Propagation of Microwaves (Inverse Square Law)

P2460403

Physics	Mechanics	Vibrations & waves

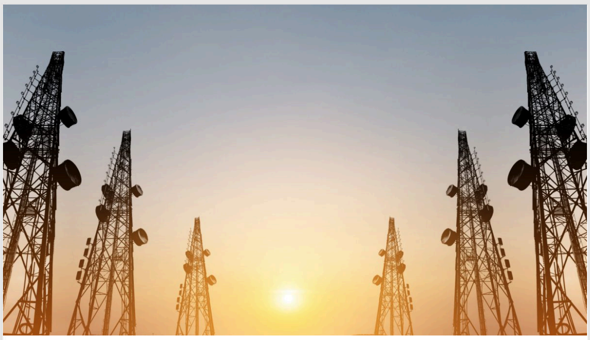
Difficulty level	Group size	Preparation time	Execution time
-	-	-	-

This content can also be found online at:

http://localhost:1337/c/60585929b622c60003db45c4

General information

Application



Microwave communication towers

Microwaves are a type of electromagnetic waves with frequencies between 300MHz and 300GHz, which are widely applied in:

- communications
- radar systems
- microwave heating system

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Other information (1/2)

Prior knowledge

The prior knowlege required for this experiment is found in the theory section.

Scientific principle

The intensity of a source of radiation, e.g. a microwave transmitter, at any given location depends on the distance of this location from the (approximately punctiform) source. Actually, due to its antenna geometry, a microwave transmitter can only be regarded as a punctiform source of radiation at long distances, which is why it is described as a virtual source for shorter distances.

Other information (2/2)

Learning objective

Understanding the propagation of microwaves in relation to the distance from the source.

Tasks

Measure the radiation intensity of the microwave transmitter for various distances r and determine the position a of the virtual source.

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Safety instructions

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For this experiment the general instructions for safe experimentation in science lessons apply.

For H- and P-phrases please consult the safety data sheet of the respective chemical.

During the experiment, do not stand in the direct vicinity of the beam path when reading the voltmeter values. The human body reflects microwaves so that the measurement result may be invalidated. The same applies to all types of metallic objects.

Theory (1/3)

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The waves that are emitted by microwave transmitters are spherical waves whose wave fronts can be described as the surfaces of spheres. During the propagation of these wave fronts, the law of conservation of energy applies: When one of the shells propagates, the next higher shell includes the same (total) energy with a lower energy density. Based on the spherical geometry (radius r, surface of sphere $O = 4\pi r^2$) the decrease in intensity I results as follows:

$$I(r) \sim \frac{1}{r^2} \qquad (1)$$

This is the inverse square law. It applies to all spherical waves.

Since the intensity is the square of the amplitude of the electric field strength E, it decreases as a function of the inverse distance:

$$E(r) \sim \frac{1}{r} \qquad (2)$$

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Theory (2/3)

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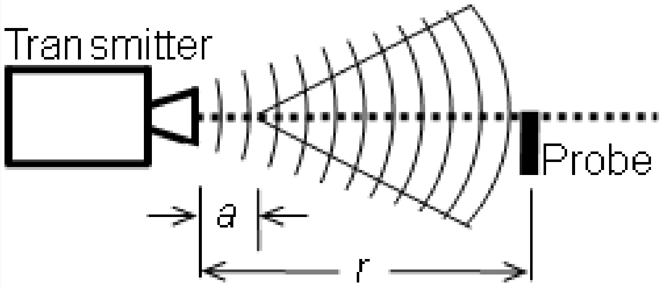
However, this is only approximately true for the present experiment, since the funnel-shaped geometry of the source affects the propagation of the waves in the case of short distances (reflection inside the funnel). This is why it is useful to calculate with an effective geometry, which assumes the existence of a virtual source at the distance a from the transmitter.

Accordingly, the length r must be corrected based on the position of the virtual source when measuring the intensity.



Transmitter and virtual source

Theory (3/3)

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In the case of the present set-up, the intensity is measured by way of a probe that emits a voltage signal U that is proportional to the intensity:

$$U \sim \frac{1}{(r-a)^2} \quad (3)$$

As a result, the following applies:

$$\frac{1}{\sqrt{U}} \sim r - a \quad (4)$$

This relationship enables not only the verification of the inverse square law, but also the determination of the location of the virtual source.

