIONS

Main feed line, Riser-rated In-Building (JFN types)

GENERAL INFORMATION

Cable Type	Foam-Dielectric, Corrugated
Size	1-5/8"

STRUCTURE

Inner Conductor Material	Corrugated Copper Tube
Diameter Inner Conductor, mm (in)	17.6 (0.69)
Diameter Dielectric, mm (in)	40.9 (1.61)
Outer Conductor Material	Corrugated Copper
Diameter Copper Outer Conductor, mm (in)	46.5 (1.83)
Diameter over Jacket Nominal, mm (in)	50.3 (1.98)

MECHANICAL SPECIFICATIONS

Cable Weight, kg/m (lb/ft)	1.19 (0.80)
Minimum Bending Radius, Single Bend, mm (in)	200 (8)
Minimum Bending Radius, Repeated Bends, mm (in)	500 (20)
Bending Moment, N•m (lb-ft)	46.0 (34.0)
Flat Plate Crush Strength, N/mm (lb/in)	30.6 (175)
Tensile Strength, N (lb)	3300 (750)
Recommended / Maximum Clamp Spacing, m (ft)	1.2 / 1.5 (4.0 / 5.0)

ELECTRICAL SPECIFICATIONS

Impedance, ohm	50 +/- 1
Velocity, percent	89
Capacitance, pF/m (pF/ft)	75.0 (22.9)
Inductance, µH/m (µH/ft)	0.190 (0.058)
Maximum Frequency, GHz	2.75
Peak Power Rating, kW	310
RF Peak Voltage, volts	5600
Jacket Spark, volt RMS	10000
Inner Conductor dc Resistance, ohm/1000 m (ohm/1000 ft)	1.26 (0.38)
Outer Conductor dc Resistance, ohm/1000 m (ohm/1000 ft)	0.42 (0.12)

See Installation, Operation and Storage Temperatures on page 16.

LCF158-50JA/JFNA ATTENUATION AND AVERAGE POWER

Frequency MHz	Attenuation dB/100 m	Attenuation dB/100 ft.	Average Power kW
0.5	0.044	0.013	266
1	0.062	0.019	188
1.5	0.076	0.023	153
2	0.088	0.027	132
10	0.199	0.060	58.5
20	0.283	0.086	41.0
30	0.350	0.106	33.2
50	0.456	0.139	25.5
88	0.615	0.187	18.9
100	0.658	0.201	17.6
108	0.686	0.209	16.9
150	0.819	0.249	14.2
174	0.888	0.270	13.1
200	0.958	0.292	12.1
300	1.20	0.365	9.70
400	1.41	0.429	8.25
450	1.50	0.458	7.72
500	1.60	0.486	7.27
512	1.62	0.493	7.18
600	1.77	0.540	6.55
700	1.94	0.590	5.99
800	2.10	0.638	5.54
824	2.13	0.649	5.45
894	2.24	0.681	5.19
900	2.25	0.684	5.17
925	2.28	0.695	5.09
960	2.33	0.711	4.98
1000	2.39	0.728	4.86
1250	2.73	0.832	4.25
1500	3.05	0.929	3.81
1700	3.29	1.00	3.53
1800	3.41	1.04	3.40
2000	3.64	1.11	3.19
2100	3.76	1.14	3.09
2200	3.87	1.18	3.00
2400	4.09	1.24	2.84
2750	4.45	1.36	2.61

Standard Conditions:
For attenuation: VSWR 1.0, cable temperature 20° C (68° F).
For average power: VSWR 1.0, ambient temperature 40° C (104°F), inner conductor temperature 100° C (212° F). No solar loading.

LCF214-50A Series
2-1/4" Low-Loss Foam Coax

APPLICATIONS

Main feed line, Riser-rated In-Building (JFN types)

GENERAL INFORMATION

Cable Type	Foam-Dielectric, Corrugated
Size	2-1/4"

STRUCTURE

Inner Conductor Material	Corrugated Copper Tube
Diameter Inner Conductor, mm (in)	20.8 (0.82)
Diameter Dielectric, mm (in)	49.0 (1.93)
Outer Conductor Material	Corrugated Copper
Diameter Copper Outer Conductor, mm (in)	56.1 (2.21)
Diameter over Jacket Nominal, mm (in)	59.9 (2.36)

MECHANICAL SPECIFICATIONS

Cable Weight, kg/m (lb/ft)	1.70 (1.14)
Minimum Bending Radius, Single Bend, mm (in)	280 (11)
Minimum Bending Radius, Repeated Bends, mm (in)	560 (22)
Bending Moment, N•m (lb-ft)	81.0 (60.0)
Flat Plate Crush Strength, N/mm (lb/in)	27.6 (150)
Tensile Strength, N (lb)	2610 (587)
Recommended / Maximum Clamp Spacing, m (ft)	1.5 / 2.0 (5.0 / 6.6)

ELECTRICAL SPECIFICATIONS

Impedance, ohm	50 +/- 1
Velocity, percent	88
Capacitance, pF/m (pF/ft)	75.0 (22.9)
Inductance, µH/m (µH/ft)	0.190 (0.058)
Maximum Frequency, GHz	2.2
Peak Power Rating, kW	425
RF Peak Voltage, volts	6520
Jacket Spark, volt RMS	10000
Inner Conductor dc Resistance, ohm/1000 m (ohm/1000 ft)	0.92 (0.28)
Outer Conductor dc Resistance, ohm/1000 m (ohm/1000 ft)	0.31 (0.09)

See Installation, Operation and Storage Temperatures on page 16.

