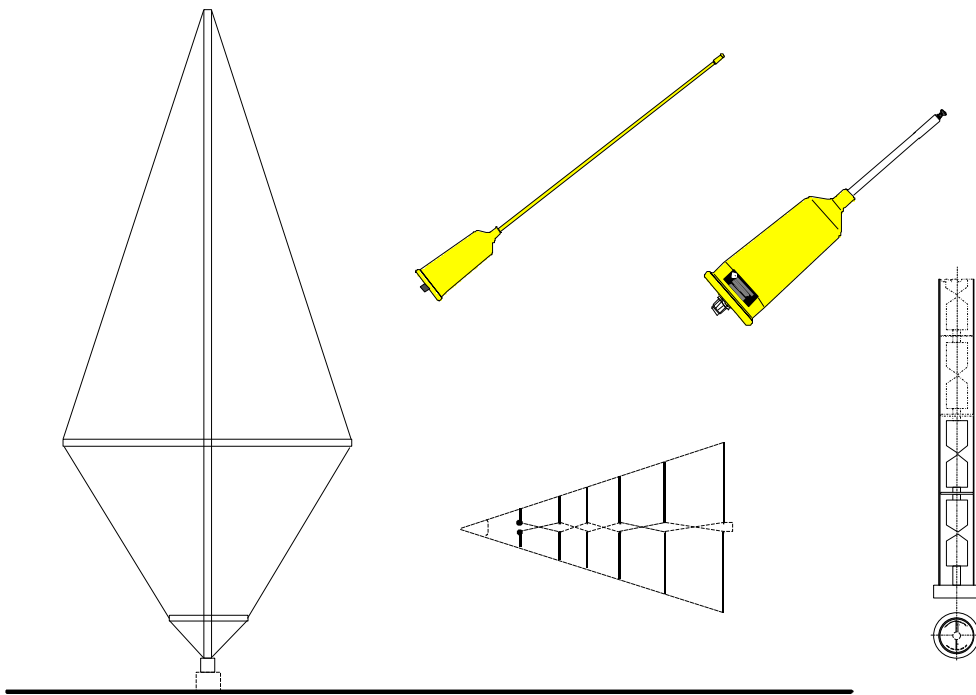




ROHDE&SCHWARZ

ANTENNA BASICS

Christof Rohner



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1 Introduction

Antennas are used for **converting** conducted electromagnetic waves into electromagnetic waves freely propagating in space and vice versa (Fig. 1.1). The name is derived from the field of zoology, where the term antennae (Latin) is used to designate the long thin feelers of insects.

The oldest existing antennas, eg those used by *Heinrich Hertz* in 1888 in his first experiments for proving the existence of electromagnetic waves, were neither physically nor functionally separated from high-frequency generators, and up to the present day resonant circuits are taken as models for illustrating certain antenna characteristics. It was not until around and after 1900 that antennas were clearly separated and regarded an independent unit in a radio system as transmitting and receiving stations were set up.

Modern antennas often do not differ much from their ancestors in their outward appearance but are usually of highly elaborate design tailored to match the application on hand. In radiocommunication, for example, efforts are directed at **converting one type of wave into another with a minimum loss**. For test antennas, which serve to provide a test receiver with an **exact measure of the field strength at the antenna site**, this requirement is of little importance. In this case it is essential that the physical characteristics of the antenna are exactly known.

From the great variety of antennas used today, only those which are preferably used in mobile radio and field-strength measurements can be described here. The same applies to the multitude of wave propagation methods. To provide a broad overview it seems appropriate to start by defining the physical quantities used to describe and also assess the behaviour of antennas and the propagation of electromagnetic waves.

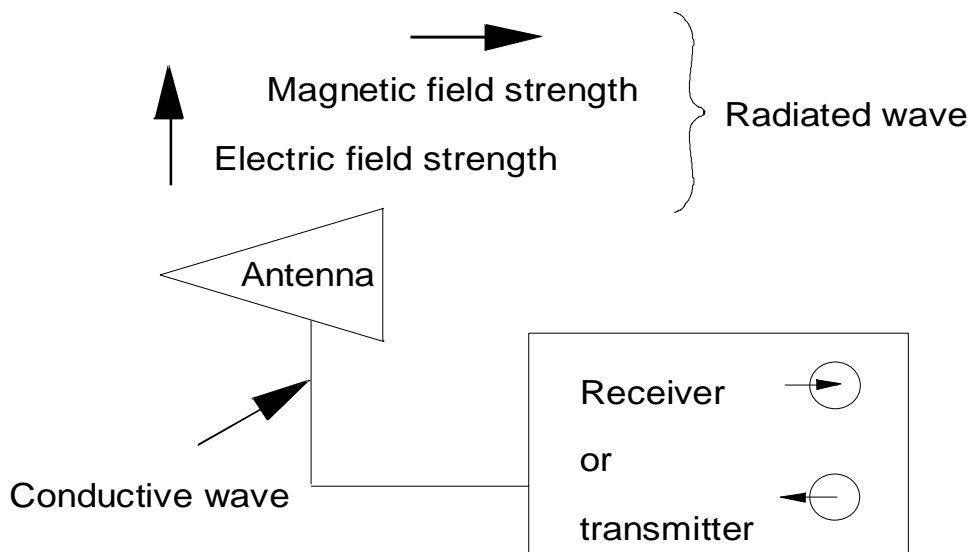


Fig. 1.1 Antenna as electromagnetic converter

2 Antenna Characteristics

As mentioned in the introduction, antennas have the function of converting one type of wave into another. The direction of energy conversion is irrelevant as far as the principle of operation and the understanding thereof are concerned. The transmitting and the receiving antenna can therefore be looked at in the same way (reciprocity principle), and the parameters described below are equally valid for transmission and reception. This also applies if the parameters are in some cases measurable only for transmission or for reception or if their specification appears to be meaningful only for one of these modes. Active antennas are the only exception: being pure receiving antennas, they are non-reciprocal. Apart from that, a clear distinction between transmitting and receiving antennas must be made if, for example, the maximum transmitter power is to be taken into account. This is however irrelevant to the characteristics and the principle of operation.

2.1 Radiation Pattern

The **spatial radiation** of antennas is described by means of **radiation patterns** (usually in the far field). Uniform radiation in all directions would be obtained only with an isotropic radiator, which can however not be realized for a particular polarization and is therefore suitable in the first place as a model or reference standard. While dipoles and monopoles do have some directivity (see Fig. 2.1), the term directional antennas is only used for antennas with radiation focussed in a specific direction. As the reciprocity theorem (see section 2) applies, it is sufficient to examine antenna parameters in the following for transmission only.

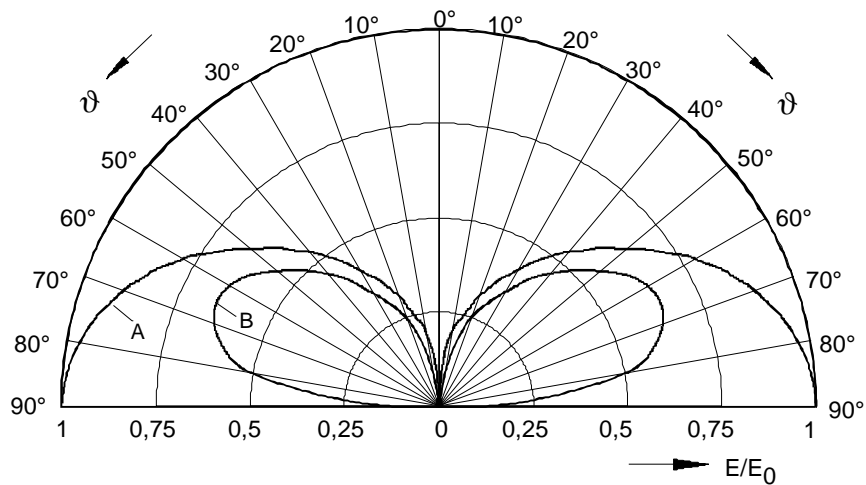


Fig. 2.1 Radiation pattern of vertical monopole above ground of perfect (A) and average (B) conductivity

When looking at directional diagrams, it must be distinguished whether the **field strength** (as is common practice) or the **power** is shown versus the solid angle. In power diagrams, the beams are narrower and the side lobes smaller than in field-strength diagrams. While spherical or polar coordinates as used in Fig. 2.1 are frequently preferred as they are more illustrative, Cartesian (and if possible logarithmized) diagrams mostly provide a much more detailed and accurate representation of radiation characteristics.

For a complete and accurate description of the spatial radiation characteristics of an antenna the following must be specified:

1. ϑ component of field strength as a function of angles ϑ and φ
2. φ component of the field strength as a function of angles ϑ and φ

in terms of magnitude and phase.

In many cases it is sufficient however to indicate the **magnitude of the field strength** for the desired (wanted) direction of polarization, this quantity usually being normalized to the field-strength maximum:

$$C(\vartheta, \varphi) = \frac{E(\vartheta, \varphi)}{E_{\max}(\vartheta_0, \varphi_0)} = \frac{H(\vartheta, \varphi)}{H_{\max}(\vartheta_0, \varphi_0)}$$

2.2 Directivity Factor

The **directivity factor D** is defined as the ratio of the radiation intensity F_{\max} obtained in the main direction of radiation to the radiation intensity F_i that would be generated by a loss-free isotropic radiator with the same **radiated power P_t** (ITG/NTG 2.1/01). The radiation intensity can be replaced by the **power density** represented by the Poynting vector as shown below:

$$\underline{\mathbf{S}} = \underline{\mathbf{E}} \times \underline{\mathbf{H}} \quad \text{with } \underline{\mathbf{S}} \text{ perpendicular to } \underline{\mathbf{E}} \\ \text{and } \underline{\mathbf{S}} \text{ and } \underline{\mathbf{E}} \text{ perpendicular to } \underline{\mathbf{H}} \text{ in the far field}$$

The power density is measured at the same distance r from the antennas (characters in bold and underlined characters in the above formula and in the following indicate vectors).