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Equipment

Position	Material	Item No.	Quantity
1	Microwave set II, 110...240 V	11743-99	1
2	Barrel base expert	02004-00	1
3	Support rod, stainless steel, l = 250 mm, d = 10 mm	02031-00	1
4	Right angle clamp expert	02054-00	1

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Setup and procedure

Setup (1/2)

Experimental setup

Connect the microwave transmitter and probe to their associated sockets of the control unit. Connect the multi-range meter to the voltmeter output of the control unit and select the 10 V measuring range (direct voltage). The loudspeaker and internal or external modulation are not required for the time being.

Position the transmitter at the far end of the meter rule (e.g. at 790 mm).

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Setup (2/2)

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Place the receiver in the beam path close to the transmitter so that the receiver is in line to the direction of propagation of the radiation.

Switch the transmitter on by connecting the control unit to the mains power supply and set the amplitude controller to half maximum.

Check the height of the receiver in its holder by varying the height in order to maximise the voltmeter reading. If necessary, reduce the amplitude if the selected measuring range is exceeded when changing the position by a few centimetres along the meter rule.

Procedure

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Measure the radiation intensity for various positions r of the receiver. To do so, extend the distance between the receiver and transmitter in steps of 1 cm and note down the reading of the voltmeter.

When reading the position, ensure to look at the meter rule perpendicularly from above without any parallax. Ensure also that the receiver is always aligned parallelly with regard to the meter rule, i.e. that it is not offset. Record a total of 40 measurement values.

In order to expedite the experiment, we recommend using a larger step width, e.g. 2 cm, for longer distances. Since the intensity changes most significantly in the case of shorter distances, it would be useful to maintain a step width of 1 cm in this case.

As a final step, switch the internal loudspeaker of the control unit on and set the modulator to "internal". Then, move the receiver along meter rule over the entire distance and listen closely to the volume of the signal. Note down your observation.

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Evaluation (1/3)

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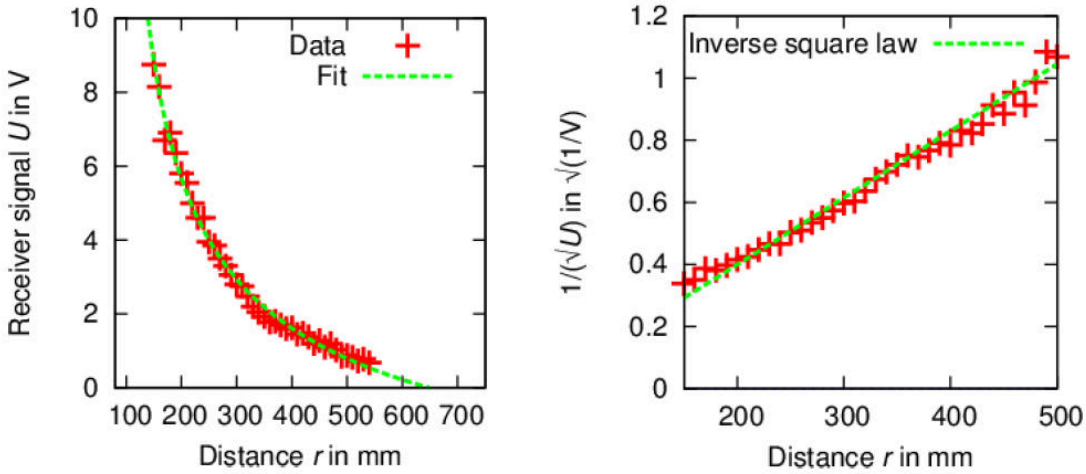

Graphical representation of the example data.

Evaluation (2/3)

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The linear relationship enables the determination of the location of the virtual source as the intersection of the straight line with the r-axis. The example data lead to the distance a = 14.5 mm, i.e. the virtual source is located inside the funnel.

There is a square dependence of the radiation intensity on the distance and location of the virtual source. The virtual source is located in front of the actual transmitter.

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Evaluation (3/3)

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Fill in the missing words

Intensity of the illuminated area is [ ] proportional to the [ ] of its distance from the source, is known as [ ] square law. It applies to all [ ] waves.

Check

Slide	Score / Total
Slide 16: Summary waves	**0/4**

Total Score 0/4

Show solutions Retry

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