LCF214-50JA/JFNA ATTENUATION AND AVERAGE POWER

Frequency MHz	Attenuation dB/100 m	Attenuation dB/100 ft.	Average Power kW
0.5	0.037	0.011	321
1	0.052	0.016	226
1.5	0.064	0.020	184
2	0.074	0.023	159
10	0.169	0.051	70.2
20	0.241	0.074	49.0
30	0.298	0.091	39.7
50	0.390	0.119	30.3
88	0.528	0.161	22.4
100	0.566	0.172	20.9
108	0.590	0.180	20.1
150	0.706	0.215	16.8
174	0.766	0.233	15.5
200	0.827	0.252	14.3
300	1.04	0.317	11.4
400	1.23	0.373	9.66
450	1.31	0.400	9.02
500	1.39	0.425	8.49
512	1.41	0.431	8.37
600	1.55	0.473	7.63
700	1.70	0.518	6.96
800	1.84	0.562	6.42
824	1.88	0.572	6.31
894	1.97	0.601	6.01
900	1.98	0.603	5.98
925	2.01	0.613	5.88
960	2.06	0.627	5.75
1000	2.11	0.643	5.61
1250	2.42	0.738	4.89
1500	2.71	0.827	4.36
1700	2.94	0.895	4.03
1800	3.05	0.928	3.89
2000	3.26	0.993	3.63
2100	3.36	1.02	3.52
2200	3.47	1.06	3.41

Standard Conditions:
For attenuation: VSWR 1.0, cable temperature 20° C (68° F).
For average power: VSWR 1.0, ambient temperature 40° C (104°F), inner conductor temperature 100° C (212° F). No solar loading.

RECOMMENDATION ITU-R BT.417-5[*]

Minimum field strengths for which protection may be sought in planning an analogue terrestrial television service

(1963-1966-1970-1986-1992-2002)

The ITU Radiocommunication Assembly,

recommends

1 that when planning a television service in Bands I, III, IV or V, the median field strength for which protection against interference is planned should not be lower than:

TABLE 1

Band	**I**	**III**	**IV**	**V**
dB(μV/m)	+48	+55	+65(1)	+70(1)

(1) The values shown for Bands IV and V should be increased by 2 dB for system K.

These values refer to the field strength at a height of 10 m above ground level;

2 that the percentage of time for which the protection may be sought should lie between 90% and 99%.

NOTE 1 – In arriving at the figures shown in *recommends* 1, it has been assumed that, in the absence of interference from other television transmissions and man-made noise, the minimum field strengths at the receiving antenna that will give a satisfactory grade of picture, taking into consideration receiver noise, cosmic noise, antenna gain and feeder loss, are: +47 dB(μV/m) in Band I, +53 dB in Band III, +62 dB[**] in Band IV (value for the centre frequency of the first channel in Band IV, around 474 MHz) and +67 dB[**] in Band V (value for channel with the centre frequency, around 842 MHz). For other channels in Bands IV and V, for systems using 8 MHz[***] channel raster, the minimum field strength value should be derived as follows:

$$E_{min}\ (\text{dB}(\mu\text{V/m})) = 62 + 20 \log (f/474)$$

with f being the channel centre frequency expressed in MHz. These values may be used to derive the noise-limited sensitivity of receivers as shown in Recommendation ITU-R BT.804.

NOTE 2 – Further information concerning the planning of television services is contained in Annex 1.

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[*] Radiocommunication Study Group 6 made editorial amendments to this Recommendation in 2002 in accordance with Resolution ITU-R 44.

[**] The values shown for Bands IV and V should be increased by 2 dB for system K.

[***] The formula for other channel raster is still under study.

NOTE 3 – In a practical plan, because of interference from other television transmissions, the field strengths that can be protected will generally be higher than those quoted in *recommends* 1, and the exact values to be used in the boundary areas between any two countries should be agreed between the administrations concerned.

NOTE 4 – The broadcasting band designations I, III, IV and V derive from the European VHF/UHF Broadcasting Conference, Stockholm, 1961 and the African VHF/UHF Broadcasting Conference, Geneva, 1963. The frequency ranges at that time were:

Band I	41-68 MHz
Band III	162-230 MHz
Band IV	470-582 MHz
Band V	582-960 MHz

According to the Radio Regulations the bands allocated to the broadcasting service start at 47 MHz (Band I) and 174 MHz (Band III) respectively.

ANNEX 1

Boundaries of the television service in rural districts having a low population density

Where television services are to be provided for a sparsely populated region, in which better receivers and antenna installations are likely to be employed, administrations may find it desirable to establish the appropriate median field strength for which protection against interference is planned as shown in Table 2.

TABLE 2

Band	I	III	IV	V
dB(μV/m)	46	49	58	64

These values refer to the field strength at a height of 10 m above ground level.

In the absence of interference other than noise, field strengths of the order of 40 dB(μV/m) in Band I, 43 dB(μV/m) in Band III, 52 dB(μV/m) in Band IV and 58 dB(μV/m) in Band V can give satisfactory pictures. However, it is generally observed that the public begin to lose interest in installing television reception equipment when the field strength falls much below these levels.

The values given above have been obtained from field-strength investigations at the edge of the coverage area and picture quality assessments for Bands I and III in rural districts of Australia, India and Italy for Bands IV and V at both rural and urban locations in Italy and the United Kingdom. Therefore it is not appropriate to provide a minimum field strength calculation formula as was done in Note 1. It may be noted that in Bands IV and V where man-made noise is not generally a problem, the field-strength values quoted for rural areas may also be applied in urban areas.

