“Hearing“ Electromagnetic Waves

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Citation: The Physics Teacher **52**, 554 (2014); doi: 10.1119/1.4902203
View online: http://dx.doi.org/10.1119/1.4902203
View Table of Contents: http://scitation.aip.org/content/aapt/journal/tpt/52/9?ver=pdfcov
Published by the American Association of Physics Teachers

"Hearing" Electromagnetic Waves

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In this work, an educational experience is described in which a microwave communication link is used to make students aware that all electromagnetic waves have the same physical nature and properties. Experimental demonstrations are linked to theoretical concepts to increase comprehension of the physical principles underlying electromagnetic waves. Moreover, students learn about the importance and historical development of communication systems, the basic principles of communication links, and the procedure to send information through an electromagnetic wave.[1,2]

Microwaves provide an alternative to visible light experiments,[3,4] since they emphasize the wave nature of the phenomenon and the electromagnetic nature of light. Moreover, microwaves present the advantage of long wavelengths, on the order of centimeters, which is 10^5 times bigger than those of light. As a consequence, the scale of the experiment is transformed and variables obscured by the small scale of traditional optical experiments can easily be manipulated at microwave frequencies.

On the other hand, in contrast to light (and mechanical) waves, no other electromagnetic waves can be perceived by our senses, which makes it difficult for students to confront reality.

Given the impact of communications in society and the interest of young students in the same, we have reproduced typical optical experiments at microwave frequencies but using a microwave communication link. This allows sound to be transmitted so that the phenomena involved can now be heard, making it a more "real" and exciting experience for students.

In an attempt to provide a motivating and formative experience, the subject is presented to students in the following order.

How did we get to modern communications systems?

Humankind's need to send messages or transmit information over large distances led to the development of communications systems.[5,6] We start by showing that any communications system or link, including oral communication, basically consists of an *emitter*, a *receiver,* and usually a transmission *medium*.

In the case of long-distance communications, primitive systems were based on transmission through the air using horns, bells, fire, or smoke, among others. The connection between science and technology in this field is evident, as almost all technological advances are preceded by scientific discoveries, hence the importance of the discoveries made in electromagnetism during the 19th century, which would lead to profound changes in the world of communications. Some of these changes were related to important inventions, like the telegraph (Samuel Morse) or the telephone (Alexander G. Bell), which immeasurably enhanced communications. The electrical communications era started when information was made to travel by an electrical signal, the *carrier*, along a metallic wire, the *medium*. Hertz's discovery of long wavelength electromagnetic radiation and the first radio emission by Marconi led to the beginning of the radio-communication era. In this case, the carrier is an electromagnetic wave, while the medium through which the information propagates is the air or even empty space (no medium is actually necessary for electromagnetic waves). In the 1970s, the development of laser and optical fiber manufacturing techniques opened up the era of optical communication, where the carrier is an electromagnetic wave in the optical range and the optical fiber is the medium of propagation.

How is information transported by an electromagnetic wave?

An electromagnetic wave with electric and magnetic fields of constant amplitude and constant frequency does not transport any information. For a message to be propagated by an electromagnetic wave as a *carrier*, it must be modified in a way that depends on the information we wish to transmit. This process is called *modulation*.[7,8]

For teaching purposes, the effect of modulation can easily be explained by listening to the changes of vocal sounds that we produce when we talk to someone or by looking at the process of sending a message in Morse code with the help of a torch. In both cases, the information is only propagated when we introduce changes according to an established code. In contrast, if our voice emits a constant sound or the torch beam is permanently switched on, no message will be transmitted.

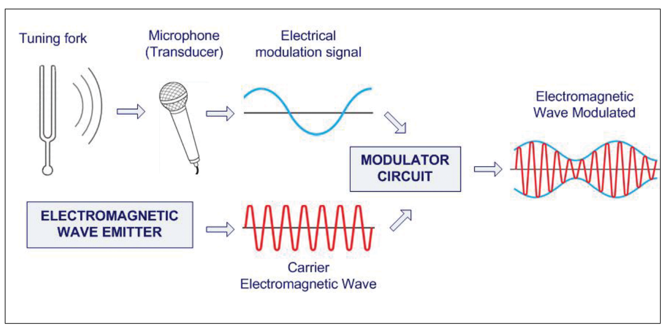

Fig. 1. Amplitude modulation of an electromagnetic wave by an acoustic signal.

A schematic view of amplitude modulation of an electromagnetic wave is shown in Fig. 1. The information from the source (sound emanating from a tuning fork) is converted into a *modulating* electrical signal using a transducer (microphone). Variations in the signal amplitude are applied to the

 DOI: 10.1119/1.4901616

carrier via the modulator circuit, producing analogous variations in the amplitudes of the electric and magnetic fields of that wave. In this way, the modulated wave carries the original information that is to be transmitted. When the carrier wave reaches the receiver, it is detected and reconverted into an electrical signal. Finally, another transducer (such as a loudspeaker) converts the electric signal back to the original sound made by the tuning fork to be perceived by the addressee/listener.

