Reflection of a single-slot antenna

Fundamentals

Preliminary remarks

In experiments 6 and 7 the partially absorbing and reflecting one-port is used as an example for an incorrectly matched "load" and its matching with the aid of a matching network. In the present experiment we will consider a case which frequently occurs in practice, namely the mismatched antenna.

An antenna can generally be considered a special form of a wave-type converter. In the case of a transmitting antenna, the power P_{in} supplied by the generator arrives in the form of a guided wave at the input of the antenna. The function of the antenna is to convert the power P_{in} as completely as possible into a free-space wave (with a given directional dependency = directional pattern). An incomplete conversion ($P_{rad} < P_{in}$) results from a reflection at the antenna input (r) and/or dissipation (efficiency $\eta < 1$) within the antenna (conversion into thermal energy). The radiated power P_{rad} resulting is

$$P_{rad} = \eta \cdot \left(1 - |\underline{r}|^2\right) \cdot P_{in} \tag{8.1}$$

In the case of a receiving antenna, it supplies receiving power to the "load" or consumer equalling

$$P_{rad} = \eta \cdot \left(1 - |\underline{r}|^2\right) \cdot P_{rec,max} \tag{8.2}$$

whereby $P_{rec,\ max}$ is the maximum available receiving power.

From equations (8.1) and (8.2) you can discern that incorrect matching ($|r| > 0$) leads to both a reduction in the radiated power as well as a drop in the power actually received (= reduction of the signal-to-noise ratio).

In the following section we will look into this special type of antenna, namely the slot antenna.

Principle of the slot antenna

For reasons of a didactic nature we shall now expound on the principle of the slot antenna step by step.

Here we will first consider a plane metal plate of infinite extent, into which a slot (width *h*, infinitely long) has been mounted as specified in Figure 8.1. Such a structure represents a special form of a double transmission line (slotted transmission line), on which guided waves can propagate in both directions (parallel to the slot). The field pattern of the guided wave of the slot is depicted in part 1 of Figure 8.1.

It is assumed in the next step of our explanation that the slot according to Fig. 8.1 (part 2, left) only has a finite length *w*. Thus, it represents a transmission line resonator short-circuited on both ends. According to theory, without any excitation a field can only exist on a transmission line of the length *w*, when *w* is an integer multiple of $\lambda_{g/2}$ (here equal to a free-space wavelength of λ_0). Hence, the following results for

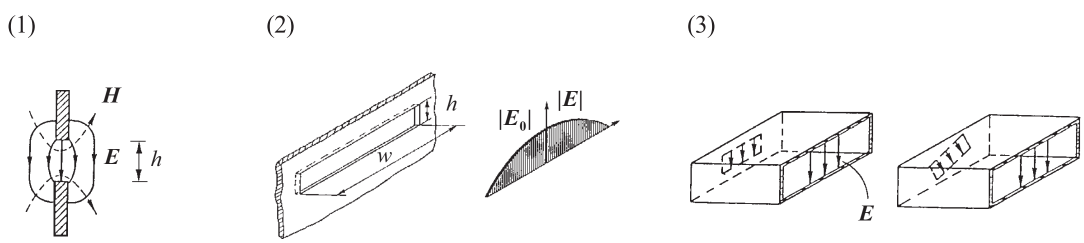

Fig. 8.1: On the principle of the slot antenna:
(1) Field pattern of the wave in a slotted line
(2) Slot guide resonator (= at the end of the shorted slotted guide) and corresponding distribution of the electric field strength along the slot
(3) Slot antenna fed via waveguide
left: Slot perpendicular to the electrical field lines of the TE_{10} fundamental mode
right: Slot at an oblique angle to the electrical field lines of the TE_{10} mode

the lowest resonance frequency ($w = l_0/2$, $f = c/l_0$):

$$f_0 = \frac{c}{2 \cdot w} \qquad (8.3)$$

The part on the right of Fig. 8.1, part 2, shows the distribution of the electrical field strength along the slot. The maximum at the middle of the slot is denoted $\left|\vec{E_0}\right|$.

