A Microwave Generator, Receiver, and Reflector

May 11, 2004

Introduction[1]

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 an antenna. When the spark "jumps" across the gap (once per 0.13 milliseconds in our experiment), 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 our experiment this natural resonance frequency of the antenna is very high, about 2.4×10^9 cycles per second or 2.4 GHz. For a brief period around the breakdown ("spark") the antenna radiates electromagnetic waves at this high frequency. We will detect and find the wavelength λ of these bursts of radiation. Using the relation $f\lambda = c = 3 \times 10^{10}\,cm/s$, we will then deduce the natural resonance frequency of the antenna, around 2.4 GHz, and show that it is what we expect on the basis of the very simple considerations given below.

The Experimental Method

Here in broad outline is how the experiment works. The 25 pF capacitor shown in Fig. 1 is charged by a high voltage power supply on your electronics

---

[1]We are grateful to Dr. Peter Dourmashkin, Professor John King, and Professor Phillip Morrison for elements of this description and for the design of the microwave experiment itself, which is from 8.02X.

board. This voltage is typically 700 Volts, but this is a very safe level because the current is limited to a very small value across the capacitor. When the voltage is high enough and the distance between the conductors in your "spark gap" is small enough, the capacitor discharges across the gap. This happens when the electric field in the gap exceeds the breakdown field of air (about a 10kV/cm). The radiation we are seeking is generated in this discharge (see explanation below). After discharging, the capacitor charges up again through a 4.5 Ω resistor. The time constant is:

$$\tau = RC = (4.5 \times 10^6 \Omega)(25 \times 10^{-12} F) = 1.3 \times 10^{-4} \text{sec}$$

So the charging and breakdown will generate a spark discharge about every 0.13 msec.

The Resonant Frequency Of The Antenna

During the discharge across the spark gap, the antenna acts as an LC oscillator in which energy sloshes back and forth between magnetic and electric energy. Initially, when the two halves of the antenna are charged up with opposites signs of charge, the two halves of the antenna act as capacitor plates with energy stored in the electric field between them. When breakdown starts and current flows across the gap to discharge the antenna halves, energy is transferred from electric to magnetic energy associated with the flowing current. The antenna halves discharge, but the current continues on in the same direction ("overshoots"), charging up the two halves of the antenna to the opposite polarity from the original configuration. The current then goes to zero, but the recharged antenna (with opposite polarity) now drives current in the opposite direction, discharging the antenna halves again and then recharging them back to the original polarity.