The following thus applies:

$$D = \frac{F_{\max}}{F_i} \quad \text{where} \quad F_i = \frac{P_t}{4\pi}$$

2.3 Gain

Analogously to the directivity factor, the **gain G** is the ratio of the radiation intensity F_{\max} obtained in the main direction of radiation to the radiation intensity F_{i0} , that would be generated by a loss-free isotropic radiator with the same **input power P_{i0}** (ITG/NTG 2.1/01):

$$G = \frac{F_{\max}}{F_{i0}} \quad \text{where} \quad F_{i0} = \frac{P_{i0}}{4\pi}$$

In contrast to the directivity factor, the **antenna efficiency η** is taken into account in the above equation since the following applies:

$$G = \eta \cdot D$$

DIN 45030 in addition defines the **practical gain** G_{pract} . Only this type of gain can be measured, whereas the gain defined above is based on ideal matching and is determined from the practical gain and the magnitude of the reflection coefficient r according to the following formula:

$$G = G_{\text{pract}} \frac{1}{1 - |r|^2}$$

Gain and directivity factor are often expressed in a logarithmic form:

$$g = 10 \lg G \quad [\text{dB}] \quad \text{and} \quad d = 10 \lg D \quad [\text{dB}]$$

In some cases and contrary to relevant rules and standards, the gain is not specified with reference to an isotropic radiator or with reference to a direction different from the main direction of radiation. In borderline cases it is common practice (although not quite to standard) is to specify the gain referred to the isotropic radiator with the pseudo unit dBi and that referred to the halfwave dipole with dBd.

2.4 Effective Area

The **effective area** A_w of an antenna is a parameter specially defined for receiving antennas. It is a measure for the maximum received power P_r that an antenna can pick up from a plane wave of the power density S :

$$P_{\text{rmax}} = S \cdot A_w$$

Although the effective area of an antenna can well be conceived as a real area perpendicular to the direction of propagation of the incident wave, it is not necessarily identical with the geometrical area A_g of the antenna. The relationship between the effective and the geometrical areas is described by the **aperture efficiency**

$$q = A_w / A_g$$

The effective area of an antenna can be converted to the gain and vice versa by means of the formula

$$A_w = \frac{\lambda^2}{4\pi} \cdot G$$

2.5 Effective Antenna Length

Analogously to the effective area of the antenna, the effective antenna length (often also referred to as effective antenna height) is the quotient of the maximum **open-circuit voltage** V_0 at the antenna terminals and the electric field strength E of the incident, linearly polarized wave obtained with the antenna optimally aligned (see Fig. 2.2):

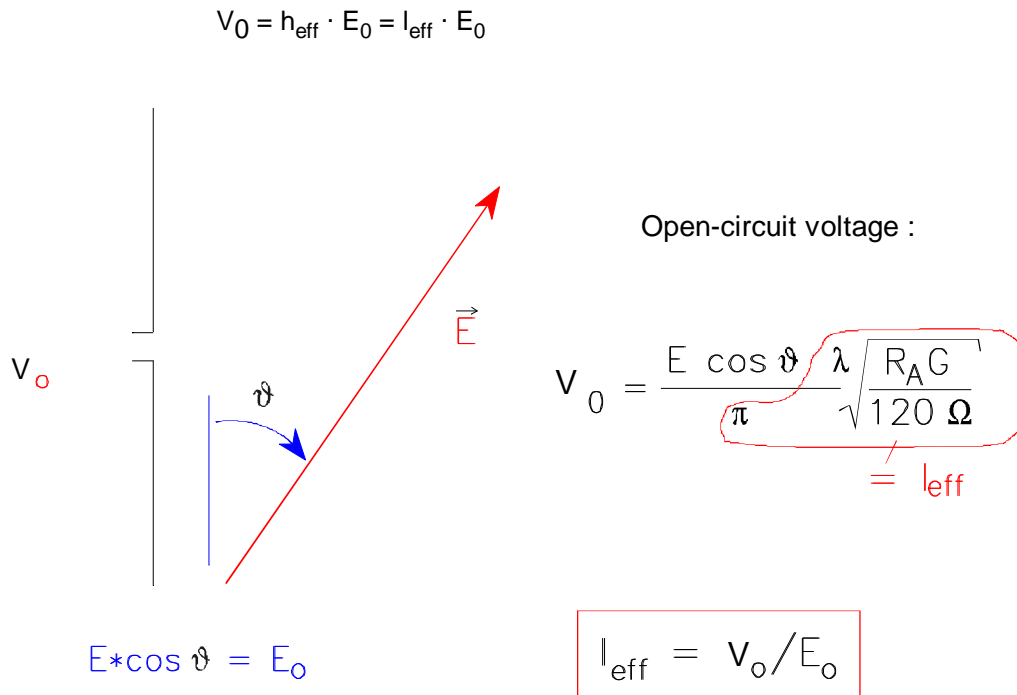


Fig. 2.2 Effective length

The effective antenna length is not identical with the geometrical antenna length (cf. effective area). The effective length can be calculated from the geometrical length l_g of the antenna and the current distribution $I(z_q)$ on the antenna during transmission by evaluating the integral

$$I_{\text{eff}} = \int_0^{l_g} \frac{I(z_q)}{I_A} dz_q$$

For a very thin half-wave dipole, $I_{\text{eff}} = 0.64 \cdot l$ is obtained, for example. From this, the effective length can well be illustrated: the effective length of an antenna is the length required for a dipole to which a homogeneous feedpoint current I_A is applied to generate the same field strength in the main direction of radiation as a radiator to which the actual current is applied (see Fig. 2.3).

To convert power-referred into voltage-referred quantities, the formula

$$I_{\text{eff}} = 2 \sqrt{\frac{R_A A_w}{120 \pi \Omega}}$$

can be used if the feedpoint impedance R_A of the antenna is known.

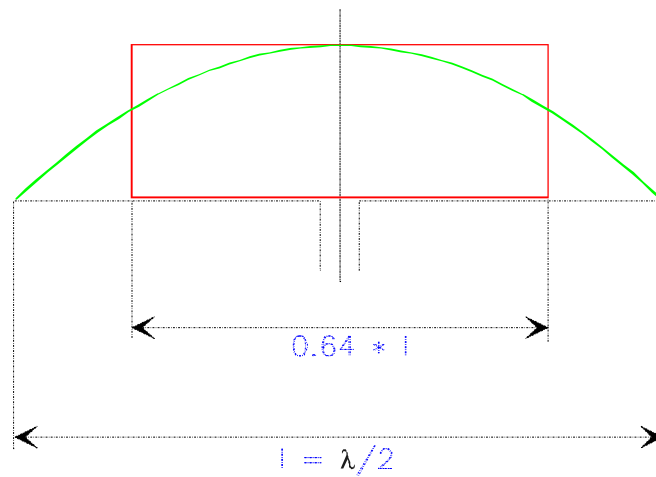


Fig. 2.3 Effective length of a half-wave dipole

2.6 Antenna Factor

Unlike the effective length, the antenna factor K is the quotient of the electric field strength E and the **voltage V_{IN} present at the matched receiver input** (Fig. 2.4):

$$K = \frac{\text{Electric field strength}}{\text{Output voltage into } 50 \Omega}$$

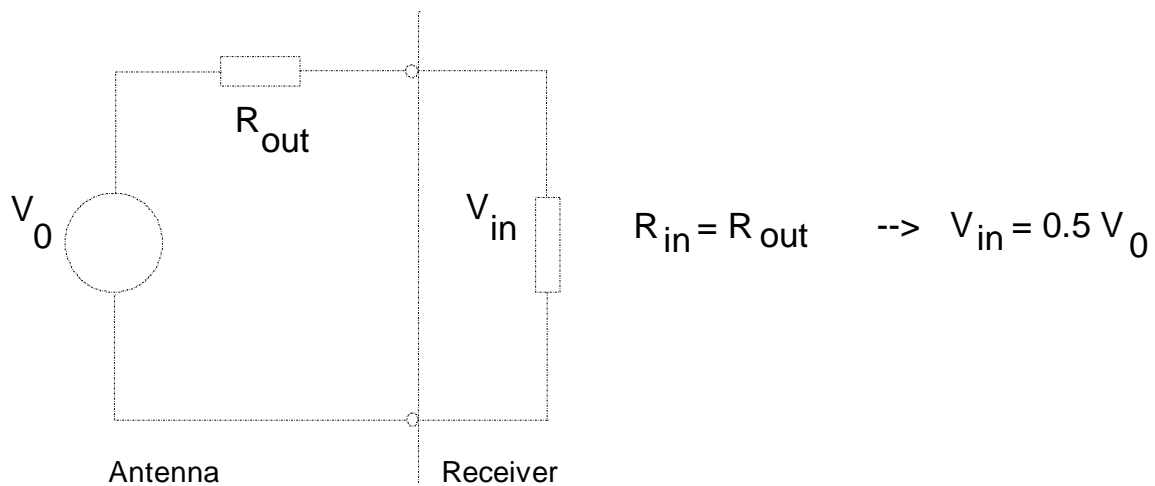


Fig. 2.4 Antenna factor

State-of-the-art test receivers have a 50-Ω input. With $R_{in} = R_{out} = 50 \Omega$, it follows that $V_{in} = 1/2 V_0$ and thus

$$K = 2 / I_{eff}$$

It is evident that for field-strength measurements **either the effective antenna length or the antenna factor of the test antenna must be exactly known**. Often, it is more convenient to use the antenna factor, especially in its logarithmic form

$$k = 20 \lg K$$

as a **transducer factor** since in this case all that needs to be done is to add the antenna factor k to the voltage level P_u indicated by the test receiver to obtain the **level F of the electric field strength**:

$$F [\text{dB}(1 \mu\text{V}/\text{m})] = P_u [\text{dB}(1 \mu\text{V})] + k [\text{dB}(1/\text{m})]$$

For the sake of completeness it should be noted that for high-precision field-strength measurements the **cable loss** between the test antenna and the receiver must be taken into account.