RECOMMENDATION ITU-R BT.419-3[*]

Directivity and polarization discrimination of antennas in the reception of television broadcasting

(1963-1986-1990-1992)

The ITU Radiocommunication Assembly,

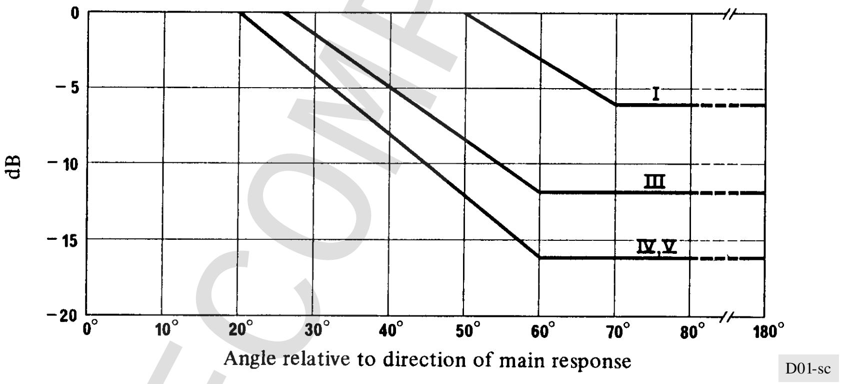
recommends

that the characteristics of directivity of the receiving antennas of Fig. 1 can be used for planning terrestrial television services in broadcasting Bands I, III, IV and V.

FIGURE 1

Discrimination obtained by the use of directional receiving antennas in broadcasting

(The number of the broadcasting band is shown on the curve)



NOTE 1 – It is considered that the discrimination shown will be available at the majority of antenna locations in built-up areas. At clear sites in open country, slightly higher values will be obtained.

NOTE 2 – The curves in Fig. 1 are valid for signals of vertical or horizontal polarization, when both the wanted and the unwanted signals have the same polarization.

NOTE 3 – In the case of orthogonal polarization the combined discrimination provided by directivity and orthogonality cannot be calculated by adding together the separate discrimination values. However, it has been found in practice that a combined discrimination value of 16 dB may be applied for all angles of azimuth in the terrestrial television Bands I to V. This value could be expected to be exceeded at more than 50% of locations (see Annexes 1 and 2).

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[*] Radiocommunication Study Group 6 made editorial amendments to this Recommendation in 2002 in accordance with Resolution ITU-R 44.

NOTE 4 – Bands I, III, IV and V are defined in Note 4 of Recommendation ITU-R BT.417.

NOTE 5 – For planning purposes, antenna systems for collective and cable distribution systems will be assumed to have directivity values at least equal to those set out in Fig. 1.

ANNEX 1

Advantages to be gained by using orthogonal wave polarizations in the planning of television broadcasting services in the VHF and UHF bands

Investigations have been conducted in several countries to ascertain the advantages which can be obtained in television broadcasting by using polarization discrimination in reception.

1 Bands I and III (VHF)

In this band of frequencies, between 30 and 300 MHz, the median value of discrimination that can be achieved at domestic receiving sites by the use of orthogonal polarization may be as much as 18 dB, and under these conditions, the values exceeded at 90% and 10% of the receiving sites are about 10 dB and 25 dB respectively.

The values of discrimination are likely to be better in open country and worse in built-up areas or places where the receiving antenna is surrounded by obstacles. For domestic installations in densely populated districts, the median values of 18 dB will usually be realized only at roof level; and this value may be reduced to 13 dB or less at street level.

No significant changes in the polarization of waves at VHF due to transmission through the troposphere have been observed over distances exceeding 200 km. Furthermore, there have been no reports of systematic changes in polarization effects with frequency in the metric band, neither with distance nor with type of terrain.

It must be emphasized, however, that to realize the discrimination ratios mentioned above, certain precautions are necessary at both the transmitting and receiving installations; cases have been reported in which, for a transmitter of horizontally polarized waves, some 7% of the radiated power was vertically polarized. It is clear that if the best discrimination is to be obtained for co-channel operation, the transmitters and antenna systems must be designed and installed so as to radiate as much as possible of the total power on the assigned polarization.

In the same way, to achieve the desired discrimination at the home receiving installation, the reception of the undesired orthogonally polarized waves on the antenna feeder and on the receiver itself must be reduced to the minimum practicable value.

It should, however, be noted that the above-mentioned advantage from the use of orthogonal polarizations can only be obtained when, in general, the polarization of the receiving antennas conforms to that of the wanted signal.

Due to problems with multipath reception in hilly and wooded terrain a comparison of vertical and horizontal polarization for VHF TV transmissions was made in Norway. The measurements show, in spite of higher field strengths for vertical polarization, that horizontal polarization in almost every measured site gave a better picture quality.

2 Bands IV and V (UHF)

Investigations have been carried out in the United Kingdom to determine the polarization discrimination in band 9 (UHF) of antennas at typical urban and rural domestic receiving sites. The results showed that for orthogonally polarized signals the median value of discrimination was 18 dB, and under the same conditions, the values exceeded at 90% and 10% of the receiving sites were about 9 dB and 25 dB respectively. There is also some small variation of discrimination with angle relative to the direction of main response. However, for television planning purposes in the United Kingdom, a value of 15 dB is used for all relative bearings.

As at VHF, care is necessary to ensure that the transmitter and receiver respectively do not emit or receive radiation of the undesired polarization. Apart from this, however, experience indicates that at UHF, the use of horizontal polarization offers advantages, because of the greater directivity obtainable at the receiving antennas; this reduces the effect of reflected waves, particularly in town areas. The European Broadcasting Union, therefore, considers that frequency assignments in these bands should be based on the general use of horizontal polarization, though exceptions may be made in cases where orthogonal polarization is necessary to achieve the desired protection.

3 Summary

From the studies described above, it is clear that the use of orthogonal polarization for broadcasting stations operating in the same frequency channel is of material assistance in discriminating against the reception of undesired signals. Worthwhile advantages are obtainable over the whole band of frequencies from 40 to 500 MHz and within the normal broadcasting service ranges. From the uniformity of the discrimination obtained over these frequencies, it is considered to be almost certain that the advantages will extend to the top of the broadcasting band in Band V at nearly 1 000 MHz.