This process continues on and on for many cycles at the resonance frequency $\omega = 1/\sqrt{LC}$. How fast do these oscillations take place? Here is a crude estimate that turns out to be right. If l is the length of one of the halves of the antenna (about 31 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 to do this, assuming that information is flowing at the speed of light, is T $= 4l/c$, where c is the speed of light. If the charges are being shaken back and forth at a frequency
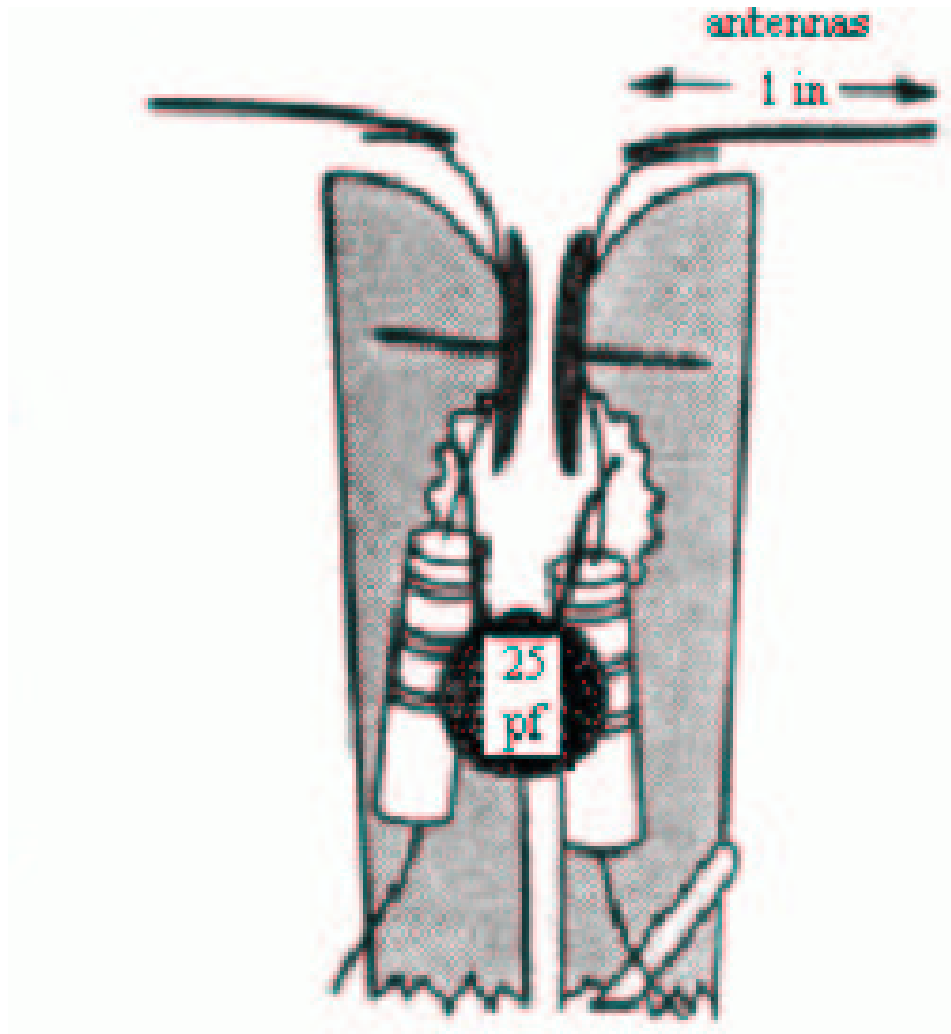
Figure 1: Microwave transmitting antenna. In the newer version of the transmitter, the thumb tack conductors have been replaced by newer half cylindrical conductors.
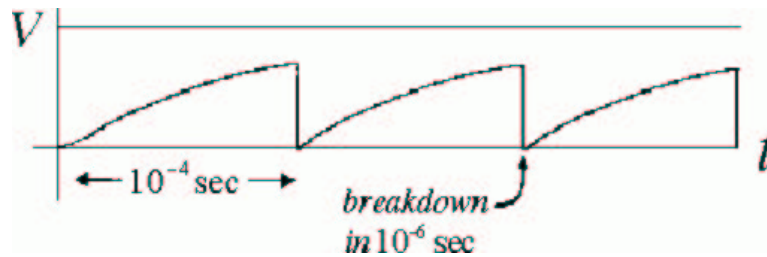
Figure 2: Potential between the conductors as a function of time. The slow rise corresponds to the charging from of the capacitor and the rapid drop is the discharge through the ionized air between the conductors.

of 1/T, they will radiate electromagnetic radiation at this frequency. For l = 31 mm, this estimate of the frequency radiated is

$$f_{rad} = 1/T = c/4l = \frac{3 \times 10^8 \text{m/s}}{0.124 \text{m}} = 2.4 \times 10^9 \text{Hz} = 2.4 \text{GHz}.$$

Electromagnetic waves with this frequency will have a wavelength of c/f, or $4l$.

Thus our simple picture predicts that we will generate electromagnetic radiation with this antenna with wavelengths of about 12.4 cm, and that is something that we will experimentally confirm in this experiment.