Whereas in field-strength measurements the antenna factor is commonly used as a key parameter for the antenna, in general antenna measurements the gain and the directivity factor are predominantly specified. The formula

$$K = \frac{9.73}{\lambda \cdot \sqrt{G}}$$

describing the relationship between the antenna factor and the practical gain is therefore often helpful. As a logarithm, this formula takes the form of

$$k = -29.8 \text{ dB} + 20 \lg (f/\text{MHz}) - g$$

2.7 Impedances and Resistances

The term **characteristic impedance**, which is still used occasionally in connection with antennas, goes back to the theory of high-frequency lines. Such lines can be represented in an equivalent circuit diagram as resistances and inductances serially distributed on the conductors and as capacitances and conductances between the conductors, and can thus conveniently be calculated. These line reactances, which may be spatially dependent, are marked by a superscript dash, which indicates "physical quantity divided by unit of length". From this the **characteristic impedance**

$$Z_W = \sqrt{\frac{R' + j \omega L'}{G' + j \omega C'}}$$

can be calculated. The characteristic impedance is sometimes confused with the resistances and impedances described below, probably because some calculation methods used for antennas are still based on the characteristic impedance as defined above.

The most important parameter for an antenna operator is the complex **input impedance**

$$Z_{in} = R_{in} + j X_{in} ,$$

ie the impedance present at the antenna feedpoint. Its real component is the sum formed by the **radiation resistance**

$$R_S = P_S / I^2$$

at the antenna feedpoint and the **loss resistance** R_L . It should be noted however that the radiation resistance, being the quotient of the radiated power and the square of the rms value of the antenna current, is spatially dependent, same as the antenna current itself, so that for the radiation resistance the point of the antenna to which it applies must always be indicated. Quite commonly the **antenna feedpoint** is specified, and equally often the **current maximum**. **The two points coincide** for some, but **by no means for all types of antenna**.

The imaginary component X_{in} of the input impedance becomes negligible if the antenna is operated in **resonance**. Electrically very short antennas have capacitive ($X_{in} < 0$) impedance values well up to several $k\Omega$, whereas electrically too long antennas can be recognized from their inductive imaginary component ($X_{in} > 0$).

The **nominal impedance** Z_n , which is also standardized (ITG/NTG 2.1/01), is a mere reference quantity. It is commonly specified as the characteristic impedance of the antenna cable, to which the antenna impedance must be matched (as a rule $Z_n = 50 \Omega$).

The **SWR (standing wave ratio)** is a measure of the quality of matching:

$$s = \frac{V_{max}}{V_{min}} = \frac{I_{max}}{I_{min}} = \frac{|V_{forw}| + |V_{refl}|}{|V_{forw}| - |V_{refl}|} = \frac{\sqrt{P_{forw}} + \sqrt{P_{refl}}}{\sqrt{P_{forw}} - \sqrt{P_{refl}}}$$

The SWR is the quotient formed by the maximum and the minimum voltage on the feeder line. With ideal matching, $s = 1$. By transposing the above formula, it can be calculated from the SWR what

amount of the power fed to the antenna is reflected and reapplied to the feeder (see Fig. 2.5 and Table).

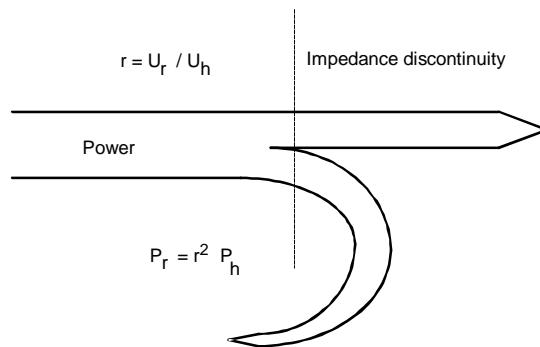


Fig. 2.5 Power reflection due to mismatch

s	1	1.5	2	3	6
Reflected power	0 %	4 %	10 %	25 %	50 %

The SWR can be measured or calculated from the feedpoint impedance and the nominal impedance using the formula

$$s = \frac{Z_E}{Z_N}$$

The relationship between SWR and the magnitude of the **reflection coefficient** given in Fig. 2.5

$$r = \frac{V_{\text{refl}}}{V_{\text{forw}}}$$

is described by the formula

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

The **return loss** derived therefrom in logarithmic form

$$a_r = -20 \lg \frac{V_{\text{refl}}}{V_{\text{forw}}} = -10 \lg \frac{P_{\text{refl}}}{P_{\text{forw}}} \quad [\text{dB}]$$

is also a commonly used measure for the reflection characteristics of a cable, circuit or antenna.

3 Basic Characteristics of Selected Antennas

3.1 Dipole Antennas

Dipole antennas are the most elementary type of antenna that can be implemented in practice. The best known representative of this type is the tuned (halfwave) dipole (Fig. 3.1) made of infinitely thin and perfectly conductive material.

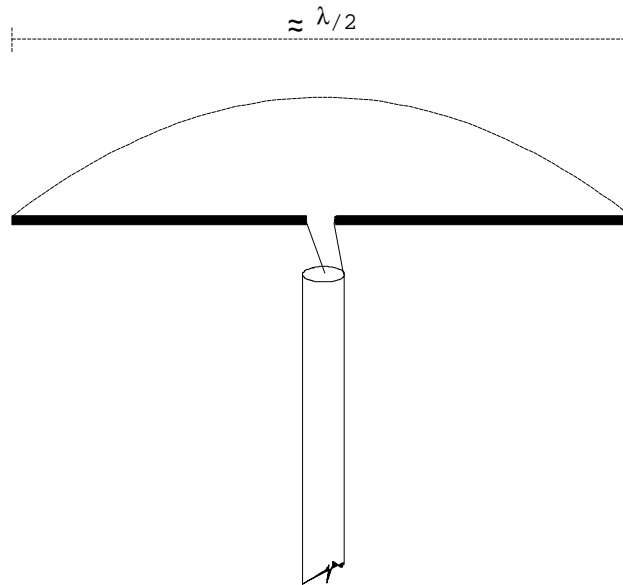


Fig. 3.1 Tuned half-wave dipole

This dipole is slightly shorter than half the wavelength. Its input impedance at the resonant frequencies is between 50Ω and 70Ω , depending on the diameter, so that feeder cables of common nominal impedance can easily be connected. The current distribution on the dipole (shown in Fig. 3.1) can to a good approximation be assumed to be sinusoidal. The radiation pattern of the dipole is similar to that of a monopole above perfectly conducting ground (see Fig. 2.1 (A) in section 2.1). The radiation is distributed uniformly in planes perpendicular to the dipole axis.

The designation "half-wave dipole" implies that this antenna is, strictly speaking, designed and usable only for a single frequency. Experience however shows that dipoles of this type can well be used for the reception (although not transmission) of broadband broadcast signals. From this it might be concluded that half-wave dipoles could be used at least as **test antennas** even at frequencies far off their resonant frequency. In practice, however, problems are encountered with broadband applications of conventional dipoles:

1. The **antenna input impedance** strongly depends on the ratio of the antenna length to the wavelength (see Fig. 3.2) so that considerable matching problems occur if the antenna is operated on another than its resonant frequency.

