4 ANTENNA MEASUREMENTS

1. Introduction

An antenna acts to convert guided waves on a transmission structure into free space waves (and vice-versa). Most antennas are reciprocal devices and have exactly the same properties regardless if they transmit or receive.

In general, antennas have directional characteristics; that is, electromagnetic power density is radiated from a transmitting antenna with an intensity that varies with angle around the antenna. According to the angular distribution type, we have directive antennas with a narrow beam that are convenient for point-to-point communications, and omnidirectional antennas with constant radiation in one plane that are useful for broadcast situations.

In this laboratory session we will measure parameters of some common microwave antennas, namely a horn antenna, a reflector antenna, and a dielectric antenna.

2. Theoretical background

Antenna parameters essential to understand the tasks in this laboratory session are briefly described here. For a full and detailed description of all antenna parameters see for instance [1].

2.1. Directivity and gain

Let us assume that the net power into an antenna is \( P_{in} \). A certain part of this power is dissipated in the antenna structure (lossy metals and dielectrics) but the major part is emitted into free space as the radiated power \( P_{r} = e \cdot P_{in} \), \( e \) being the antenna radiation efficiency. At a large distance from the antenna (far-field), the radiated power within an element of solid angle \( d\Omega \) is

\[
U(\theta, \varphi) \cdot d\Omega,
\]

where \( U(\theta, \varphi) \) is the radiation intensity. The directivity \( D(\theta, \varphi) \) is defined as the ratio of the radiation intensity in a certain direction to the average radiation intensity:

\[
D(\theta, \varphi) = \frac{U(\theta, \varphi)}{\pi}.
\]

The directivity reflects the fact that the power radiated by an antenna is concentrated in certain direction(s). It expresses how much greater the radiation intensity (or power density) is for an antenna than it would be if all the radiated power were distributed uniformly around the antenna. The antenna gain \( G(\theta, \varphi) \) differs from the antenna directivity by the radiation efficiency:

\[
G(\theta, \varphi) = e \cdot D(\theta, \varphi).
\]

The maximum gain is defined as the gain in the direction of maximum radiation:

\[
G = \max[G(\theta, \varphi)].
\]

All the antennas in this laboratory session are rather directive, with the maximum gain in the direction perpendicular to their apertures and parallel to their axes.
2.2. **Polarization**

The polarization of an antenna is defined by the shape of a curve traced by the electric field vector tip at a fixed location in the far-field, when the antenna is transmitting. In general, the antenna polarization is elliptical. However, there are important special cases of the polarization ellipse. If the electric field vector moves back and forth along a line, it is said to be linearly polarized. If the electric field vector remains constant in length, but rotates around in a circular path, it is circularly polarized. The polarization of an antenna always varies with direction. However, usually it remains relatively constant around the direction of maximum radiation and this polarization is typically used to describe the antenna polarization. Again, as antennas are reciprocal devices, the polarization remains the same in the receiving mode.

It should be noticed that, in the ideal case, a receiving antenna does not respond to the orthogonal polarization (horizontally polarized antenna will not receive a signal in vertical polarization; left-hand circularly polarized antenna will not receive a signal in right-handed circular polarization).

All the antennas under test in this laboratory session are linearly polarized. The polarization of any of these antennas is aligned with the electric field in the waveguide through which they are fed.

2.3. **Radiation pattern, principal planes, and half-power beamwidth**

A radiation pattern is a graphical description of the angular distribution of radiation level (field or power) of an antenna in the far-field. By definition, it is normalised to the maximum radiation level.

A radiation pattern taken in the plane defined by the electric field vector and the direction of the maximum radiation is called an \( E \)-plane pattern. A pattern taken in the plane perpendicular to the \( E \)-plane and cutting through the antenna is called an \( H \)-plane pattern. These two planes are referred to as principal planes. It should be noticed that this definition is only valid for linearly polarised antennas.

A main lobe is the lobe containing the maximum radiation direction. Its width is usually quantified through a half-power (HP) beamwidth, which is the angular separation of the points where the main beam of the power pattern equals one-half of the maximum value. Apart from the main lobe, typically a number of side lobes exist. A measure of how well the power is concentrated into the main lobe is the side lobe level (SLL), which is the ratio of the side lobe peak level to the main beam level.