ANNEX 2

Polarization of emission in television broadcasting

1 Linear polarization

Linear polarization of emissions is in almost universal use in television broadcasting. The plane of polarization is usually horizontal but from the viewpoint of planning there is much to be gained from allowing the possibility of also using vertical polarization.

The available evidence suggests that the use of horizontal polarization provides improved picture quality in hilly and wooded terrain compared with vertical polarization, at least for the VHF bands (see Annex 1).

The use of orthogonally polarized transmissions, together with appropriately polarized receiving antennas, offers significant advantages in terms of spectrum utilization. Planning based on the use of receiving antennas not offering polarization discrimination does not give this advantage.

2 Circular or elliptical polarization

There is a lack of information concerning the use of circular or elliptical polarization in planning the television broadcasting services. However, some administrations permit the use of circular or elliptical polarization as an alternative to the more usual horizontal or vertical. It is reported that the reception of circular polarized television emissions by simple portable or indoor antennas is improved because the orientation of these antennas by individual receivers is less critical than for the case of linear polarization.

However, it should be remembered that the use of simple portable or indoor antennas can lead to poor quality reception as a result of multipath propagation and low input signal levels.

Theoretically, the use of circularly polarized transmissions offers the possibility of filtering out most of the first order reflections. However, this advantage can only be achieved by the use of a circularly polarized receiving antenna and at this time such an antenna is not in practical use for individual television reception.

For a given transmitter power, a circularly polarized transmitting antenna will result in a field strength lower by 3 dB in the horizontal or in the vertical plane than that provided using a linearly polarized transmitting antenna, thus effectively giving a reduced coverage area.

3 Summary

From the foregoing it can be concluded that for optimum planning it is necessary to take full advantage of polarization discrimination, and that this can only be done economically and realistically by using horizontal and/or vertical polarizations.

RECOMMENDATION ITU-R BT.565[*],[**]

Protection ratios for 625-line television against radionavigation transmitters operating in the shared bands between 582 and 606 MHz

(1978)

The ITU Radiocommunication Assembly,

considering

a) the Final Acts of the European VHF/UHF Broadcasting Conference, Stockholm, 1961[***], and the Special Agreement relating to the use of the band 582-606 MHz by the radionavigation service, Brussels, 1962;

b) the assumption, which remains to be fully confirmed, that the results of tests carried out with monochrome television signals are also applicable to colour television;

c) that protection ratios should be such that they are satisfied for 99% of the time;

d) that values of protection ratios refer to the conditions at the input to the television receiver;

e) that the level of the television signal is expressed in terms of the power at the peak of the modulation envelope;

f) that the level of the radionavigation signal is expressed as the power at peak-pulse level,

recommends

that the values of protection ratio given below should be used in determining the protection available to monochrome or colour-television systems operating in the band 582 to 606 MHz:

1 Protection ratios required when the radionavigation signal falls within the passband of the television receiver

When the radionavigation signal falls within the passband of the television receiver, the required signal-to-interference ratio should be:

– 10 dB for systems with negative modulation,
– 15 dB for systems with positive modulation.

The ratio is sensibly constant over the greater part of the passband of the television receiver, but decreases in accordance with the selectivity of the receiver as shown in Fig. 1.

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[*] This Recommendation should be brought to the attention of Radiocommunication Study Group 8.

[**] Radiocommunication Study Group 6 made editorial amendments to this Recommendation in 2002 in accordance with Resolution ITU-R 44.

[***] However, at the European VHF/UHF Broadcasting Conference, Stockholm, 1961, some delegates made reservations as to the prospect of fulfilling the technical criteria in actual planning.

The protection ratios given in Fig. 1 do not relate to interference to the sound channel from signals of the radionavigation services. Further studies should be carried out on this subject.

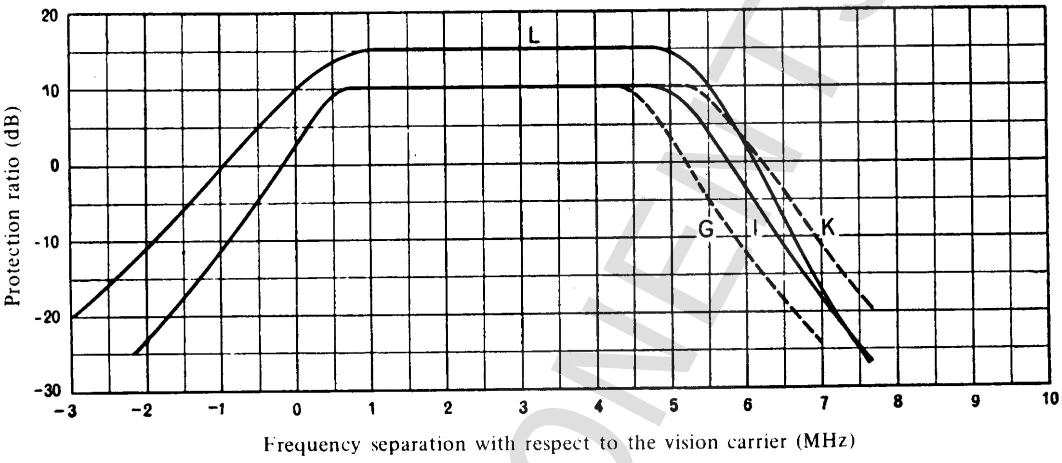

FIGURE 1 – *Protection ratio required by system L, G, I and K picture signals against a radionavigation signal in the band 582 to 606 MHz*

D01-sc

2 Protection ratios required when the radionavigation signal falls outside the passband of the television receiver

Reference should be made to Recommendation ITU-R BT.655 for image channel interference.

No information exists at present on adjacent channel interference.

NOTE – Other interference effects (intermodulation) are likely to occur if radionavigation stations, which in general use high peak powers and highly directional antennas, are situated near receiving locations, especially where the television signal is weak.