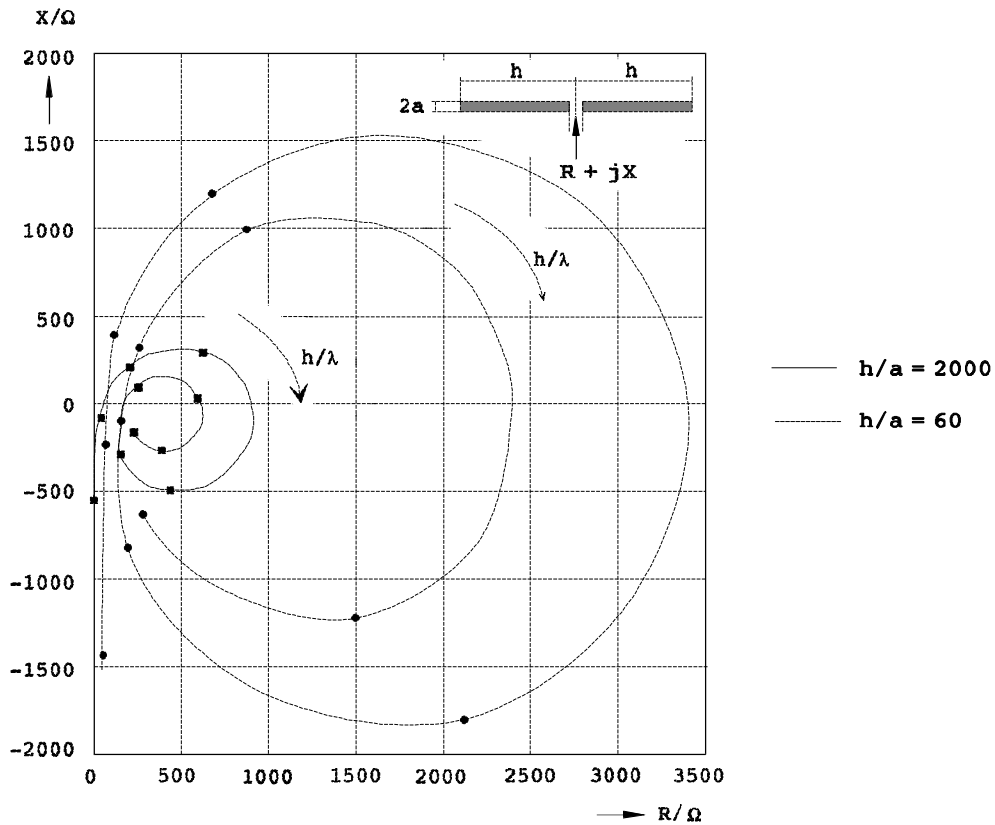


Fig. 3.2 Input impedances of a thin and a thick dipole

- The **radiation pattern** too changes above a certain frequency as a function of the ratio of antenna length to the wavelength (Fig. 3.3) so that, for instance, the main direction of radiation or the gain cannot be uniquely determined.

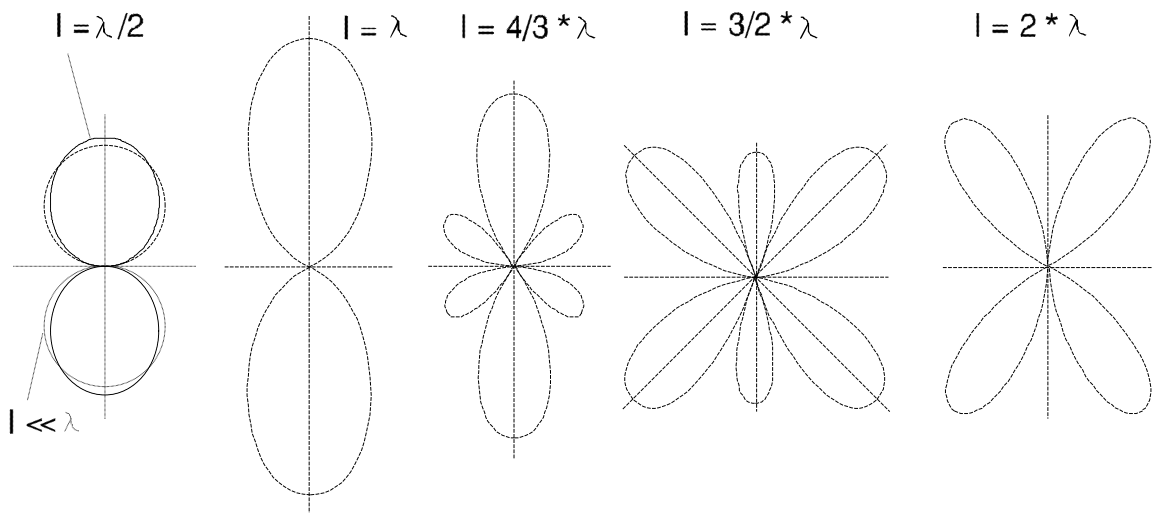


Fig. 3.3 Radiation patterns of a dipole at different frequencies

The problems can be solved in various ways:

1. The antenna is designed as a **telescopic rod** or in the form of several rods that can be connected in order to vary the antenna length as required for the operating frequency. In this way the dipole is in resonance at any frequency.
2. The diameter of the antenna is increased relative to the antenna length. The dashed curve in Fig. 3.2 shows the typical impedance characteristic of a dipole whose radius is increased. From this it can be seen that the effect of frequency on the antenna characteristics decreases as the diameter of the antenna increases relative to its length. Fig. 3.4 shows several versions of such “**thick**” dipoles. To save material and above all weight, dipoles are often designed not as a massive cylinder but in the form of a **cage**. A common type of test antenna is the **biconical antenna**, for example, which is normally also in the form of a cage (shown in Fig. 3.4 on the right).

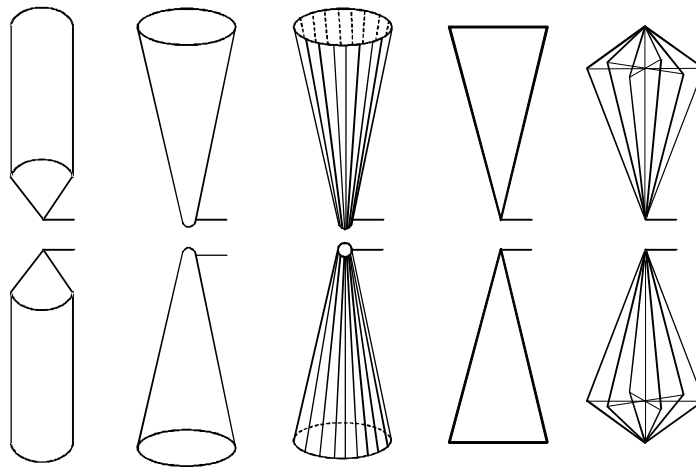


Fig. 3.4 Versions of broadband dipoles

3. The **current distribution** on the antenna is influenced (eg by means of reactive elements, resonant circuits or ferrite rings) so that at high frequencies only part of the antenna is active. In this way, the ratio of wavelength to antenna length remains approximately constant even with changing frequency. Electrically, this solution is similar to the telescopic antenna described under 1., although with less complexity of design.
4. The dipoles are made considerable shorter than the half wavelength. The associated impedance change (see Fig. 3.2) is compensated for by tapping the open-circuit voltage by means of a high-impedance active component (FET) and subsequent impedance transformation. This kind of **active antenna** cannot be used for transmissions but it may be used as a receiving antenna when there is little space available or as a test antenna.

For all antenna versions shown above, not only correct matching to the feeder cable is important but also the interfacing of the (usually coaxial) unbalanced cable to the balanced radiators. If no **balun** is used, sheath currents will occur on the outer conductor of the coaxial cable that

- may cause severe spurious radiation in transmission,
- markedly change the radiation pattern and other radiation characteristics,
- considerably corrupt results when the antenna is used for testing.

Matching the antenna impedance to the coaxial cable impedance can be done also with an **antenna tuning unit** ("ATU"). Such a tuning device is principally an impedance matching network which transforms the impedance of an antenna with arbitrary length to 50Ω . However, it needs to be pointed out that the radiator length is determining the radiation efficiency and that particularly for lower frequencies a certain minimum antenna length is ultimately required.