If half-power beamwidths in the principal planes \( HP_e \) and \( HP_h \) of a directive single beam antenna are known, the gain can be approximated by the following equation:

\[
G = \frac{-33000}{HP_e \cdot HP_h} \quad \text{(HP-beamwidths are expressed in degrees)}.
\]

All the antennas under test in this laboratory session have a single, relatively narrow beam, and rather low SLL.
2.4. Friis transmission formula

Friis transmission formula is an equation that relates the received (RX) and transmitted (TX) power in a basic radio communication system shown in Fig. 4.1. With the variables noted in the figure, it reads

\[
P_{RX} = P_0 \cdot G_{RX} \cdot G_{TX} \left( \frac{\lambda}{4\pi L} \right)^2.
\]

The following must be fulfilled for a successful application of this equation:

- Antennas are in free space and far from each other \((L >> \lambda; L >> D; L > \frac{2D^2}{\lambda})\;\text{; } D\) being the maximum extent of any of the two antennas
- Antennas are well matched to the transmitter/receiver
- Antennas are aligned in polarisation and point each other with their maximums of radiation.

In our laboratory we can only approximately satisfy the requirements above. In particular, reflection from the walls and nearby objects can be minimized by high frequency absorbers, but it cannot be fully avoided. This results in a considerable measurement uncertainty. A better facility for antenna measurements is an electromagnetic anechoic chamber, which will be presented during this laboratory session.

![Fig. 4.1 Basic radio communication system.](image)

3. Experiments

3.1. Utilised equipment

- Gunn diode source *Marconi 6058A*
- Adapter coaxial to waveguide *HP X281A*
- Wavemeter *HP X532B*
- Directional coupler 10 dB *HP X752C*
- Power meter *HP 432A* with the thermistor mount *HP X486A*
- Power meter *Marconi 6460* with the thermistor mount *Marconi 6425*
- SWR meter *Marconi 6593A*
- Crystal detector *HP X424A*
- Two waveguide twists *Lectronic*
- Horn antenna
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- Reflector antenna
- Dielectric antenna
- High frequency absorber panel
- Turn-table B&K 3922
- Pen recorder B&K 2307 with various pen colours and polar paper sheets
- Meter for measuring distance

3.2. Experiment setup

The experiment setup shown in Fig. 4.2 allows radiation pattern and gain measurements. On the transmitter side, the generator (Gunn diode source) is connected to the TX-antenna via the coax-to-waveguide transition. The wavemeter is utilised for precise frequency control. Transmitted power is measured and monitored by the power meter mounted on the directional coupler’s coupled port. The transmitting antenna is directly mounted on the directional coupler (a waveguide twist will also be placed between the directional coupler and the antenna to rotate the antenna polarization in certain measurements).

On the receiver side, the antenna under test (AUT) is mounted on the turn-table, which is connected to the pen recorder. For the radiation pattern measurements, where we are only interested in relative power levels (reference will be the maximum received signal), the SWR meter will be utilised. For the gain measurements, where we must know the absolute power level, the power meter will be utilised. High frequency absorbers will be placed near the RX-antenna to minimise reflections from laboratory walls and other objects.

![Experiment setup diagram](image-url)

Fig. 4.2 Experiment setup for the antenna measurements.
3.3. Measurements

3.3.1. Radiation patterns

Experiment setup preparation

We will start by measuring the radiation pattern of the horn antenna. Therefore, mount this antenna on the turn-table (RX-side). Mount the dielectric antenna on the TX-side. Do not use the waveguide twists at this point. The TX-antenna must be directed exactly towards the RX-antenna (check this by looking from the RX-side and adjust if necessary). On the TX-side, turn the Gunn source on, set frequency precisely to 10 GHz, power to 0 dBm, and choose the square wave modulation. On the RX-side, turn on all the equipment. Set the turn-table Motor to Sweep, and Sweep range to 360°. As for the pen recorder, the sensitivity should be nearly at maximum so set the Input Attenuator to 0 dB and Input Potentiometer to setting 8. Now, carefully align the antennas. To do this, start turning the RX-antenna by pressing the Start button on the pen recorder (Pen Drive must be off as we are not plotting the radiation patterns yet). Observe the SWR meter and stop turning the antenna (Stop button on the pen recorder) exactly when the signal is at the maximum. Perhaps another turn will be needed to stop the rotation in the right moment. Once having done this, adjust the SWR meter to 0 dB, choose the pen colour, and load the polar paper sheet (0° line should be exactly below the pen tip). The radiation patterns measurements are performed by pressing the Start and Stop buttons on the pen-recorder (this time with Pen Drive on). Thanks to the preparations done, the main lobe will be directed at 0° on the polar paper and dynamic range will be the best possible.