The oscillations of the charge back and forth between the two halves of the antenna damp out as energy is dissipated, and the antenna is finally discharged. Then the 25 pF-capacitor starts charging up again, ultimately headed toward breakdown in another 0.13 millisecond. The antenna will thus emits bursts of damped radiation at frequencies around 2.4 GHz every 1.3×10^{-4} sec. The overall time series looks like Fig. 2 on a long time scale:

And, if we blow up the region around the spark discharge, is shown in Fig. 3:

The curves just above represent the current flowing in your receiver as a result of the oscillating electric fields of the microwave radiation. We have a diode in the receiver that allows current to flow in only one direction, and we detect that current using the amplifier and multimeter.
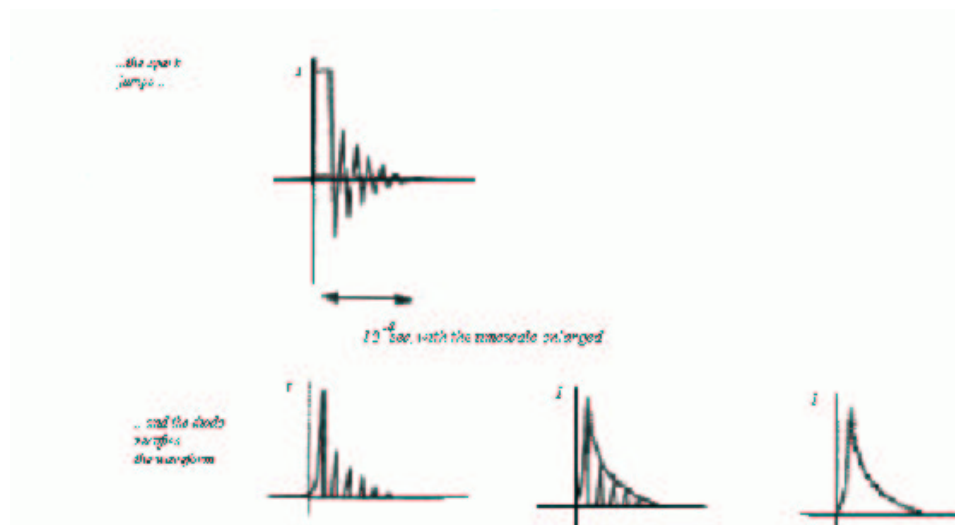
Figure 3: Current in the conductors as a function of time.

Setting up the Apparatus

WARNING: DO NOT TOUCH PARTS ON YOUR ELECTRON-ICS BOARD WHILE OPERATING, SINCE THEY MAY BE-COME QUITE WARM!!!

Plug the power supply into your electronics board at the position indicated. Plug in your receiving antenna (which looks like the tube to the left) to the remaining input jack on the board. Your transmitting antenna is the clothespin assembly, and is already connected. Once you have connected up the power supply, turn on the transmitter (using the off-on switch-the LED will light when it is on).