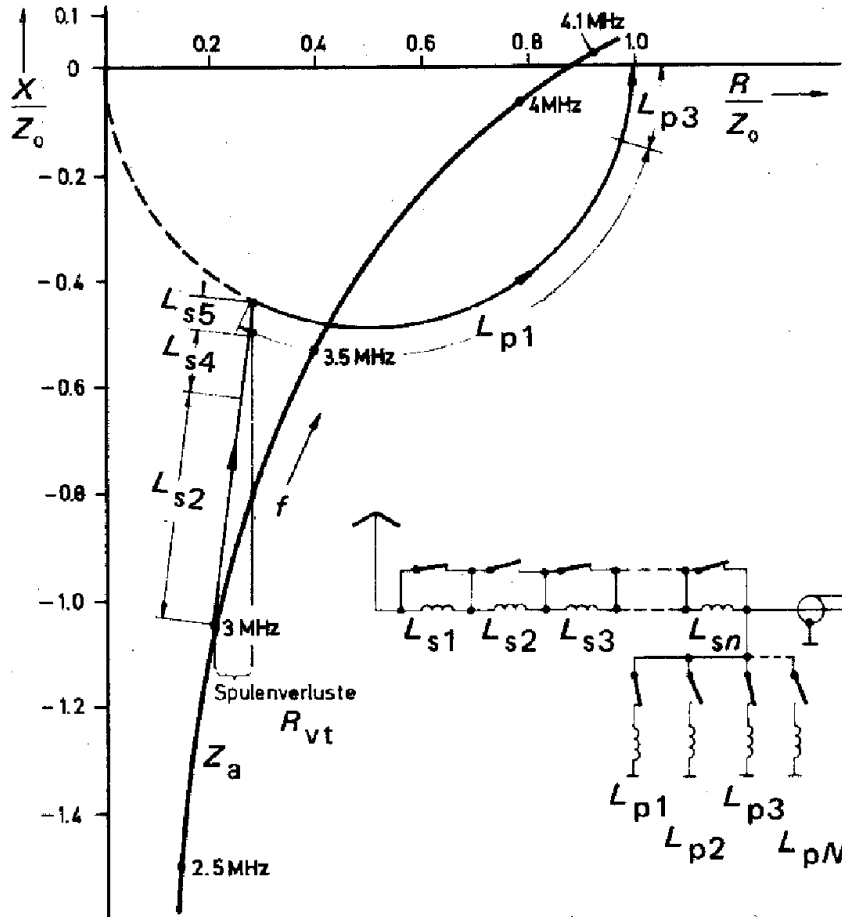


Fig. 3.5 Principle of an antenna tuning unit

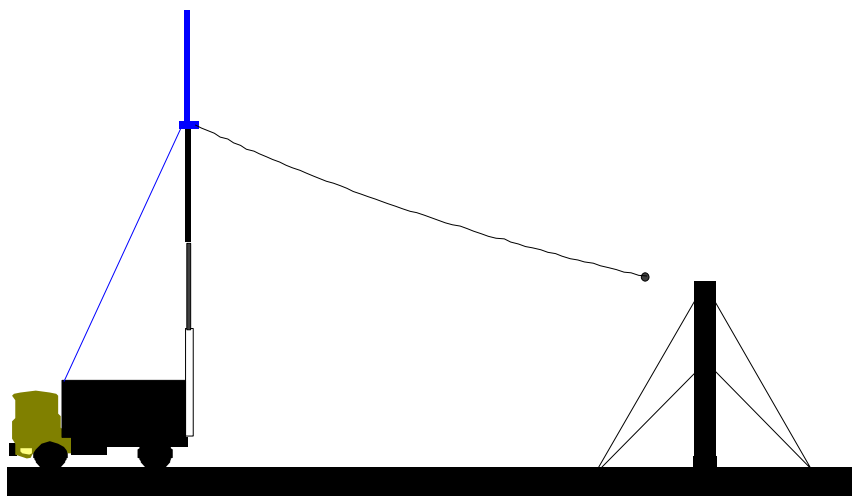


Fig. 3.6 Tuned longwire antenna for different distance ranges

Moreover, an ATU is a switchable device and thus not suitable for fast frequency hopping applications. Antennas working with traveling waves like the TFD-antenna (Terminated folded dipole) avoid this disadvantage. The current distribution on these antennas is uniformly (and thus completely differing from the sinusoidal shape shown in fig. 3.1) due to a built-in resistor. Thus, real broadband and frequency hopping operation is possible without switching.

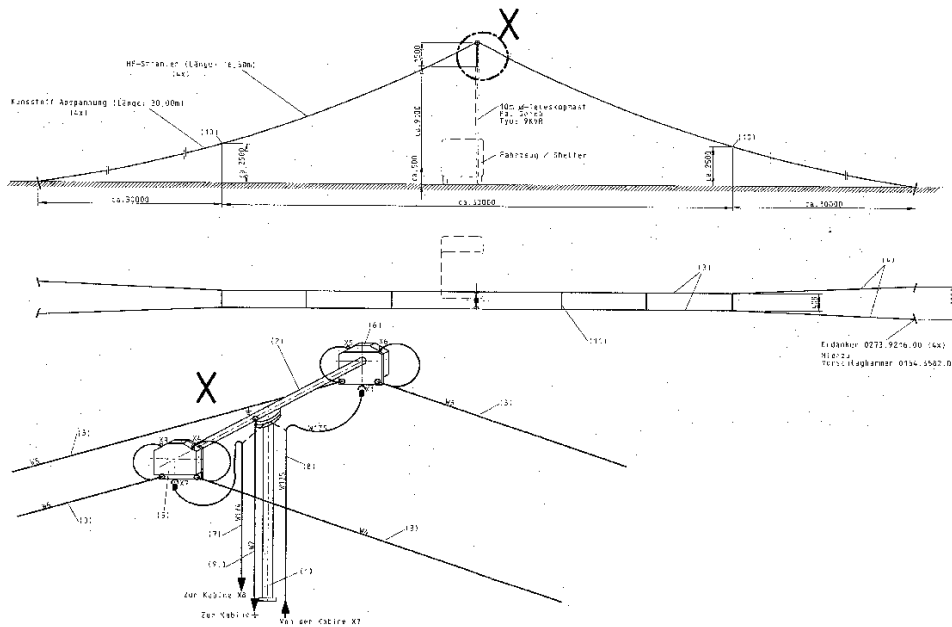


Fig. 3.7 TFD broadband antenna

3.2 Rod Antennas

The operating principle of **rod antennas** (or **monopoles**) is based on the fact that on an antenna of only a quarter of a wavelength the same current distribution is obtained as on a half-wave dipole (see Fig. 3.1) if the length of the antenna that would be required to give a complete half-wave dipole is "made up for" by a highly conductive plate. As a result of this mirroring effect (see Fig. 3.8), vertical quarter-wave antennas installed on conductive ground have the same radiation pattern as dipole antennas. There is of course no radiation into the shielded half-space. The input impedance is halved compared to that of a dipole, ie the values are between 30Ω and 40Ω ; the directivity factor increases to 5.1 dB.

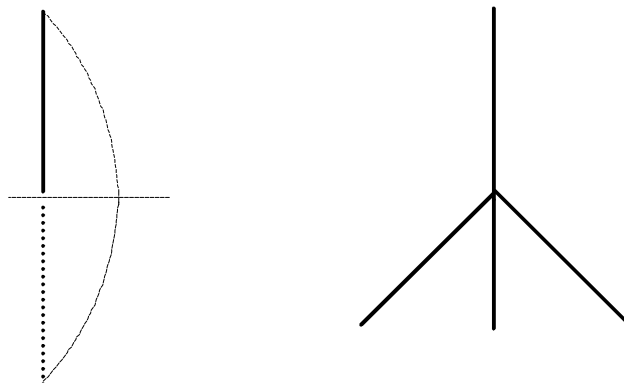


Fig. 3.8 Mirroring principle and ground-plane antenna

Like dipoles, monopoles come in a wide variety of versions. Especially in the lower frequency ranges, it is monopoles that allow the emission of vertically polarized waves. For long and very long waves, monopoles are the type of antenna that can be implemented most easily. Broadband shortwave monopoles are frequently designed as cage antennas.

For mirroring to be effective, the conductive surface on which a monopole is installed is of particular importance. It is common practice, and also advisable, to install a ground wire net over ground of poor conductivity (eg dry sand). This is advantageous even over ground of average conductivity (wet meadow).

In the VHF/UHF range, too, monopoles are used as vertically polarized omnidirectional antennas (**ground-plane antennas**); in this case, the conductive ground can be simulated particularly easily by means of wires (radials). If the radials are installed at an angle of 135° relative to the quarter-wave radiator as shown in Fig. 3.5 (and not at right angles as would be the case on real ground), the feedpoint impedance will increase to between 50Ω and 60Ω , which eliminates the need for more complex measures for matching the antenna to the nominal impedance of commercial coaxial cables. Furthermore, no balun is needed as monopoles are unbalanced antennas, so that they can in many cases be directly connected to the feeder cable.

For rod antennas mounted on handheld transceivers or mobile phones, the electrical counterpoise is formed by the device chassis and the person capacitively coupled to it. For vehicle antennas, on the other hand, there is defined grounding provided the vehicle roof is made of metal. The radiation pattern of these antennas considerably differs from that shown in Fig. 2.1 and a (horizontal) omnidirectional radiation pattern is normally no longer the case.

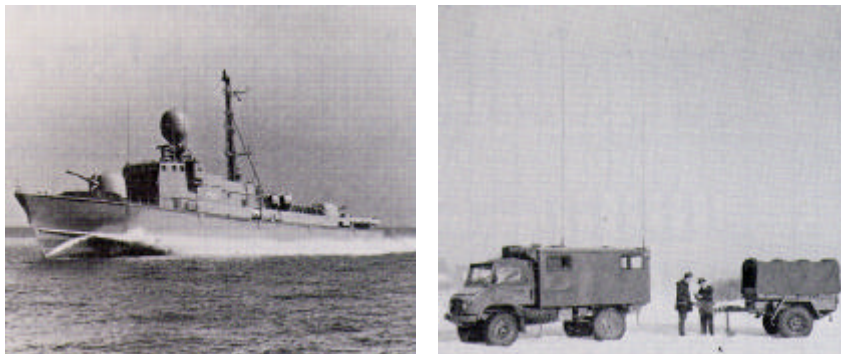


Fig. 3.9 Rod antennas for mobile applications

Due to the principal shape of the radiation pattern (cf. fig. 2.1) rod antennas designed for the shortwave frequency range (1.5 MHz to 30 MHz) are generally not suitable for short distance communications.

3.3 Directional Antennas

As explained above, an ideal omnidirectional antenna cannot be realized. The term directional antenna, on the other hand, is used only for antennas whose radiated power is focussed in a specific direction. These antennas feature a clear improvement of the S/N ratio without any reduction of the transmitted power. They must however be lined up to the intended direction of reception or emission, which in many cases requires the use of a **rotation facility**. The extent to which an antenna is able to suppress signals from directions other than the main direction of radiation is expressed by the gain and the directivity factor defined earlier, and frequently also by the **front-to-back ratio**

$$v = 20 \lg \frac{\text{Far field strength in main direction of radiation}}{\text{Far field strength in backward direction}}$$

or the **half-power beamwidth** HPBW). The latter describes the angle between the two directions of the radiation pattern at which the radiated power is reduced to half the value and the field strength therefore to approx. 70 % (- 3 dB). However, since this parameter, same as the gain and the directivity factor, provides only very limited information on the number and size of the radiation **side lobes**, it is always necessary to know the **directional pattern** to ensure a complete assessment of the radiation characteristics of a directional antenna.