Note: remember that we use the crystal detector that operates in the quadratic zone (no need to check this here as we are using it at the RX-side where the signal level is rather low in general). The most important characteristic of this detector is that its output voltage (and therefore the output voltage from the SWR meter) is proportional to the microwave power level. As the result, we are plotting the power patterns.

Horn antenna

The measurement system should now be ready for measuring the radiation patterns of the horn antenna in the principal planes. It should be noticed that, at this moment, both antennas are vertically polarised. Therefore, we have the polarisation alignment necessary for this measurement. Also, the E-plane of the AUT is currently the vertical plane. Since we will rotate the AUT in the (perpendicular) horizontal plane, the first result will be the radiation pattern in the H-plane.

Measure the radiation pattern in the H-plane (Start and Stop buttons; Pen Drive on/off). After having done this, mount the waveguide twists on both sides of the measurement system. Be careful not to move the turn-table or the TX-setup while doing it because the alignment would be lost. Thanks to the waveguide twists, both antennas are now horizontally polarized (E-plane of the AUT now coincides with the plane of rotation) and radiation measurement in the E-plane can start. Change the pen colour (keep the same paper sheet) and the measurement.

From the obtained graphical results determine the HP beamwidths and SSLs in both principal planes, and estimate the antenna gain.
Reflector antenna

Replace the horn antenna by the reflector antenna and measure its radiation patterns in both principal planes following the procedure as above. Before the measurements, re-align the antennas and re-adjust the SWR meter.

From the obtained results, determine the HP beamwidths and SSLs in both principal planes, and estimate the antenna gain.

Gain $\approx \ldots$ dB.

Dielectric antenna

Perform the same measurement for the dielectric antenna. Use the horn antenna for transmitting. Before the measurements, re-align the antennas and re-adjust the SWR meter.

From the obtained results, determine the HP beamwidths and SSLs in both principal planes, and estimate the antenna gain.

Gain $\approx \ldots$ dB.

3.3.2. Antenna gain

Mount the dielectric antenna on the TX-side and the horn antenna on the RX-side (waveguide twists are not needed). Align the antennas if necessary. Measure the distance between them. Zero the power meter and replace the crystal detector by the thermistor mount. Switch the Gunn source to CW. Re-adjust the TX-power level to +13 dBm (20 mW).

Looking at the Friis formula applied to the current experiment setup, it is clear that only the antenna gains are unknowns while all the other parameters are already known or can be readily measured. Having the three antennas at hand, we will create three combinations of the RX/TX antenna and each time measure the received power. Mathematically, we will be creating the system with three equations and three unknowns.

Let us call the three antennas $A_1$ (the horn antenna), $A_2$ (the dielectric antenna), and $A_3$ (the reflector antenna). Keeping the TX-power constant (check each time and re-adjust if necessary), measure the received power levels $P_{12}$, $P_{13}$, and $P_{23}$ corresponding to antenna combinations $A_1$-$A_2$, $A_1$-$A_3$, and $A_2$-$A_3$ (the first letter indicates the RX-antenna, the second TX-antenna). Calculate the gain of each antenna using the following relations:
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\[ G_1 = \frac{4\pi L}{\lambda} \sqrt{\frac{P_{12} P_{13}}{P_{23} P_0}} ; \]

\[ G_2 = \frac{4\pi L}{\lambda} \sqrt{\frac{P_{12} P_{23}}{P_{13} P_0}} ; \]

\[ G_3 = \frac{4\pi L}{\lambda} \sqrt{\frac{P_{13} P_{23}}{P_{12} P_0}} . \]

\[ L = \text{________ m} \quad P_{12} = \text{________ mW} \quad G_1 = \text{________ dB} \]

\[ \lambda = \text{________ m} \quad P_{13} = \text{________ mW} \quad G_2 = \text{________ dB} \]

\[ P_0 = 1 \text{ mW} \quad P_{23} = \text{________ mW} \quad G_3 = \text{________ dB} \]

4. References


Photography of the experiment setup for Laboratory session 4 – TX-side.
Photography of the experiment setup for Laboratory session 4 – RX-side.

Electromagnetic anechoic chamber of LEMA, EPFL.