In the case of external excitation of the electromagnetic field in the slot, there results a non-vanishing field for each excitation frequency f where

$$\left|\vec{E_0}\right| = \left| \frac{2 \cdot \beta_c}{(1+\beta_c) + j \cdot \left(2 \cdot Q_0 \cdot \frac{f - f_0}{f_0}\right)} \right| \cdot \left|\vec{E_1}\right| \qquad (8.4)$$

Here $\left|\vec{E_1}\right|$ stands for the amplitude of the excited field (presupposing a suitable definition). β_c is the coupling coefficient and Q_0 is the “unloaded Q” of the transmission line resonator. β_c and Q_0 are among other things functions of the slot width h.
The dependency of interest here is that for a given coupling coefficient β_c (degree of excitation) $\left|\vec{E_0}\right|$ reaches maximum at $f = f_0$ and is severely reduced, if f deviates radically from f_0.
There are various possibilities for feeding the slot antenna. Frequently a coaxial line is connected in a suitable form to the slot (see the relevant literature in the bibliography).
Here we will study the case of a waveguide feed. Fig. 8.1 (part 3) demonstrates this principle. The dominant wave (TE_{10} mode) propagates in the rectangular waveguide; its electrical field is polarized parallel to the narrow sides of the waveguide. The electrical field of the guided wave is excited in the slot by this field. If the exciting frequency f is in agreement with f_0, then we find a slot width w, so that it is true that $\beta_c = 1$ for $f = f_0$ and thus $P_{rad} = P_{in}$ and $|r| = 0$.
In the slot antennas used in this experiment the conditions $f = f_0$ and $\beta = \beta_c$ are more or less severely violated so that it is true that $|r| \neq 0$. Therefore, these antennas require the use of a matching element.

Required equipment

1 Basic unit	737 021
1 Gunn oscillator	737 01
1 Isolator	737 06
1 PIN modulator	737 05
1 Slotted measuring line	737 111
1 Coax detector	737 03
1 Cross directional coupler	737 18
1 Transition waveguide / coax	737 035
1 Waveguide termination	737 14
1 Waveguide 200 mm	737 12
1 3-screw transformer	737 135
1 Diaphragms with slits incl. holder	737 22
1 Set of thumb screws (6 each)	737 399

Additionally required equipment

1 Oscilloscope (optional)	575 29
1 XY-recorder (optional)	575 663
3 Coax cable with BNC/BNC plugs, 2 m	501 022
2 Stand bases	301 21
2 Supports f. waveguide components	737 15
1 Stand rod 0.25 m	301 26

Recommended

1 E-field probe	737 35
1 Slide screw transformer	737 13
1 Digital oscilloscope	575 292
1 XY recorder	575 663

Notes:

- As in experiment 7 a cross directional coupler is used here (coupling diaphragm with 2 cross-shaped holes) to measure the reflected wave. For more detailled information please refer to Experiment 7 or Experiment 10.
- Instead of the 3-screw transformer (with 200 mm waveguide) the slide screw transformer can also be employed. The experiment points can be carried out in like fashion.
- To be able to obtain reproducible findings, you need to use the PIN modulator with isolator. If you only use the oscillator with internal modulation, normally the Gunn oscillator is so severely affected by reflections that it generates high-frequency modes with the result that the experiment objective can no longer be achieved.