Planning criteria, including protection ratios, for digital terrestrial television services in the VHF/UHF bands

The ITU Radiocommunication Assembly,

considering

a) that systems have been developed for the transmission of digital terrestrial television services (DTTS) in the VHF/UHF bands;

b) that the VHF/UHF television bands are still occupied by analogue television services;

c) that the analogue television services will remain in use in some administrations for a considerable period of time;

d) that the availability of consistent sets of planning criteria agreed by administrations will facilitate the planning of digital terrestrial television services;

e) that parts of the VHF/UHF television bands are shared with other primary services;

f) that sharing between digital terrestrial television broadcasting (DTTB) and some other primary services is an evolving situation;

g) that the protection ratios established for the protection of digital terrestrial television need to be at the threshold of signal failure,

Proposed preferable DVB-T mode types for measurements on protection ratios

Modulation	Code rate	C/N(1) (dB)	Bit rate(2) (Mbit/s)
QPSK	2/3	6.9	≈ 7
16-QAM	2/3	13.1	≈ 13
64-QAM	2/3	18.7	≈ 20

(1) The figures are given for a Gaussian channel (including a typical implementation margin) for a BER $< 1 \times 10^{-11}$.

(2) For a guard interval of 1/4.

To reduce the number of measurements and tables, it is proposed that protection ratio measurements for DTMB systems should preferably be made with the following 11 modes shown in Table 2.

Proposed preferable DTMB mode types for measurements on protection ratios

Modulation	Code rate	*C*/*N*(1) (dB)	Bit rate(2) (Mbit/s)
4-QAM	0.4	2.5	5.414
16-QAM	0.4	8.0	10.829
64-QAM	0.4	14.0	16.243
4-QAM	0.6	4.5	8.122
16-QAM	0.6	11.0	16.243
64-QAM	0.6	17.0	24.365
4-QAM-NR	0.8	2.5	5.414
4-QAM	0.8	7.0	10.829
16-QAM	0.8	14.0	21.658
32-QAM	0.8	16.0	27.072
64-QAM	0.8	22.0	32.486

(1) The figures are given for a Gaussian channel at BCH output BER $< 3 \times 10^{-6}$.

(2) For a guard interval of 1/9 and RF bandwidth 8 MHz.

Wanted analogue terrestrial television systems

Measurements of protection ratios for the vision signal of a wanted analogue terrestrial television system should preferably be made with the subjective comparison method with a sine-wave reference interferer described in Annex 7.

The values of protection ratio quoted apply to interference produced by a single source. Except where otherwise stated, the ratios apply to tropospheric, *T*, interference and correspond closely to a slightly annoying impairment condition. They are considered to be acceptable only if the interference occurs for a small percentage of the time, not precisely defined but generally considered to be between 1% and 10%. For substantially non-fading unwanted signals, it is necessary to provide a higher degree of protection and ratios appropriate to continuous, *C*, interference should be used (see Annex 9).

When the wanted signal is an analogue television signal, two or more protection ratio values should be considered, one for the protection ratio of the vision signal and others for the protection ratios of sound signals. The most stringent value should then be used.

Significantly strong wanted input signals can require higher protection ratio values because of non-linear effects in the receiver.

For 625-line systems, the reference impairment levels are those which correspond to co-channel protection ratios of 30 dB and 40 dB, when two-thirds line offset is used, see Recommendation ITU-R BT.655. These conditions approximate to impairment grades 3 (slightly annoying) and 4 (perceptible but not annoying) and apply to tropospheric, *T*, and continuous, *C*, interference, respectively.

Minimum field strengths for ATSC terrestrial digital television

Derivation by the figure of merit method ATSC 6 MHz system*

Planning parameter[(1)]	**Low VHF 54-88 MHz**	**High VHF 174-216 MHz**	**UHF 470-806 MHz**
Frequency (MHz)	69	194	615
C/N (dB)	19.5[(2)]	19.5[(2)]	19.5[(2)]
k (dB)	−228.6	−228.6	−228.6
B (dB(Hz)) (6 MHz)	67.8	67.8	67.8
$G_{1\mathrm{m}^2}$ (dB)	−1.8	7.3	17.2
G_D (dB)	6	8	10
G_I (dB)	8.2	10.2	12.2
Transmission line loss (dB) α_{line}	1.1	1.9	3.3
Antenna 300/75 balun loss (dB) α_{balun}	0.5	0.5	0.5
Receiver noise figure (dB)	5	5	10
T_{rx} (K)	627.1	627.1	2 610
T_{line} (K)	65.0	102.9	154.4
LNA noise figure (dB)	5	5	5
LNA gain (dB)	20	20	20
T_{LNA} (dB)	627.1	627.1	627.1
T_{balun} (K)	31.6	31.6	31.6
T_a (K)	9 972.1	569.1	Negligible
$T_a\ \alpha_{balun}$ (K)	8 885.1	507.1	Negligible
$T_{line}/\alpha\ G$ (K)	0.8	1.6	3.3
$T_{rx}/\alpha\ G$ (K)	8.1	9.7	55.8
T_e (K)	9 552.6	1 176.8	717.8
10 log(T_e) (dB(K))	39.8	30.7	28.6
G_A (dB)	7.7	9.7	11.7
E_{rx} (dB(μV/m))[(2), (3)] (TBC)	35	33	39

* The values in the Table were calculated assuming C/N with typical multipath reception impairment and equal partitioning for noise and interference. The receiving system model is a typical receiving installation located near the edge of coverage and consists of an externally mounted antenna, a low noise amplifier (LNA) mounted at the antenna, an interconnecting downlead cable and an ATSC receiver.

(1) For definitions see Attachment 1 to Annex 1.

(2) Figures should be adjusted downward (towards better performance) by 6 dB for 1/2 rate concatenated trellis coding or 9 dB for 1/4 rate concatenated trellis coding.