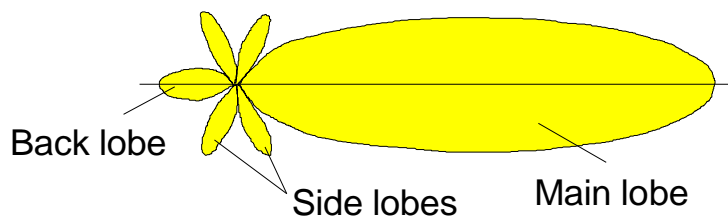


Fig. 3.10 Radiation pattern of directional antenna (main lobe, side lobe and back lobe)

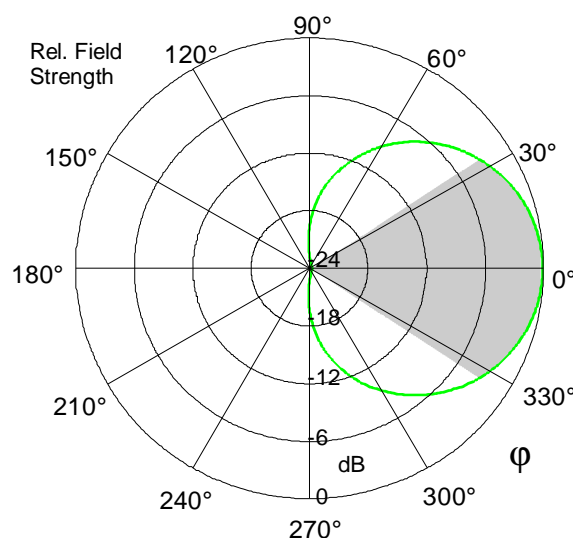


Fig. 3.11 Horizontal pattern of directional antenna with half-power beamwidth of 65°

By setting up two omnidirectional antennas at a defined distance relative to each other (see Fig. 3.12) and feeding them with signals of different phase, the simplest type of directional antenna is obtained. In the example below, the distance is $\lambda/4$ and the phase shift 90° , so that the **added far field strengths of the two radiators** yield a cardioid directional pattern (see Fig. 3.13). While one cannot speak of a pronounced focussing with this array, the sharp null allows effective **interference suppression**.

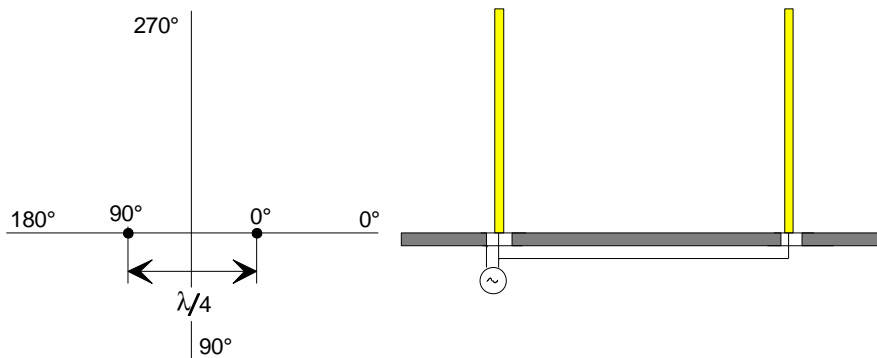


Fig. 3.12 Principle of a simple directional antenna

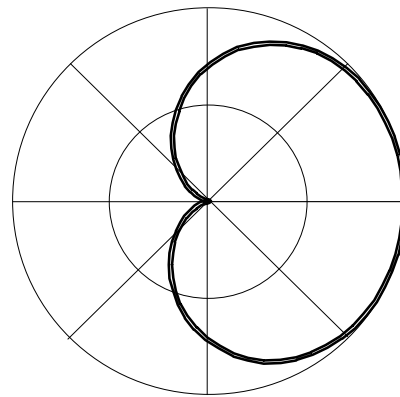


Fig. 3.13 Cardioid diagram of directional antenna as shown in Fig. 3.12

By **superimposing the diagrams** obtained by combining two or several radiators arranged at defined distances and with defined phase shifts, directional patterns can be generated whose directivity is limited mainly by the available space. Instead of feeding the radiators via cables as shown in Fig. 3.12, the principle of **radiation coupling** is mostly applied in practice, with only one radiator being fed from the cable and the remaining elements activated by this radiator. **Yagi-Uda antennas**, which are commonly used for the reception of TV and VHF sound broadcast signals, have typically between 4 and 30 elements, which yields a gain of 10 dB and more.

The possibility of changing the direction of the main beam of a highly directive antenna by purely electronic means is utilized to an increasing extent also with antenna arrays for very high frequencies (eg for satellite radio services). The antennas used are referred to as **planar antennas** and mostly consist of a dipole curtain which, in contrast to curtain antennas, is installed in front of a conductive plane. This array can also be implemented by etching the radiators as tracks into a copper-clad PCB (**microstrip antenna**). In this way, even large arrays of antennas can be implemented for the microwave range with high precision and efficiency.

A special type of directional antenna is the **log-periodic dipole antenna (LPDA)**, where beam shaping is performed by means of several driven elements. The LPDA is made up of a number of parallel dipoles of increasing lengths and spacings (see Fig. 3.14). The angle α formed by the lines joining the dipole ends and by the longitudinal axis of the antenna remains constant, and the dipole lengths l_n and spacings s_n are governed by the following law:

$$\frac{l_{n+1}}{l_n} = \frac{s_{n+1}}{s_n} = \text{const.}$$

If such a dipole array is fed starting at the front (ie with the shortest dipole), the electromagnetic wave first passes through all dipoles that are markedly shorter than half the wavelength. The dipoles in the order of half a wavelength are brought into resonance and form the active region, which radiates the electromagnetic wave back to the shorter dipoles. This means that the longer dipoles located behind this active region are not reached by the electromagnetic wave at all.

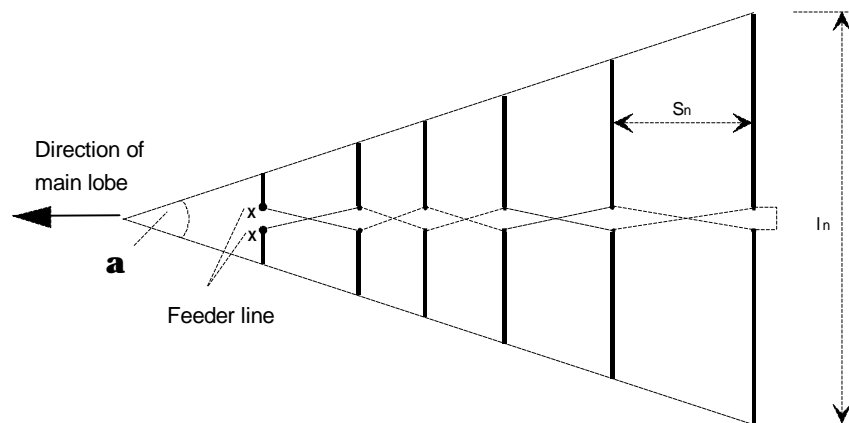


Fig. 3.14 Log-periodic dipole antenna

Due to the fact that the directional pattern is formed by only part of the dipoles in each case, the directivity (and thus the gain) achievable with an LPDA is **significantly lower than for example with a Yagi antenna** of similar geometrical dimensions. The LPDA, on the other hand, has the advantage that its bandwidth can - theoretically - be infinitely increased, a characteristic which qualifies it not only as a communication antenna but also as a test antenna offering the further advantage that the radiation pattern and the gain versus frequency do not appreciably change.

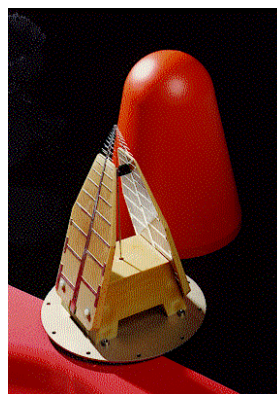


Fig. 3.15 Example for a LPDA (frequency range 1 GHz to 26.5 GHz, $g = 8$ dBi (typ.))