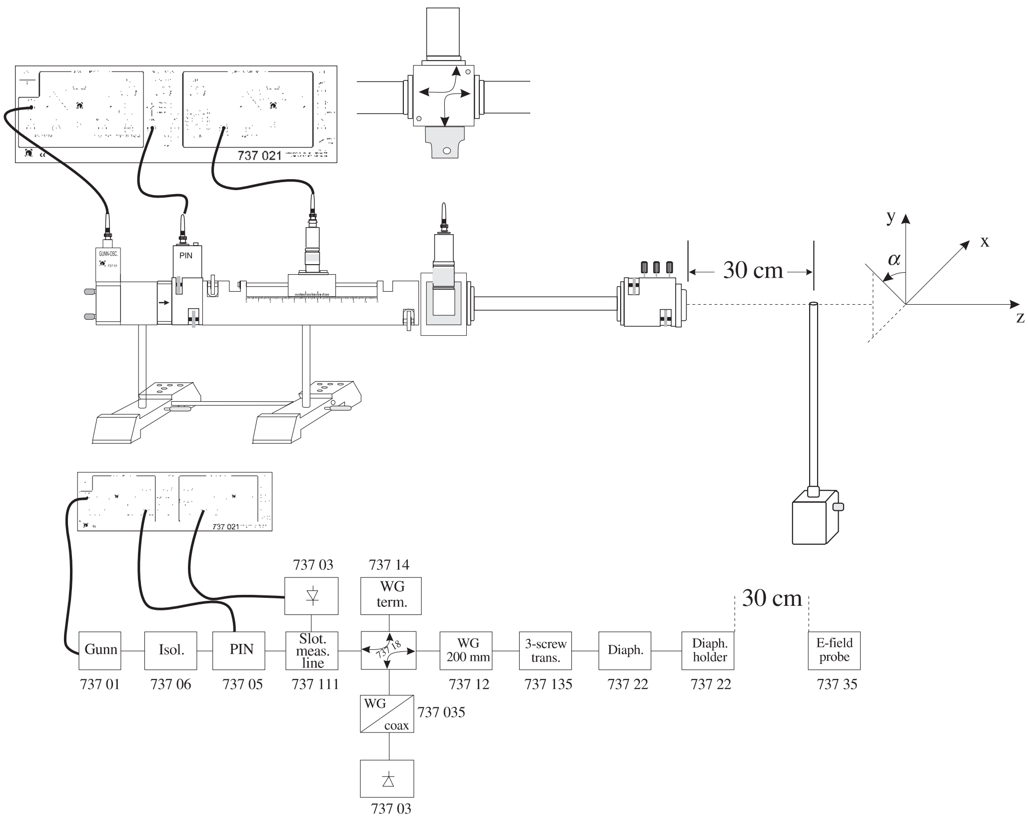

Fig. 8.2: Experiment setup

Experiment procedure

1. *Set up the experiment arrangement in accordance with Fig. 8.2. Set the screws of the 3-screw transformer to a penetration depth of approx. 0 (i.e. no effect from the matching transformer).*
   (Optional: Set up the E-field probe as receiving antenna approx. 30 cm in front of the open end of the waveguide. Keep the intermediate space free of objects which might cause scattering.)
2. *Investigating mismatching using the three different slot antennas (versions A, B and C according to Fig. 8.3).*

2.1 Attach slot antenna A to the open end of the waveguide.

2.2 Connect the measurement amplifier with detector to the slotted measuring line.

2.3 Determine the standing wave ratio s and enter the value into Table 8.1. Calculate the magnitude $|r|$ of the reflection coefficient and enter the value into Table 8.1 a).

2.4 Repeat measurements 2.1 to 2.3, but replace slot antenna A with the slot antenna versions B resp. C (see Fig. 8.3). Enter the findings for s and $|r|$ in Table 8.1 a).

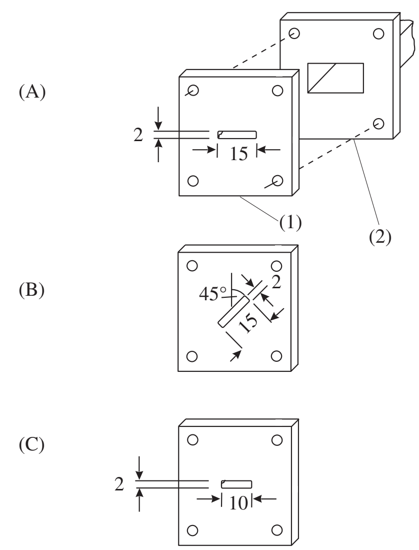

Fig. 8.3: Dimensions and alignment of the three slot antennas used here
(1) Metal cover with slit (= slot antenna)
(2) Waveguide flange

Note:
Large standing wave ratios should be determined according to Fig. 6.2 and Equations 6.13 resp. 6.14. However, the applicability of these methods are limited by the fact that Δl becomes increasingly smaller with increasing s and consequently more and more difficult to determine using measuring techniques. Alternatively the standing wave ratio can also be computed from the level at the minimum a_{min} (bear in mind the adjustment of the gain selection switch V/dB). With a_{max} = 0 dB (maximum level set to 0 dB) the standing wave ratio can be calculated according to the following equation:

$$s = \frac{E_{max}}{E_{min}} = \sqrt{\frac{U_{D\,max}}{U_{D\,min}}} \Rightarrow \underline{\underline{s}} = 10^{\frac{|a_{max} - a_{min}|/\mathrm{dB}}{20}}$$

$$= \underline{\underline{10^{\frac{|a_{min}|/\mathrm{dB}}{20}}}}$$

Optional (when using the E-field probe) :

2.5 Establish the connection of the measurement amplifier to the E-field probe. Work through points 2.6 and 2.7 using the slot antennas A, B and C.