(3) For formula see Attachment 1 to Annex 1.

Attachment 1
to Annex 1

Derivation by the figure of merit method

Required field strength

$$E_{rx}\ (\mathrm{dB(V/m)}) = \varphi\ (\mathrm{dB(W/m^2)}) + 10\log(120\,\pi)$$

$$C/N = \varphi - G_{1\mathrm{m}^2} + G_A/T_e - k - B_{rf}$$

$$E_{rx}\ (\mathrm{dB(\mu V/m)}) = \varphi\ (\mathrm{dB(W/m^2)}) + 25.8\ (\mathrm{dB}) + 120\ (\mathrm{dB})$$

$$= 145.8 + C/N + G_{1\mathrm{m}^2} - G_A/T_e + 10\log(k) + 10\log(B_{rf})$$

E_{rx}: required field strength at the receive system antenna

φ: power flux-density at the receive system antenna

C/N: carrier-to-noise ratio

$G_{1\mathrm{m}^2}$: gain of 1 m^2

G_A/T_e: figure of merit of the receive system

k: Boltzmann's constant (J/K)

B_{rf}: system equivalent noise bandwidth.

Receive system figure of merit

(For receiving system model with LNA)

$$G_A/T_e = (G - L)/(\alpha_{balun}\,T_a + T_{balun} + T_{LNA} + T_{line}/(\alpha_{line}\,G_{LNA}) + T_{rx}/(\alpha_{line}\,G_{LNA}))$$

Receiver noise temperature

$$T_{rx} = (10^{NF/10} - 1) \times 290^\circ$$

LNA noise temperature

$$T_{LNA} = (10^{NF/10} - 1) \times 290^\circ$$

Transmission line noise temperature

$$T_{line} = (1 - \alpha_{line}) \times 290^\circ$$

Balun noise temperature

$$T_{balun} = (1 - \alpha_{balun}) \times 290^\circ$$

Antenna noise temperature

$$T_a = 10^{(6.63 - 2.77(\log f))} \times 290^\circ \quad \text{(for dipole antenna)}$$

where *f* is expressed in MHz.

Antenna noise temperature (referred to LNA input)

$$\alpha\,T_a = T_a(\alpha_{balun})$$

System noise temperature

$$T_e = (\alpha_{balun}\,T_a + T_{balun} + T_{LNA} + T_{line}/(\alpha_{line}\,G_{LNA}) + T_{rx}/(\alpha_{line}\,G_{LNA}))$$

$$T_e\ (\mathrm{dB(K)}) = 10\log(\alpha_{balun}\, T_a + T_{balun} + T_{LNA} + T_{line}/(\alpha_{line}\, G_{LNA}) + T_{rx}/(\alpha_{line}\, G_{LNA}))$$

or

$$= 10\log(T_{balun} + T_{LNA} + T_{line}/(\alpha_{line}\, G_{LNA}) + T_{rx}/(\alpha_{line}\, G_{LNA})) + N_{ext}$$

when T_a is not known.

Gain of 1 m^2

$$G_{1\mathrm{m}}{}^2 = 10\log(4\,\pi/\lambda\lambda^2)$$

Data

G_I: antenna gain (isotropic) (dB)
L: transmission line loss (dB)
α_{line}: transmission line loss (numeric ratio)
T_a: antenna noise temperature (K)
T_{rx}: receiver noise temperature (K)
n_f: noise factor (numeric ratio)
NF: noise figure (dB)
T_0: reference temperature = 290 K
λ: wavelength of frequency of operation
G_A: system gain (dB)
T_e: system noise temperature (K)
N_{ext}: dB value representing the contribution due to external noise
k: Boltzmann's constant 1.38×10^{-23} (–228.6 dB) (J/K)
B: system equivalent noise bandwidth (dB(Hz))
α_{balun}: antenna 300/75 Balun loss (numeric ratio)
LNA: low noise amplifier
T_{LNA}: LNA noise temperature (K)

Calculation of minimum field strength DVB-T 8 MHz system

Frequency (MHz)	200			550			700		
System variant guard interval 1/4	QPSK 2/3	16-QAM 2/3	64-QAM 2/3	QPSK 2/3	16-QAM 2/3	64-QAM 2/3	QPSK 2/3	16-QAM 2/3	64-QAM 2/3
Receiver noise figure, F (dB)	5	5	5	7	7	7	7	7	7
Receiver carrier/noise ratio⁽¹⁾ (C/N) (dB)	8	14	20	8	14	20	8	14	20
Feeder loss A_f (dB)	3	3	3	3	3	3	5	5	5
Antenna gain, G (dB)	5	5	5	10	10	10	12	12	12
Minimum field strength for fixed reception, E_{min} (dB(μV/m))⁽²⁾	27	33	39	33	39	45	35	41	47

(1) For Rice channel.

(2) For formula, see Attachment 1 to Annex 2.

Calculation of minimum field strengths for ISDB-T 6 MHz system

Frequency (MHz)	**Low VHF**				**High VHF**				**UHF**			
	100				**200**				**600**			
System	DQPSK 1/2	QPSK 1/2	16-QAM 3/4	64-QAM 7/8	DQPSK 1/2	QPSK 1/2	16-QAM 3/4	64-QAM 7/8	DQPSK 1/2	QPSK 1/2	16-QAM 3/4	64-QAM 7/8
Noise bandwidth, *B* (MHz)	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
Receiver noise figure, *F* (dB)	5	5	5	5	5	5	5	5	7	7	7	7
Receiver noise input voltage, U_N⁽¹⁾ (dB(μV))	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	9.1	9.1	9.1	9.1
Receiver carrier/ noise ratio(2) (*C*/*N*) (dB)	6.2	4.9	14.6	22.0	6.2	4.9	14.6	22.0	6.2	4.9	14.6	22.0
Urban noise (dB)	1	1	1	1	1	1	1	1	0	0	0	0
Minimum receiver input voltage, U_{min} (dB(μV))(1)	14.3	13.0	22.7	30.1	14.3	13.0	22.7	30.1	15.3	14.0	23.7	31.1
Conversion factor (1) *K* (dB)	6.4	6.4	6.4	6.4	12.4	12.4	12.4	12.4	21.9	21.9	21.9	21.9