Your one remaining task is to adjust the spark gap using the wing nut on the clothespin antenna until you get a spark discharge. Once you get that discharge, and learn how to make it reasonably steady, you can use your receiver to make measurements of the radiation emitted. Arrange the transmitting antenna (Figure 4 above right) on your desktop as far away from metal as possible. Put your electronics boards on the desk and somewhat back so that you can explore the radiation field with the receiver (Figure 4 above left). You should be able to move the receiving antenna from a few inches from the transmitter to as far as the shielded wire will let you
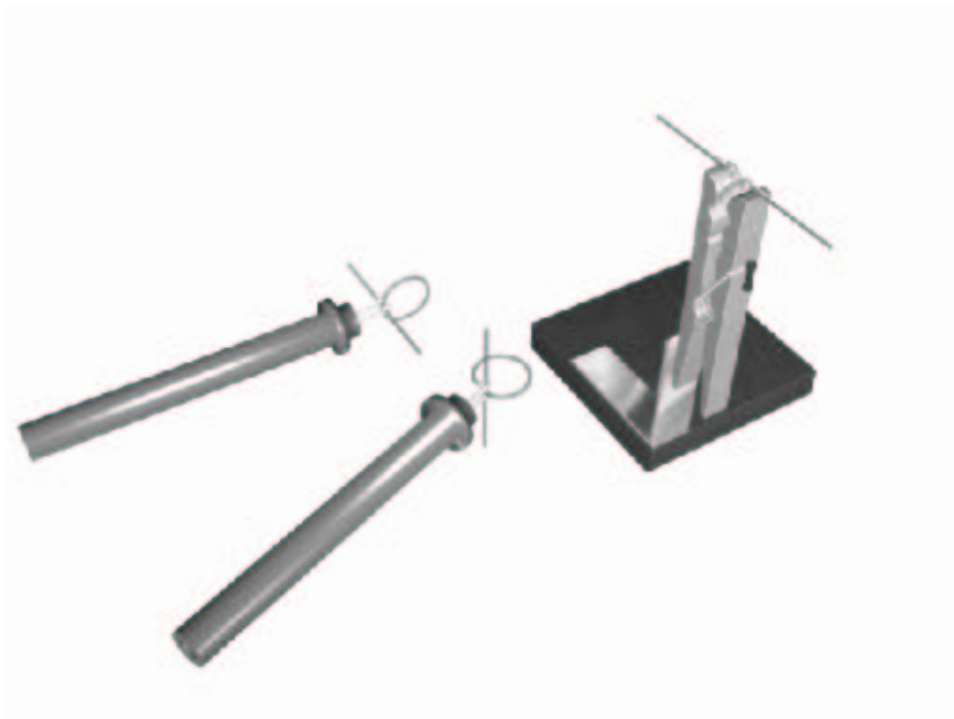
Figure 4: The spark gap, transmitting antenna, and the receiver.(The receiver is shown in two different orientations.
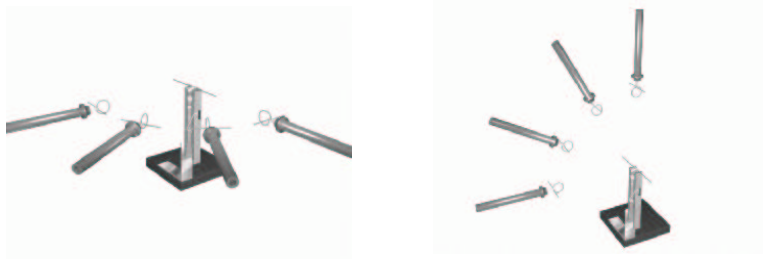
Figure 5:

go on the other side – for larger distances, move the amplifier. Now, with your power supply connected, vary the distance between the thumbtacks by adjusting the nut. You will be able to see the spark when breakdown occurs. To measure the characteristics of the radiation emitted, you explore the radiation generated using signals from your receiver that are amplified by an amplifier and read out on your voltmeter.

Exercise 1: Measuring The Polarization

Prediction 1-1: The radiation we are generating is produced by charges oscillating back and forth between the two halves of your antenna (see Figure 1 above). If you hold the receiver in the two orientations shown in Figure 4 above, which should produce the biggest signal on the voltmeter connected to your receiver? (Answer before starting the lab.)

_____ Receiver wire vertical _____ Receiver wire horizontal

Activity 1-1: Measure the polarization with your receiver and check this prediction.

Exercise 2: Measuring The Angular Dependence

Prediction 2-1: The radiation we are generating is produced by charges oscillating back and forth along the length of your antenna. If you move the receiver in the two patterns shown above(Fig. 5), which should show the biggest change in signal on your voltmeter over the range of motion? (Answer before starting the lab.)

_____ the left pattern _____ the right pattern

Activity 2-1: Measure the angular dependence of the emitted radiation with your receiver and check this prediction. Record the voltage on at $\theta=0$, 30, 45, 60 and 90 degrees. Plot on the the graph paper provided. θ is the polar angle, taking the antenna along the $\hat{z}$ axis. Does you plot agree with what you expect?

Exercise 3: Measuring the radial dependence

Prediction 3-1 Do you expect the reading on the volt meter to go like $1/r$ or $1/r^2$? (Answer before starting the lab.)

Activity 3-1 Measure and record the signal strength at $\theta=0$ for $r=10$, 20, 30cm, ... increments as far out as you can and plot on the graph paper provided. Does your plot agree with prediction?

