Radiation field of a horn antenna / Microwaves

LEP 4.5.08

Related topics

Horn antenna, directional characteristic pattern, directivity, law of distance, phase center

Principle and task

The directional characteristic of a horn antenna is received in two perpendicular planes by means of a receiving dipole. The law of distance for the antenna is verified.

Equipment

Microwave transmitter w. klystron	11740.01	1
Microwave receiver	11740.02	1
Microwave power supply, 220VAC	11740.93	1
Tripod base -PASS-	02002.55	1
Barrel base -PASS-	02006.55	1
Support rod -PASS-, square, l 250 mm	02025.55	3
Support rod -PASS-, square, l 400 mm	02026.55	1
Support rod -PASS-, square, l = 1000 mm	02028.55	1
Right angle clamp -PASS-	02040.55	5
Articulated radial holder	02053.01	1
Graduated disk, f. demonstration	02053.02	1
Digital multimeter	07134.00	1
Screened cable, BNC, l 1500 mm	07542.12	1
Adapter, BNC-socket/4 mm plug pair	07542.27	1
Measuring tape, l = 2 m	09936.00	1

Problems

1. Measurement of the directional characteristic of the horn antenna in two perpendicular planes and evaluation of the corresponding directivity from the directional characteristic.
2. Determination of the microwave irradiance I as a function of the distance between the receiving dipole and the horn antenna *r*, which verifies the validity of the law.

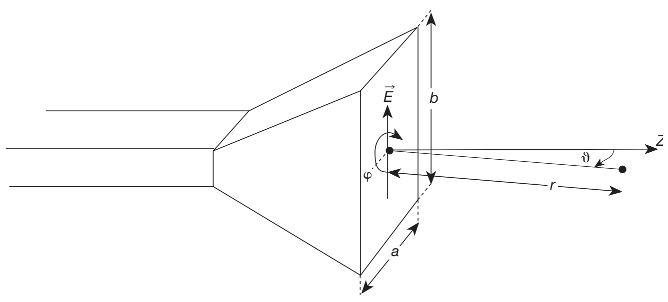
Set-up and procedure

The experimental set-up of both parts of the experiment is illustrated in Fig. 1. The transmitter and the receiving dipole are set up about 60 cm. above the surface of the table, in order to avoid interference with microwaves reflected from the surface of the table (wavelength λ = 3.18 cm). Reflecting objects should be removed from the near vicinity of the experimental set-up. Furthermore, the vicinity of the multimeter together with the BNC cable to an exterior source of electromagnetic interference (e.g. a plug socket) may cause a background signal at the rectifier diode.

To start with, the reflector voltage is set to the maximum transmitting signal. The receiving dipole should be parallel to the electric field vector $\vec{E}$ (i.e. along the narrow side of the horn antenna) of the microwaves during all measurements, so as to ensure a maximum reception signal.

Fig. 1: Experimental set-up: Radiation field of a horn antenna / microwaves.

Fig. 2: Diagram of the pyramid horn.



1. It is recommended to determine the main radiating direction of the antenna ($\vartheta = 0°$; cf. 1), by determining the two angular positions of the receiving dipole (with constant distance r of the receiving dipole from the front edge of the transmitting antenna), for which the measured DC voltage has decreased to the same value (approx. half the maximum voltage). The central point between these two positions is the main radiating direction, due to symmetry. The directional radiation characteristic of the horn antenna is then measured between $\vartheta = -90°$ and $\vartheta = +90°$ in steps of 5° and for different values of r, in the polarization plane $C_u(\vartheta, \varphi = 0°)$ (formed by the electric field vector and the direction of propagation of the microwave) and in the plane perpendicular to the latter $C_u(\vartheta, \varphi = 90°)$. The emitter is rotated by 90° and screwed in this position to the support rod to measure $C_u(\vartheta, \varphi = 90°)$.

2. The support rod "PASS" l = 1000 mm is rotated back into the main radiating direction. DC voltage U at the receiving diode, and thus irradiance I, which is proportional to U, is determined for r = 10 cm till 100 cm, in steps of 5 cm. The results of the experiment are compared with the law of distances.

Theory and evaluation

Antennae act as wave converters, which convert electromagnetic guided waves such as for example waveguide modes to free space waves and vice versa. Antennae are thus necessary for wireless transmission of electromagnetic energy or messages. If the antenna is optimized, the field wave characteristic impedance of a waveguide, defined as quotient between the transversal electric and the transversal magnetic field components:

$$Z = \frac{E_t}{H_t} \tag{1}$$

is continuously approximated to that of free space.
The latter is determined by Maxwell's rules:

$$Z_0 = \frac{|\vec{E}|}{|\vec{H}|} = \sqrt{\frac{\mu_0}{\epsilon_0}} = 120\,\pi\,\Omega \tag{2}$$

If this is the case, the guided wave is radiated from the antenna practically without reflection and correspondingly it is reconverted with very little loss by a receiver from a free space wave to a guided wave.