Frequency (MHz)	**Low VHF**				**High VHF**				**UHF**			
	100				**200**				**600**			
System	DQPSK 1/2	QPSK 1/2	16-QAM 3/4	64-QAM 7/8	DQPSK 1/2	QPSK 1/2	16-QAM 3/4	64-QAM 7/8	DQPSK 1/2	QPSK 1/2	16-QAM 3/4	64-QAM 7/8
Feeder loss, L_f (dB)	3	3	3	3	3	3	3	3	3	3	3	3
Antenna gain, *G* (dB)	3	3	3	3	5	5	5	5	10	10	10	10
Minimum field strength for fixed reception, E_{min} (dB (μV/m))(1)	20.7	19.4	29.1	36.5	24.7	23.4	33.1	40.5	30.2	28.9	38.6	46.0

(1) For formula, see Attachment 1 to Annex 3.

(2) For noise bandwidth noted above.

TABLE 85

Calculation of minimum field strengths for ISDB-T 8 MHz system

Frequency (MHz)	**Low VHF**				**High VHF**				**UHF**			
	100				**200**				**600**			
System	DQPSK 1/2	QPSK 1/2	16-QAM 3/4	64-QAM 7/8	DQPSK 1/2	QPSK 1/2	16-QAM 3/4	64-QAM 7/8	DQPSK 1/2	QPSK 1/2	16-QAM 3/4	64-QAM 7/8
Noise bandwidth, B (MHz)	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4	7.4
Receiver noise figure, F (dB)	5	5	5	5	5	5	5	5	7	7	7	7
Receiver noise input voltage, U_N (1) (dB(μV))	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	10.4	10.4	10.4	10.4
Receiver carrier/noise ratio(2) (C/N) (dB)	6.2	4.9	14.6	22.0	6.2	4.9	14.6	22.0	6.2	4.9	14.6	22.0
Urban noise (dB)	1	1	1	1	1	1	1	1	0	0	0	0
Minimum receiver input voltage, U_{min} (dB(μV))(1)	15.5	14.2	23.9	31.3	15.5	14.2	23.9	31.3	16.5	15.2	24.9	32.3
Conversion factor (1) K (dB)	6.4	6.4	6.4	6.4	12.4	12.4	12.4	12.4	21.9	21.9	21.9	21.9
Feeder loss, L_f (dB)	3	3	3	3	3	3	3	3	3	3	3	3
Antenna gain, G (dB)	3	3	3	3	5	5	5	5	10	10	10	10
Frequency (MHz)	**Low VHF**				**High VHF**				**UHF**			
	100				**200**				**600**			
Minimum field strength for fixed reception, E_{min} (dB(μV/m))(1)	21.9	20.6	30.3	37.7	25.9	24.6	34.3	41.7	31.4	30.1	39.8	47.2

(1) For formula, see Attachment 1 to Annex 3.

(2) For noise bandwidth noted above.

Calculation of minimum field strength DTMB 8 MHz system

Frequency (MHz)	**65**			**200**			**500**			**700**		
Receiver noise figure, F (dB)	5	5	5	5	5	5	7	7	7	7	7	7
Receiver carrier/noise ratio(1) (C/N) (dB)	8	14	20	8	14	20	8	14	20	8	14	20
Feeder loss A_f (dB)	1	1	1	3	3	3	3	3	3	5	5	5
Antenna gain, G (dB)	3	3	3	5	5	5	10	10	10	12	12	12
Minimum field strength for fixed reception, E_{min} (dB(μV/m))(1)	17	23	29	27	33	39	33	39	45	35	41	47

(1) For formula, see Attachment 1.

Calculation of minimum field strength DTMB 7 MHz system

Frequency (MHz)	**65**			**200**			**500**			**700**		
Receiver noise figure, F (dB)	5	5	5	5	5	5	7	7	7	7	7	7
Receiver carrier/noise ratio(1) (C/N) (dB)	8	14	20	8	14	20	8	14	20	8	14	20
Feeder loss A_f (dB)	1	1	1	3	3	3	3	3	3	5	5	5
Antenna gain, G (dB)	3	3	3	5	5	5	10	10	10	12	12	12
Minimum field strength for fixed reception, E_{min} (dB(μV/m))(1)	16.5	22.5	28.5	26.5	32.5	38.5	32.5	38.5	44.5	34.5	40.5	46.5

(1) For formula, see Attachment 1.

Calculation of minimum field strength DTMB 6 MHz system

Frequency (MHz)	**65**			**200**			**500**			**700**		
Receiver noise figure, F (dB)	5	5	5	5	5	5	7	7	7	7	7	7
Receiver carrier/noise ratio(1) (C/N) (dB)	8	14	20	8	14	20	8	14	20	8	14	20
Feeder loss A_f (dB)	1	1	1	3	3	3	3	3	3	5	5	5
Antenna gain, G (dB)	3	3	3	5	5	5	10	10	10	12	12	12
Minimum field strength for fixed reception, E_{min} (dB(μV/m))(1)	16	22	28	26	32	38	32	38	44	34	40	46

(1) For formula, see Attachment 1.

Electric Power

Electric power is the rate of energy consumption in an electrical circuit.
The electric power is measured in units of watts.

- Electric power definition
- Electric power calculation
- Power of AC circuits
- Power factor
- Power calculator

Electric power definition

The electric power P is equal to the energy consumption E divided by the consumption time t:

$$P = \frac{E}{t}$$

P is the electric power in watt (W).
E is the energy consumption in joule (J).
t is the time in seconds (s).

