Experiment 10: Microwaves

OBJECTIVES

1. To observe the polarization and angular dependence of radiation from a microwave generator

PRE-LAB READING

INTRODUCTION

Heinrich Hertz first generated electromagnetic waves in 1888, and we replicate Hertz’s original experiment here. The method he used was to charge and discharge a capacitor connected to a spark gap and a quarter-wave antenna. When the spark “jumps” across the gap the antenna is excited by this discharge current, and charges oscillate back and forth in the antenna at the antenna’s natural resonance frequency. For a brief period around the breakdown (“spark”), the antenna radiates electromagnetic waves at this high frequency. We will detect and measure the wavelength \( \lambda \) of these bursts of radiation. Using the relation \( f \lambda = c = 3 \times 10^{10} \text{cm/s} \), we will then deduce the natural resonance frequency of the antenna, and show that this frequency is what we expect on the basis of the very simple considerations given below.

Figure 1 Spark-gap transmitter. The “33” is a 33 pF capacitor. It is responsible for storing energy to be rapidly discharged across a “spark gap,” formed by two tungsten cylinders pictured directly above it (one with a vertical axis, one horizontal). Two MΩ resistors limit current off of the capacitor and back out the leads, protecting the user from shocks from the 800 V to which the capacitor will be charged. They also limit radiation at incorrect frequencies.
The 33-pF capacitor shown in fig. 1 is charged by a high-voltage power supply on the circuit board provided. This HVPS voltage is typically 800 V, but this is safe because the current from the supply is limited to a very small value. When the electric field that this voltage generates in the “spark gap” between the tungsten rods is high enough (when it exceeds the breakdown field of air of about 1000 V/mm) the capacitor discharges across the gap (fig. 2a). The voltage on the capacitor then rebuilds, until high enough to cause another spark, resulting in a continuous series of charges followed by rapid bursts of discharge (fig. 2b).

![Figure 2 Charging and Discharging the Capacitor](image)

**Figure 2 Charging and Discharging the Capacitor.** The capacitor is slowly charged (limited by the RC time constant, with R = 4.5 MΩ) and then (a) rapidly discharges across the spark gap, resulting in (b) a series of slow charge/rapid discharge bursts. This is an example of a “relaxation oscillator.”

The radiation we are seeking is generated in this discharge.

**Resonant Frequency of the Antenna**

The frequency of the radiation is determined by the time it takes charge to flow along the antenna. Just before breakdown, the two halves of the antenna are charged positive and negative (+,−) forming an electric dipole. There is an electric field in the vicinity of this dipole. During the short time during which the capacitor discharges, the electric field decays and large currents flow, producing magnetic fields. The currents flow through the spark gap and charge the antenna with the opposite polarity. This process continues on and on for many cycles at the resonance frequency of the antenna. The oscillations damp out as energy is dissipated and some of the energy is radiated away until the antenna is finally discharged.

How fast do these oscillations take place – that is, what is the resulting frequency of the radiated energy? An estimate can be made by thinking about the charge flow in the antenna once a spark in the gap allows charge to flow from one side to the other. If \( l \) is the length of one of the halves of the antenna (about \( l = 31 \text{ mm} \) in our case), then the distance that the charge oscillation travels going from the (+,−) polarity to the (−,+) polarity and back again to the original (+,−) polarity is \( 4l \) (from one tip of the antenna to the other tip and back again). The time \( T \) it takes for this to happen, assuming that information flows at the speed of light \( c \), is \( T = 4l / c \), leading to electromagnetic radiation at a frequency of \( 1/T \).
Detecting (Receiving) the Radiation

In addition to generating EM radiation we will want to detect it. For this purpose we will use a receiving antenna through which charge will be driven by the incoming EM radiation. This current is rectified and amplified, and you will read its average value on a multimeter (although the fields come in bursts, the multimeter will show a roughly constant amplitude because the time between bursts is very short.

APPARATUS

1. Spark Gap Transmitter & Receiver

These have been described in detail above. The spark gap of the transmitter (pictured left) can be adjusted by turning the plastic wing nut (top). It is permanently wired in to the high voltage power supply on the circuit board. The receiver (pictured right) must be plugged in to the circuit board.

2. Circuit Board

This board contains a high voltage power supply for charging the transmitter, as well as an amplifier for boosting the signal from the receiver. It is powered by a small DC transformer that must be plugged in (AC in). When power is on, the green LED (top center) will glow.

3. Science Workshop 750 Interface and Voltage Probe

We read the signal strength from the receiver – proportional to the radiation intensity at the receiver – by connecting the output (lower right of circuit board) to a voltage probe plugged in to channel A of the 750.
GENERALIZED PROCEDURE

In this lab you will turn on the transmitter, and then, using the receiver, measure the intensity of the radiation at various locations and orientations. It consists of three main parts.

Part 1: Polarization of the Emitted Radiation
In this part you will measure to see if the produced radiation is polarized, and if so, along what axis.

Part 2: Angular Dependence of the Emitted Radiation
Next, you will measure the angular dependence of the radiation, determining if your position relative to the transmitter matters.

END OF PRE-LAB READING
IN-LAB ACTIVITIES

EXPERIMENTAL SETUP

1. Download the LabView file from the web and save the file to your desktop. Start LabView by double clicking on this file.
2. Plug the power supply into the circuit board
3. Plug the receiver into the input jack on the circuit board
4. Turn on the transmitter – a LED will light indicating it is on
5. Adjust the spark gap using the wing nut on the clothespin antenna. Start with a large gap, and close the gap until a steady spark is observed. You should observe a small, steady bright blue light and hear the hum of sparking.
6. Use the receiver to measure the intensity of the radiation as described below

MEASUREMENTS

Part 1: Polarization of the Emitted Radiation

In this part we will measure the polarization of the emitted radiation.

1. Press the green “Go” button above the graph to perform this process.
2. Rotate the receiver between the two orientations (a & b) pictured at right

Question 1:
Which orientation, if either, results in a larger signal in the receiver?

Question 2:
Is the electric field polarized? That is, is it oscillating along a certain direction, as opposed to being unpolarized in which case it points along a wide variety of directions? If it is polarized, along which axis?

Question 3:
Is the magnetic field polarized? If so, along which axis? How do you know?
Part 2: Angular Dependence of the Emitted Radiation

1. Now measure the angular dependence of the radiation intensity by moving the receiver along the two paths indicated in the below figures.

![Angular dependence - Horizontal](image1.png)

![Angular dependence - Vertical](image2.png)

Question 4:
Which kind of motion, horizontal or vertical, shows a larger change in radiation intensity over the range of motion?

Further Questions (for experiment, thought, future exam questions…)

- Is there any radiation intensity of any polarization off the ends of the antenna?

- An antenna similar to this was used by Marconi for his first transatlantic broadcast. What issues would you face to receive such a broadcast?