The directional characteristics $C_E(\vartheta, \varphi)$ and $C_U(\vartheta, \varphi)$ are important characteristic values of a transmitting antenna. They represent the directional dependence of the electric field intensity $|\vec{E}|$ of the microwave or respectively of the reception voltage U at a receiving antenna (proportional to irradiance I) under Fraunhofer region conditions (Fraunhofer region conditions are valid for wavelengths λ of the spatial wave and for antenna dimensions which are significantly smaller than r).

The directivity D of an antenna

$$D = \frac{S_A}{S_I} \tag{3}$$

is totally determined by its directional characteristic. S_A and S_I are the beam intensities in the main radiating direction of the considered antenna or of an isotropic radiator, that is, the angular microwave power radiated per radiating surface unit and per unit spatial angle, under the condition that both antennae radiate the same power. In the case of a receiving diode which is small in relation to the field, directivity D is also given by the corresponding relations of signal voltages U or of irradiances I at the receiving dipole:

$$D = \frac{S_A}{S_I} = \frac{I_A}{I_I} = \frac{U_A}{U_I} \tag{4}$$

Directivity can thus be calculated:

$$D = \frac{C_{U,\,\max}}{\int_0^{2\pi}\int_0^{\pi} C_U(\vartheta, \varphi)\,\sin\vartheta\,d\vartheta\,d\varphi} \tag{5}$$

where $C_{U,\max}$ is the signal voltage in the main radiating direction. In the case of an antenna characteristic $C(\vartheta, \varphi)$ in which the main radiation lobe distinctly dominates the secondary lobes, (5) may be replaced by the following approximation (cf. literature reference):

$$D \approx \frac{47000}{\Delta\vartheta_{1/4} \cdot \Delta\Theta_{1/4}} \tag{6}$$

where $\Delta\vartheta_{1/4}$ and $\Delta\Theta_{1/4}$ are angular widths of the radiation lobe (given in degrees) for two perpendicular planes, within which irradiance I amounts to over a fourth of the maximum value U. The pyramid horn radiators investigated in this experiment (cf. Fig. 2) are often used as directional antennae, because as

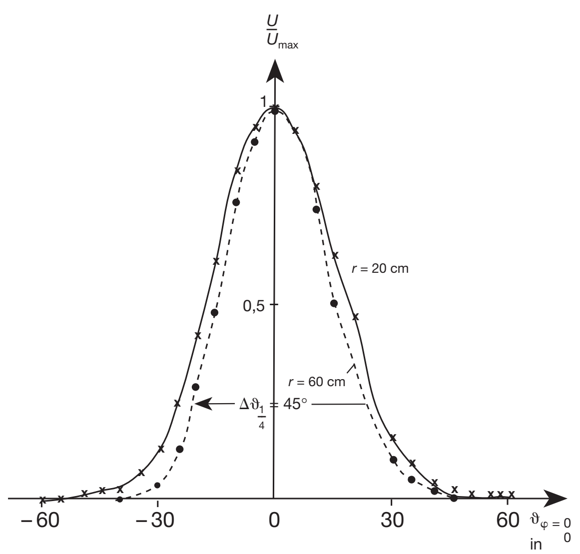
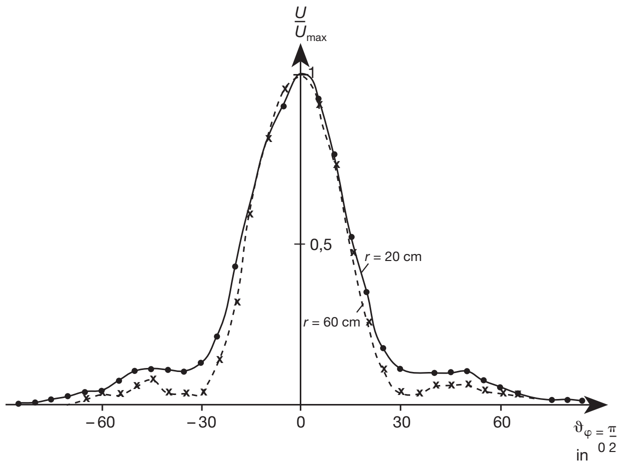


Fig. 3: Directional characteristic $C_u(\vartheta, \varphi = 0)$ of the horn antenna in the polarization plane for different distances.

Fig. 4: Directional characteristic $C_u(\vartheta, \varphi = \frac{\pi}{2})$ of the horn antenna perpendicularly to the polarization plane for different distances.



extensions of rectangular waveguides, they continuously approximate the field wave impedance of the waveguide to that of free space:

$$Z = \frac{Z_0}{\sqrt{1-(\lambda/2a)^2}} \tag{7}$$

If $a >> \lambda$, only a small part of the guided wave is reflected at the horn. A further important point is the large directivity of the antenna, as may be recognized both through the directional characteristic of the polarization plane (Fig. 3) as well as through the perpendicular plane (Fig. 4). Furthermore, a secondary maximum can be seen at $\vartheta = 45°$ in Fig. 4. The slight deviation of the directional characteristics for $r = 20$ cm and $r = 60$ cm is due to near field effects. With (6), one obtains a directional value of

$$D \approx 23 \tag{8}$$

from the quarter value widths $\Delta\vartheta_{1/4} = 45°$ and $\Delta\Theta_{1/4} = 45°$. With increasing distance r from the source, an electromagnetic spherical wave steadily loses its radiation intensity due to the law of conservation of energy: the energy radiated into a spatial angle Ω crosses an area which increases quadratically ($A = \Omega r^2$, cf. Fig. 5), due to which the irradiance I of the wave:

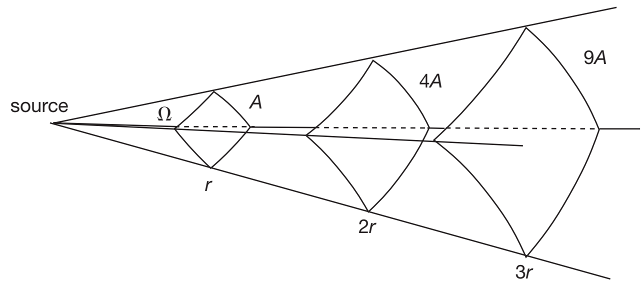
$$I = \frac{\left\langle \frac{dE}{dt} \right\rangle}{A} \tag{9}$$

(where $\left\langle \frac{dE}{dt} \right\rangle$ is the average energy passing through a surface A per time unit) decreases quadratically with r (law of distances):

$$I \sim \frac{1}{r^2} \tag{10}$$

The Fraunhofer region of an antenna forms a spheric wave with spherical wave fronts. The relation between signal voltage U or $\sqrt{U}^{\,-1}$ and the distance r verify the law of distance (10). The oscillating deviations from a straight line which can be seen in Fig. 7 as of $r = 60$ cm, are due to interference with reflected microwaves. As a result, the electric field intensity $|\vec{E}| \sim \sqrt{I}$ decreases inversely to the distance from the source of radiation:

Fig. 5: Geometry of the law of distance.



$$|\vec{E}| \sim \frac{1}{r} \tag{11}$$

The virtual position of the punctual source, also called the phase center, lies approximately 15 cm behind the front edge of the horn antenna. The phase center moves from the center of the aperture plane of the horn to the interior of the funnel as the angle of aperture increases.

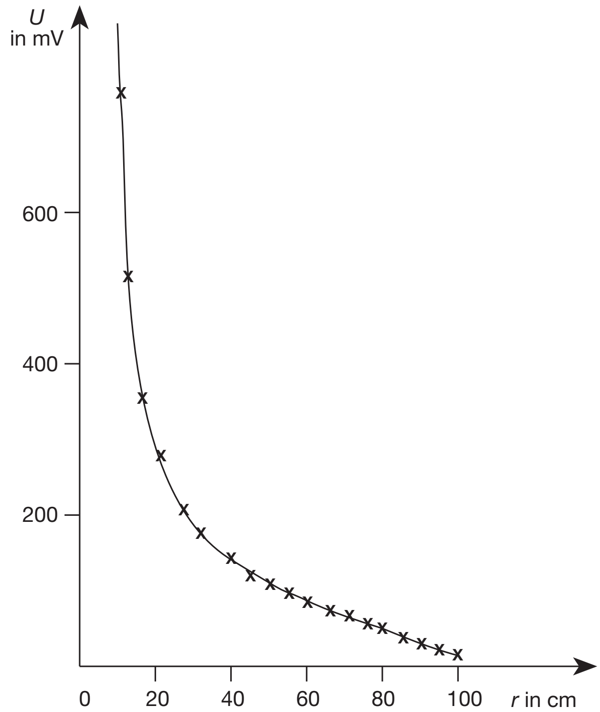
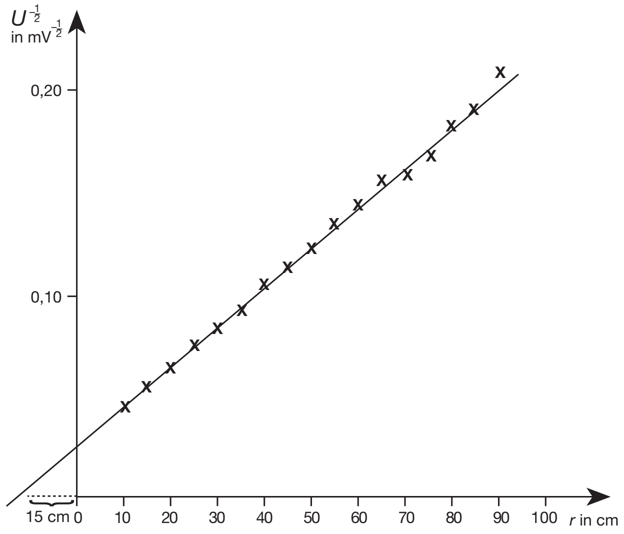


Fig. 6: Signal voltage as a function of distance.

Fig. 7: $U^{-1/2}$ as a function of distance.



Literature

A. Bloch et al.: A new approach to the design of super-directive areal arrays, Proc.IEE 100, Part III (1953) 303 – 315

Caution

Although the clystron only has low power, one must avoid looking directly into the microwave.