Example

Find the electric power of an electrical circuit that consumes 120 joules for 20 seconds.
Solution:

$E = 120J$

$t = 20s$

$P = E / t = 120J / 20s = 6W$

Electric power calculation

$P = V \cdot I$

or

$P = I^2 \cdot R$

or

$P = V^2 / R$

P is the electric power in watt (W).
V is the voltage in volts (V).
I is the current in amps (A).
R is the resistance in ohms (Ω).

Power of AC circuits

The formulas are for single phase AC power.
For 3 phase AC power:
When line to line voltage (V_{L-L}) is used in the formula, multiply the single phase power by square root of 3 (√3=1.73).

When line to zero voltage ($V_{L\text{-}0}$) is used in the formula, multiply the single phase power by 3.

Real power

Real or true power is the power that is used to do the work on the load.

$$P = V_{rms}\, I_{rms} \cos \varphi$$

P is the real power in watts [W]
V_{rms} is the rms voltage = $V_{peak}/\surd 2$ in Volts [V]
I_{rms} is the rms current = $I_{peak}/\surd 2$ in Amperes [A]
φ is the impedance phase angle = phase difference between voltage and current.

Reactive power

Reactive power is the power that is wasted and not used to do work on the load.

$$Q = V_{rms}\, I_{rms} \sin \varphi$$

Q is the reactive power in volt-ampere-reactive [VAR]
V_{rms} is the rms voltage = $V_{peak}/\surd 2$ in Volts [V]
I_{rms} is the rms current = $I_{peak}/\surd 2$ in Amperes [A]
φ is the impedance phase angle = phase difference between voltage and current.

Apparent power

The apparent power is the power that is supplied to the circuit.

$$S = V_{rms}\, I_{rms}$$

S is the apparent power in Volt-amper [VA]
V_{rms} is the rms voltage = $V_{peak}/\surd 2$ in Volts [V]
I_{rms} is the rms current = $I_{peak}/\surd 2$ in Amperes [A]

Real / reactive / apparent powers relation

The real power P and reactive power Q give together the apparent power S:

$$P^2 + Q^2 = S^2$$

P is the real power in watts [W]
Q is the reactive power in volt-ampere-reactive [VAR]
S is the apparent power in Volt-amper [VA]

Power factor calculator

The power factor correction capacitor should be connected in parallel to each phase load.
The power factor calculation does not distinguish between leading and lagging power factors.
The power factor correction calculation assumes inductive load.

Single phase circuit calculation

Power factor calculation:

$$PF = |\cos \varphi| = 1000 \times P_{(kW)} / (V_{(V)} \times I_{(A)})$$

Apparent power calculation:

$$|S_{(kVA)}| = V_{(V)} \times I_{(A)} / 1000$$

Reactive power calculation:

$$Q_{(kVAR)} = \sqrt{(|S_{(kVA)}|^2 - P_{(kW)}{}^2)}$$

Power factor correction capacitor's capacitance calculation:

$$S_{\text{corrected (kVA)}} = P_{(kW)} / PF_{\text{corrected}}$$

$$Q_{\text{corrected (kVAR)}} = \sqrt{(S_{\text{corrected (kVA)}}{}^2 - P_{(kW)}{}^2)}$$

$$Q_{c\ (kVAR)} = Q_{(kVAR)} - Q_{\text{corrected (kVAR)}}$$

$$C_{(F)} = 1000 \times Q_{c\ (kVAR)} / (2\pi f_{(Hz)} \times V_{(V)}{}^2)$$

Three phase circuit calculation

For three phase with balanced loads:

Calculation with line to line voltage

Power factor calculation:

$$PF = |\cos \varphi| = 1000 \times P_{(kW)} / (\sqrt{3} \times V_{L\text{-}L(V)} \times I_{(A)})$$

Apparent power calculation:

$$|S_{(kVA)}| = \sqrt{3} \times V_{L\text{-}L(V)} \times I_{(A)} / 1000$$

Reactive power calculation:

$$Q_{(kVAR)} = \sqrt{(|S_{(kVA)}|^2 - P_{(kW)}{}^2)}$$

Power factor correction capacitor's capacitance calculation:

$$Q_{c\,(\mathrm{kVAR})} = Q_{(\mathrm{kVAR})} - Q_{\mathrm{corrected}\,(\mathrm{kVAR})}$$

$$C_{(\mathrm{F})} = 1000 \times Q_{c\,(\mathrm{kVAR})} / (2\pi f_{(\mathrm{Hz})} \times V_{\mathrm{L\text{-}L(V)}}{}^{2})$$

Calculation with line to neutral voltage

Power factor calculation:

$$PF = |\cos\varphi| = 1000 \times P_{(\mathrm{kW})} / (3 \times V_{\mathrm{L\text{-}N(V)}} \times I_{(\mathrm{A})})$$

Apparent power calculation:

$$|S_{(\mathrm{kVA})}| = 3 \times V_{\mathrm{L\text{-}N(V)}} \times I_{(\mathrm{A})} / 1000$$

Reactive power calculation:

$$Q_{(\mathrm{kVAR})} = \sqrt{(|S_{(\mathrm{kVA})}|^{2} - P_{(\mathrm{kW})}{}^{2})}$$

Power factor correction capacitor's capacitance calculation:

$$Q_{c\,(\mathrm{kVAR})} = Q_{(\mathrm{kVAR})} - Q_{\mathrm{corrected}\,(\mathrm{kVAR})}$$

$$C_{(\mathrm{F})} = 1000 \times Q_{c\,(\mathrm{kVAR})} / (3 \times 2\pi f_{(\mathrm{Hz})} \times V_{\mathrm{L\text{-}N(V)}}{}^{2})$$

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