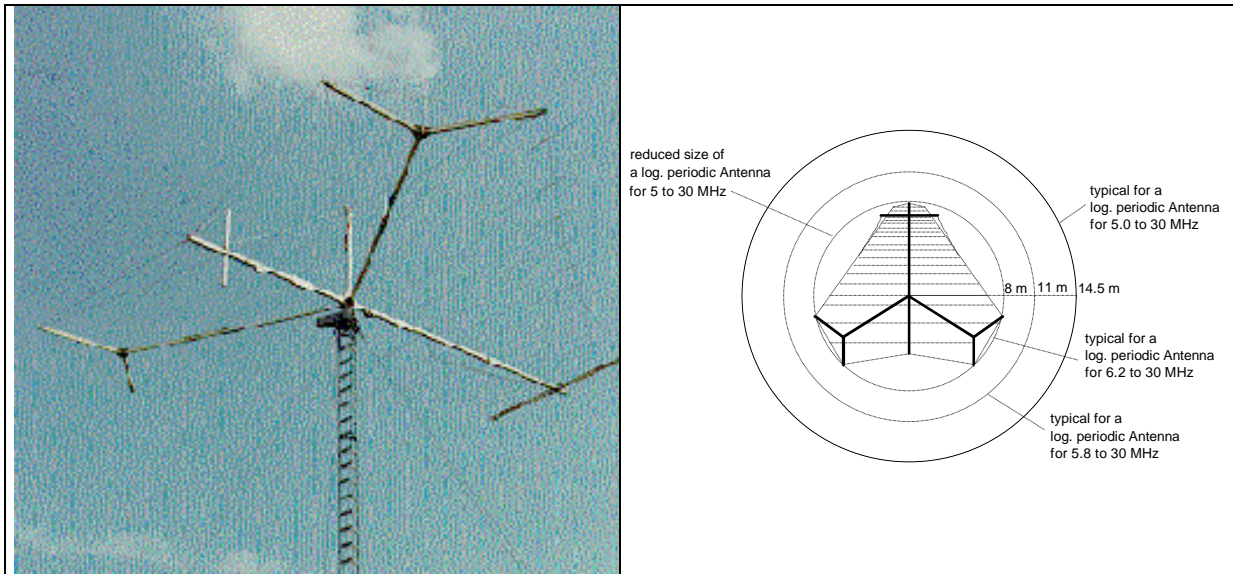


Fig. 3.16 Small and efficient LPDA for the frequency range 5 MHz to 30 MHz

The radiated power can, especially at higher frequencies, be directed employing methods based on what appears to be geometric-optical or acoustic principles. The most well-known representative of this type of antenna is the **parabolic antenna**, in which an exciter (dipole or directional antenna) is fitted at the focus of a conducting rotational paraboloid which focuses the rays due to its geometrical shape. From the mirroring principle described above it is obvious that this physical process is fully identical to beam shaping by means of several radiators.

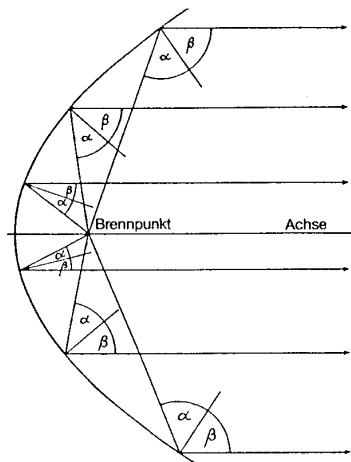


Fig. 3.17 Parabolic reflector principle

With parabolic antennas and suitable exciters very **high gains** (50 dB and more) can be obtained.

Steerable Microwave System AC090, AC120, AC180 and AC300

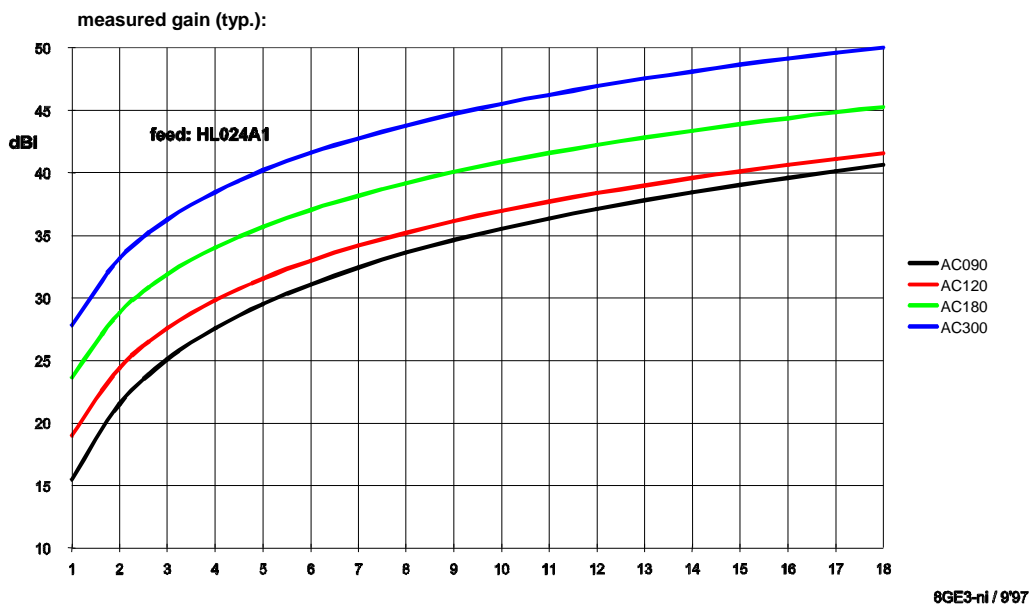
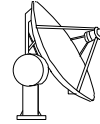


Fig 3.18 Gain of a parabolic antenna system depending on diameter and frequency

Horn antennas, too, come in a variety of shapes. As the dimensions of a horn antenna must as a rule be a multiple of the operating wavelength, the use of this antenna is for practical reasons limited to **high frequencies**.

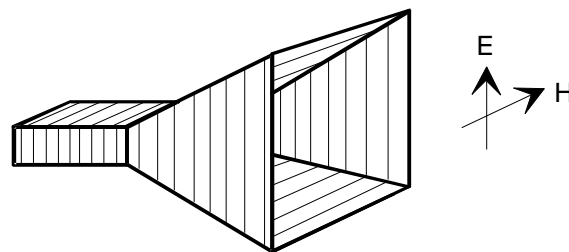


Fig. 3.19 Horn antenna

Horn antennas are commonly used as communication antennas, feeder antennas for parabolic and other reflector antenna systems or as **measurement antennas** ("standard gain horns").

3.4 Active Antennas

Active antennas are another type of antenna that can be designed for broadband operations. They are based on the idea that a drastic **reduction of the radiator length** results in a corresponding reduction of the output voltages both of useful and interfering signals. Consequently, the **signal-to-noise ratio (S/N ratio)**, which solely determines the reception quality, **remains constant** over a wide range (see Fig. 3.20).

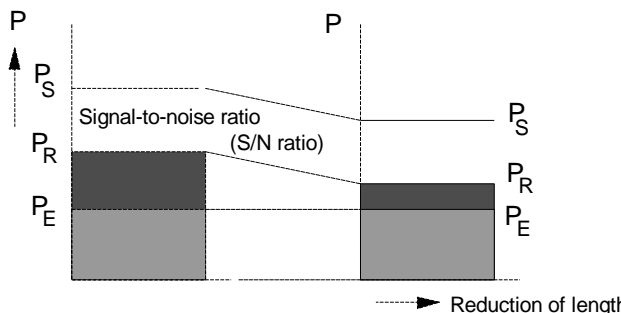


Fig. 3.20 S/N ratio with reduced radiator length

The extremely large impedance change resulting from this shortening (see Fig. 3.2) is compensated by applying the antenna terminal voltage directly to an active component (usually an FET) of very high impedance that acts as an impedance converter and often as an amplifier, too. Active antennas are thus by definition antennas in which an **active element is provided directly at the radiators** (see Fig. 3.21). They must not be confused with systems in which the output signal of a passive antenna is looped through an amplifier in the mast.

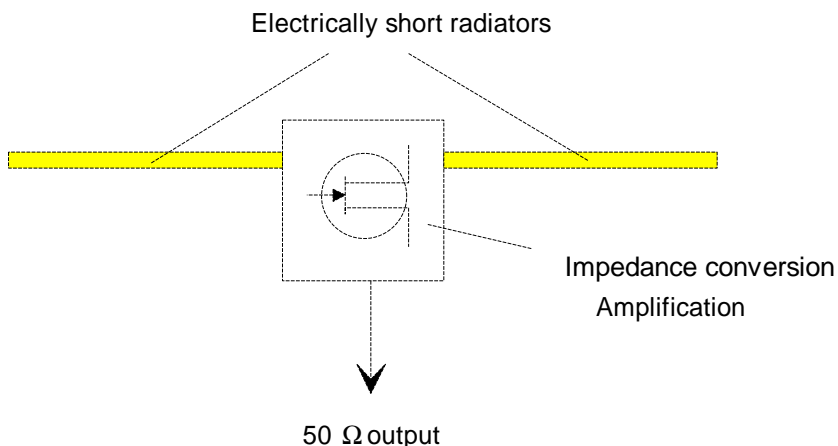


Fig. 3.21 Principle of an active antenna

An advantage in active antennas is the fact that as a result of the shortened radiators the radiation pattern is no longer frequency-dependent (see continuous line in Fig. 3.3 on the left). Moreover, by carefully matching the electronic circuitry to the antenna geometry and by some additional measures, the antenna factor too can be made largely independent of frequency (see Fig. 3.22), so that field-strength measurements can be performed very conveniently.