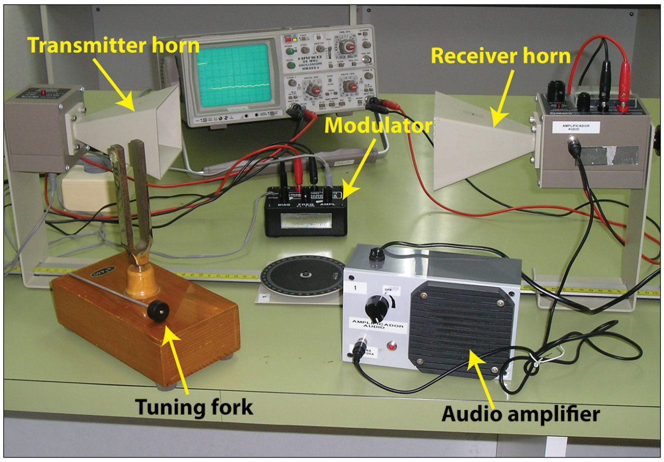

Fig. 2. Experimental system for sound transmission.

Required instrumentation

Three basic units are required to perform the experiments described, all supplied by PASCO: a transmitter, a modulator circuit, and a receiver (Fig. 2).

The transmitter unit consists of a pyramidal horn with a built-in Gunn diode in a 10.525-GHz resonant cavity, which provides a 15-mW coherent, linearly polarized microwave output at a wavelength of 2.85 cm. The unit can be rotated around its axis, allowing changes of the polarization angle of the emitted radiation.

The receiver unit consists of a microwave horn identical to that of the transmitter unit, which collects the microwave signal and channels it to a built-in Schottky diode in a 10.525-GHz resonant cavity. The diode produces a dc voltage that varies with the magnitude of the microwave signal. A meter that provides a reading that is approximately proportional to the intensity of the incident microwave signal is mounted in the unit. There is also a voltage output with banana plug connectors that can be used for closer examination of the signal using an oscilloscope and an audio output. As with the transmitter, rotation is allowed for convenient measurements of the polarization angle on a rotating scale.

The microwave modulation kit turns the transmitter and receiver into a microwave communications system. Features of the PASCO modulator kit[9] include microphone input, 9-V dc power input, Gunn diode output, and voltage output with banana plug connectors to monitor the modulating signal. Modulation can be accomplished with an audio signal via the microphone input in the modulator or, alternatively, with an electric triangular wave output that the modulator provides. The technical specifications for modulation are described in the referenced manual, so that the circuit can be easily constructed in the lab.

In addition, an audio player, a tuning fork, a microphone, a function generator, and an oscilloscope should be on hand. To provide an audible output for the standard microwave experiments, we also need an audio amplifier and speaker system. Now, signals can be "seen" on the oscilloscope screen and simultaneously "heard" from the speaker.

Transmission of electrical and acoustic signals

We begin by sending simple information such as the electrical signals of a function generator. The screen of the oscilloscope simultaneously shows both signals (emitted by the emitter antenna and received by the receiver antenna), which permits the quality of the signal received to be compared with the quality of the signal sent and the similarity between both to be appreciated. To demonstrate that the information travels exclusively via microwave, an object can be placed between the antennas to block the transmission of the signal, which disappears from the screen of the oscilloscope.

The next step is to add a microphone to transmit simple acoustic information of just one frequency, generated by a tuning fork (Fig. 2). Again, with the oscilloscope, the fidelity of the received information can be checked while the signal disappears when the microwaves are obstructed with an object.

The experiment becomes more exciting when the microwaves are modulated with a more complex electrical signal from an audio player. Now we can connect the induced signal at the receiver to an audio amplifier to hear it instantaneously. Once again, the presence of an object between the antennas leads to a loss of the transmitted signal, which usually has greater impact on the students as they now hear this effect instead of just seeing fluctuations on the meter reading or the oscilloscope screen.

Optical experiments

Many of the experiments described in the manual that accompanies the PASCO Microwave Optics System[10] can be performed with the audible output via the communication link. In this way, variations in loudness of an audible sound modulating a microwave are associated with the analyzed physical phenomenon.

We select the following experiments in the PASCO manual[9] and summarize some of the most interesting aspects of the sound version:

- Microwave reflection on a not very polished metallic plate.
- Measurement of the refractive index of an ethafoam prism mold filled with dielectric pellets of 2-3 mm diameter.

In both experiments, the maximum sound level from the receiver is clearly heard at the correct reflection and refraction angles, respectively. Furthermore, both experiments allow students to observe the importance that the relative values of the wavelengths and of the size of the roughness and discontinuities has in the appearance of the physical phenomenon. Students will realize that for microwaves, unlike light, the imperfections of a not very well polished reflective metallic plate or the discontinuity of the dielectric pellets in refraction effects do not affect the results of the experiments due to the longer wavelength.

Other possible experiments are:

- Investigation of the phenomenon of polarization either by rotating the antennas about their common axis or by inserting a metallic polarizer slit between them. The sound level is maximum when the receiver antenna is aligned with the field direction.
- The typical double-slit interference pattern observed for light is now transformed into maximum and null sounds when the receiver antenna is moved transversally.
- A simple flexible tubular plastic bag filled with dielectric pellets ("microwave optical fiber") allows transmission based on the phenomenon of total internal reflection to be investigated.

With this homemade "fiber," uncoated and considerably bigger than optical fibers, students can observe experimentally the main advantages of using these structures for communication purposes. First, the strong enhancement of the intensity of the received sound can be perceived. Second, it is possible to guide an electromagnetic wave through different trajectories. If we take the fiber and bend it to connect the non-aligned antennas, we will be able to recover the sound.

Conclusions

The educational experience we have presented here found great acceptance among pre-university high school students as well as first-year university students with a basic background in electromagnetic waves. The experiments were also successful in non-academic demonstrations. Students mentioned that the experiments motivated them to study electromagnetic waves and helped them to understand the underlying physical properties and concepts. Moreover, a connection was established between abstract physical theories and everyday technological advances related to electromagnetic waves.

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