Exercise 4: Measuring The Wavelength

This is by far the most challenging part of the experiment. We will measure the wavelength of the radiation from your transmitter by using a reflector to reflect the radiation so that it returns to interfere with itself. By measuring the distance we must move the reflector to go from constructive to destructive interference and back again, we will determine the wavelength of the radiation.

First adjust your gap so that the spark produces a steady reading on the meter. Unless you can perform this task, you will have a hard time locating the adjacent maxima and minima blow. Then set up one of the reflectors you are given in the positions shown below, and position the receiver and transmitter as shown. **With this configuration, you want to vary the distance between the reflector and transmitter, holding both the transmitter and receiver fixed in space.**

Search for the positions for constructive and destructive interference by moving the reflector slowly toward or away from the transmitter, watching the voltmeter scale as you do so. The clearest signal is probably obtained in moving the reflector in the region from about 10 cm to about 24 cm away from the transmitter. You hope to see the voltage rise and drop rhythmically with your motion as you move along this distance. Adjacent maxima should be separated by $\frac{1}{2}$ wavelength. A maximum and a minimum should be separated
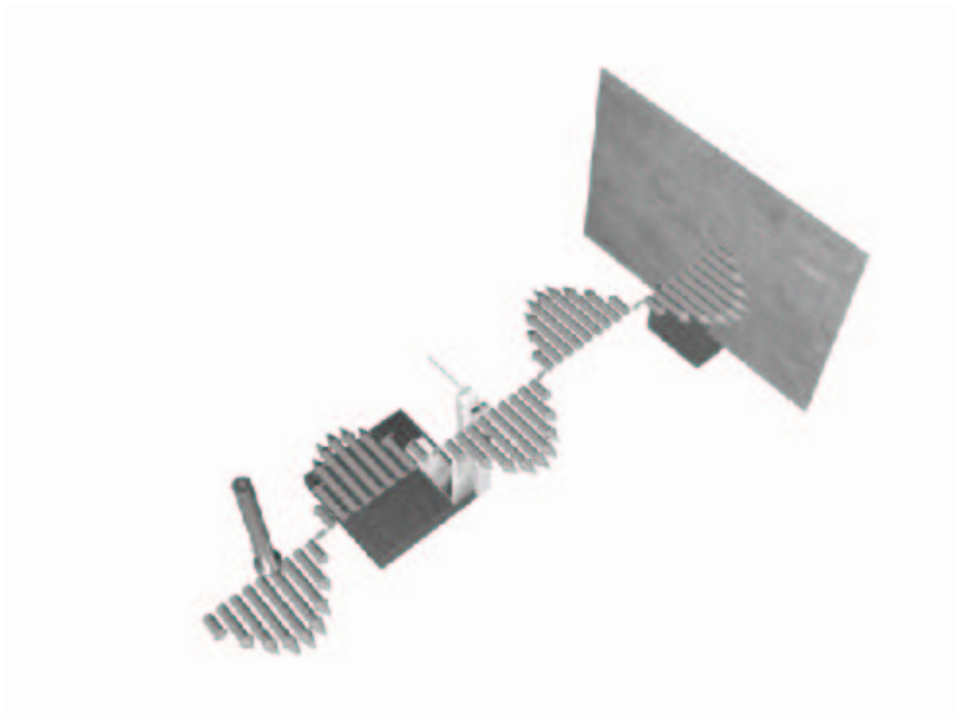
Figure 6: Setup with transmitter, receiver and reflector for measuring the wavelength.

by $\frac{1}{4}$ wavelength. Make a number of different measurements to arrive at a reasonable average for the wavelength of your wave using this method.

Problems In Making The Measurement: It is not easy to get a convincing result here unless the spark is cooperating. Cleaning the tack faces with a scrap of paper will usually calm things down, at least for a fraction of a minute. Mark the positions of the antenna that give meter maxima (minima would do as well), performing the sweep several times to counteract the spark's general jumpiness. Use your ruler to get the wavelengths. It is best for one person to both move the receiver and judge the meter reading, a subtle feedback mechanism. The peaks are a half- wavelength apart.