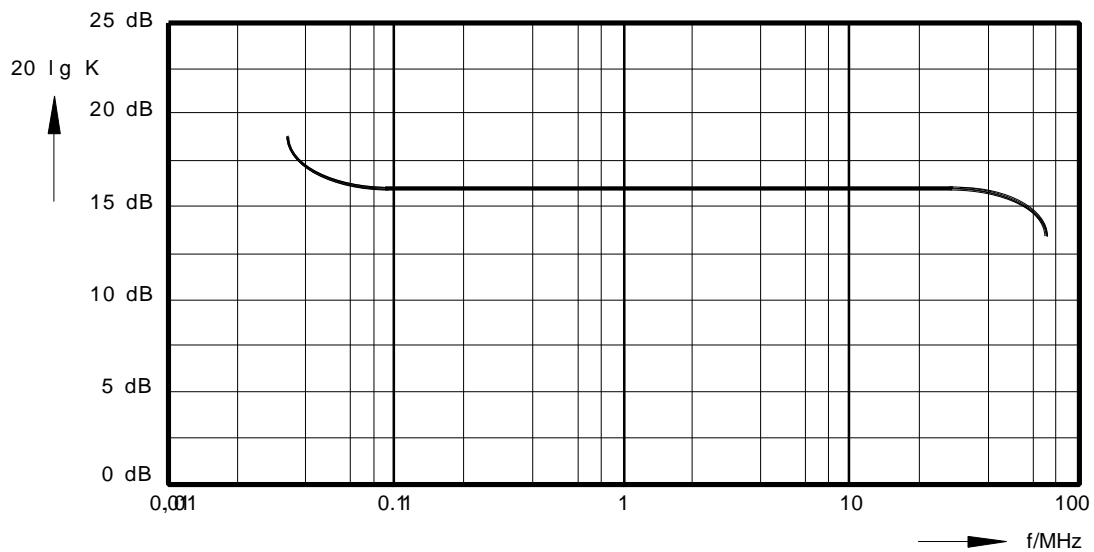


Fig. 3.22 Frequency response of antenna factor of an active antenna

Active antennas are mainly but not exclusively used at low frequencies (down to approx. 200 MHz), at which the atmospheric noise is very high. Being extremely broadband, active antennas are increasingly used also at higher frequencies. In contrast to active antennas for the long-, medium- and shortwave ranges, one cannot exclusively speak of electrically short radiators at higher frequencies. Moreover, electronic noise is no longer negligible at higher frequencies. This means that careful noise matching is required at the point where the source voltage is tapped at high impedance at the antenna terminals.

The small size of active antennas makes it possible to select the **direction of polarization** as required for the task on hand. For measurements, the direction of polarization is often defined in the test specifications. It is of advantage that in many cases a single active dipole is sufficient for covering the entire frequency band in which measurements are performed and that due to the compact size of the antenna a change of polarization, if necessary, can be made in no time.

Active antennas for radiomonitoring and radiodetection will be aligned in the direction of the incoming signal. This is very easy in the VHF-/UHF range, where signal polarization is mostly predictable. But with shortwaves for example, elliptical and thus non-predictable directions of polarization are obtained after a wave is reflected once by the ionosphere. It is quite common to make do with an active monopole (see Fig. 3.23), especially since for horizontally polarized dipoles the direction of incidence would have to be known. More complex, but also more effective is the use of two crossed, horizontally polarized active dipoles whose signals are added via a 90° coupler so that an omnidirectional radiation pattern of horizontal polarization is obtained (**turnstile antenna**). If, in addition, a monopole is stacked on the turnstile antenna (see Fig. 3.24) and remote switching capability is added, any type of incoming wave can be handled.

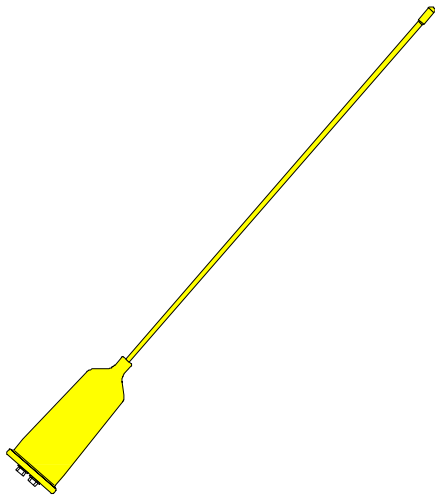


Fig. 3.23 Active monopole

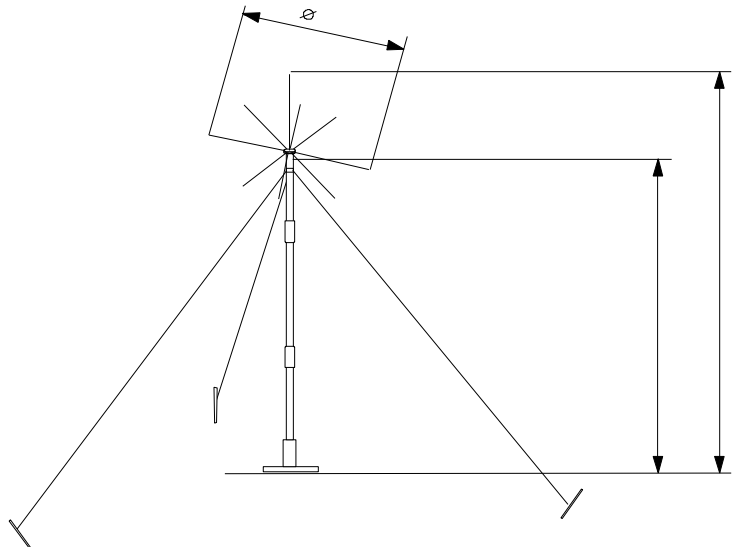


Fig. 3.24 Active turnstile antenna with monopole stacked on top

Fig. 3.25 is a summary of the characteristics and operation of active antennas and their conditions of use.

Active antennas...

- ... are smaller than comparable passive antennas,
- ... are more broadband than comparable passive antennas,
- ... cannot be used for transmission,
- ... are minimally coupled to their environment,
- ... are more prone to failures if not properly mounted,
- ... are very suitable as broadband test antennas,
- ... have a frequency-independent radiation pattern,
- ... must have sufficient large-signal immunity,
- ... must be balanced very carefully,
- ... must not be located in electronic smog,
- ... may be installed very close to each other,
- ... are not as bad as one might think!

Fig. 3.25 Basic points for the use of active antennas

4 Most Important Antenna Characteristics at a Glance

Antenna type	Directivity factor	In dB	Effective length	Radiation resistance
Isotropic radiator	1	0	-	-
Electrically short antenna on conductive plane	3	4.7	$h/2$	$40 \left(\frac{\pi h}{\lambda}\right)^2 \Omega$
$\lambda/4$ antenna on conductive plane	3.3	5.1	0.16λ	40Ω
$5 \lambda/8$ antenna on conductive plane	6.6	8.2		
Electrically short dipole	1.5	1.8	$l/2$	$20 \left(\frac{\pi l}{\lambda}\right)^2 \Omega$
Half-wave dipole	1.64	2.1	$\lambda/\pi = 0.32 \lambda$	73Ω
Turnstile antenna	0.82	- 0.86		
Full-wave dipole	2.4	3.8	$\gg \lambda$	200Ω
Small loop antenna with n loops	1.5	1.8	$n \cdot \frac{\pi^2 D^2}{2 \cdot \lambda}$	$20 \Omega \pi^6 n^2 (D/\lambda)^4$
Full-wave loop (ring, circumference = 1λ)	2.23	3.5		
Yagi-Uda antenna (6 elements)	typ. 10	typ. 10 dB		

Note: Directivity factor and gain of an antenna differ by the radiation efficiency of the antenna (see section 3.1).

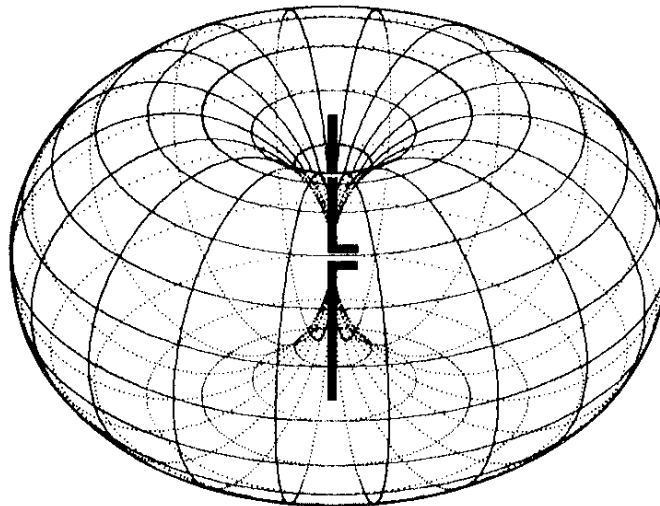


Fig. 4.1 Spatial radiation pattern of a dipole antenna

5 Used and Recommended References

Author:	Title:	Publisher:
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Chatterjee	Antenna Theory and Practice	John Wiley & Sons
Collin	Antennas and Radiowave Propagation	McGraw-Hill
Dombrowski	Antennen	Porta München Technik Berlin
Heilmann	Antennen (3 Bände)	Hochschultaschenbücher
Herter/Röcker/Lörcher	Nachrichtentechnik	Hanser
Hille/Krischke	Antennenlexikon	vth
Hock/Pauli	Antennentechnik	Expert
Jasik	Antennas	McGraw-Hill
Kraus	Antennas	McGraw-Hill
Meinke/Gundlach	Taschenbuch der Hochfrequenztechnik	Springer
Reithofer	Praxis der Mikrowellenantennen	UKW-Berichte
Rohner	Meßantennen und ihre Kalibrierung	Rohde & Schwarz
Rothammel	Antennenbuch	Franckh-Kosmos
Spindler	Das große Antennenbuch	Franzis
Stecher/Rohner	Feldstärkemessung und Antennenkalibrierung	Rohde & Schwarz
Stirner	Antennen (3 Bände)	Hüthig
Zuhrt	Elektromagnetische Strahlungsfelder	Springer