2.6 Rotate the E-field probe around its own axis ($\alpha = 0, \pm 45°$ and $\pm 90°$) (Attention: leave the receiving dipole of the E-field probe on the symmetrical axis of the waveguide). At the same time observe the receiving voltage. Determine $\alpha = \alpha_{opt.}$ for maximum receiving voltage. Enter the value of $\alpha_{opt.}$ in Table 8.1 b).

2.7 Select a "calibrated" (clear) setting for the measurement amplifier e.g. "ZERO" to the far right limit. Read off the receiving voltage (relative unit in dB). Enter the result into Table 8.1 b) together with the setting of the range switch V/dB.

3. Matching the slot antennas A and determining the radiated power (relative measurement).

3.1 Reattach the slot antenna A to the open end of the waveguide.

3.2 Connect the coax-detector to the cross directional coupler to measure the reflected wave.

3.3 Successively adjust the 3-screw transformer (see Experiment 7 point 2.3, to minimize the reflected wave (i.e. matching). Set to the achievable maximum matching (a value of $s < 1.5$ should be reached; very good matching is reached when $s < 1.15$).

3.4 Reconnect the detector to the slotted measuring line and determine the standing wave ratio (here again set the display to 0 dB at the maximum). Enter the values for s and $|r|$ in Table 8.2 a). (If necessary you can remove the cross directional coupler and waveguide section again, see Experiment 7.)

Optional (when using the E-field probe) :

3.5 Establish the connection of the measurement amplifier to the E-field probe.

3.6 Verify the optimum angle $\alpha = \alpha_{opt}$ from point 2.6. Transfer the value of α_{opt} into Table 8.2 b).

3.7 Select the calibrated setting for the measurement amplifier ("ZERO" to the far right limit). Read off the receiving voltage (relative unit in dB). Enter the result into Table 8.2 b) together with the setting of the range switch.

4. Matching of the slot antenna B and determining the radiated power (relative measurement).

4.1 Replace slot antenna A with slot antenna B.

4.2 Repeat experiment points 3.2 to 3.4 for this case.

Optional (when using the E-field probe) :

4.3 Repeat the experiment points 3.5 to 3.7 for this case.

5. Matching the slot antenna C and determining the radiated power (relative measurement).

5.1 Replace slot antenna B with slot antenna C.

5.2 Repeat experiment points 3.2 to 3.4 for this antenna type. At the maximum attainable matching you should achieve $s < 2$.

Optional (when using the E-field probe) :

5.3 Repeat experiment points 3.5 to 3.7 for this antenna type.

Optional (when using the E-field probe) :

6. Calculate the "absolute" level $a' = a - V$, (here a and a' are negative and V > 0). Determine the maximum level a'_{max}. Then compute the value for $a' - a'_{max}$

Table 8.1

a) Standing wave ratio and reflection coefficient **without** matching.

Antenna type	s	$\lvert r \rvert$
A		
B		
C		

Optional :

b) Receiving level at the E-field probe **without** matching.

Antenna type	α_{opt}	V/dB	a/dB	a'/dB	$(a' - a'_{max})$/dB
A					
B					
C					

Table 8.2

a) Standing wave ratio and reflection coefficient **with** maximum matching

Antenna type	s	$\lvert r \rvert$
A		
B		
C		

Optional :

b) Receiving level at the E-field probe **with** maximum matching

Antenna type	α_{opt}	V/dB	a/dB	a'/dB	$(a' - a'_{max})$/dB
A					
B					
C					

The “absolute” level computed is: $a' = a - V$

The maximum level is a'_{max} = ________ dB

Questions

1. Why is there a considerably higher reflection coefficient resulting for version C of the slot antennas (see Fig. 8.3) than for versions A and B?

2. Why is the matching of version C with the aid of a matching transformer less sensible from a technical point of view?

Optional:

3. In parts 2.6, 3.6 etc. of the experiment procedure the polarization of the electrical field was experimentally determined for the radiated waves (α_{opt}). What conclusion could be drawn from this result?

4. Compare the magnitude of the receiving signal for versions A and B. Why do signals of nearly the same magnitude result, although the reflection coefficients are considerably different (measurements 2, Table 8.1)?

5. Assess the matching based on the level difference $a' - a'_{max}$ while keeping in mind for which case a'_{max} is reached.

Bibliography

See Experiment 5