Basic Principles of Microwave Energy

Chapter Two

2.1 INTRODUCTION

Microwaves are very short, invisible electromagnetic waves of energy that travel at the speed of light, which is 186,282 miles per second. Electromagnetic waves can be illustrated by tossing a pebble into a quiet pond. The pebble striking the still surface of the water creates a disturbance. The disturbance causes the water to move up and down in the form of ripples that radiate in ever-widening circles over the surface of the pond (Fig 2-1). These ripples, or vibrations, rising and falling away from the point where the pebble hits the water are called *waves*. Because these waves move up and down at right angles (or perpendicular) to the direction they are traveling, they are called *transverse* waves (Fig. 2-2). Electromagnetic waves are examples of transverse waves.

Figure 2-1 How a pebble creates wave motion to the surface of a pond (Wagner/Gallawa)

Observing some of the characteristics of these waves in the pond, it is evident that they travel at a fairly constant rate of speed. Also, if they strike an obstacle, such as a log or boat dock, they are *reflected* back in the opposite direction. Consider, too, the effect of these ripples or vibrations on a floating object such as a leaf. As each wave passes, the leaf rises and falls (or vibrates) at the frequency of the passing ripples, finally ending up at about the same position it was in before the waves passed through. Electromagnetic waves have similar characteristics. They travel at a constant rate of speed; they are *reflected* by some objects and pass right *through* certain others.

The disturbance resulting from the pebble landing in the water is transmitted through the water in the form of waves. The water serves merely as a medium through which the disturbance travels. (The water itself does not actually move along with the traveling waves, as is evidenced by the floating leaf having no sideward movement.) In this sense, the waves in the pond are more like *sound* waves which, unlike electromagnetic waves, also need a medium through which to travel, normally using the molecules that exist in the air or water. For example, thundering rocket engines that deafen the ears at lift-off become inaudible in the quiet vacuum of space.

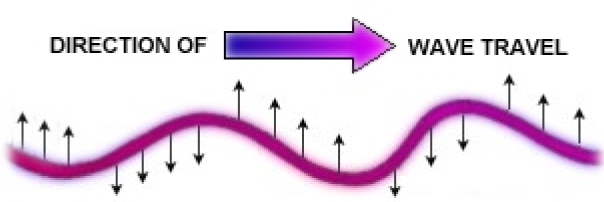

Figure 2-2 Transverse waves. (Wagner/Gallawa)

On the other hand, ELECTROMAGNETIC forms of energy, such as sunlight and radio waves, travel millions of miles through the emptiness of space without the need of any material medium through which to travel. This is true because, simply put, electromagnetic waves are, in themselves, *stored* energy in motion. While an entire chapter could be devoted to the *theory* of *electromagnetic radiation* with its quantum of quandaries and quotients, a basic explanation is sufficient for the purposes of this text.

Electromagnetic radiation begins with a phenomenon that occurs when electric current flows through a conductor, such as a copper wire. The motion of the electrons through the wire produces a field of energy that surrounds the wire and floats just off its surface. This floating zone or cloud of energy is actually made up of two different fields of energy, one ELECTRIC and one MAGNETIC (Fig. 2-3). As we will discuss later, these two fields, although different, are so closely interrelated and interdependent that they are merely different aspects of the same ELECTROMAGNETIC field that surrounds the wire. If the current flowing through the wire is now made to *oscillate* (or alternate the direction of its flow) very rapidly, the floating electromagnetic field will break free from the conductor and be launched into space. Then, at the speed of light, the energy will *radiate* outward in a pulsating pattern, much like the waves in the pond. It is theorized that these waves are made up of tiny packets of radiant energy called *photons.* Streams of photons, each carrying energy and momentum, travel in waves like an undulating string of cars on a roller coaster.

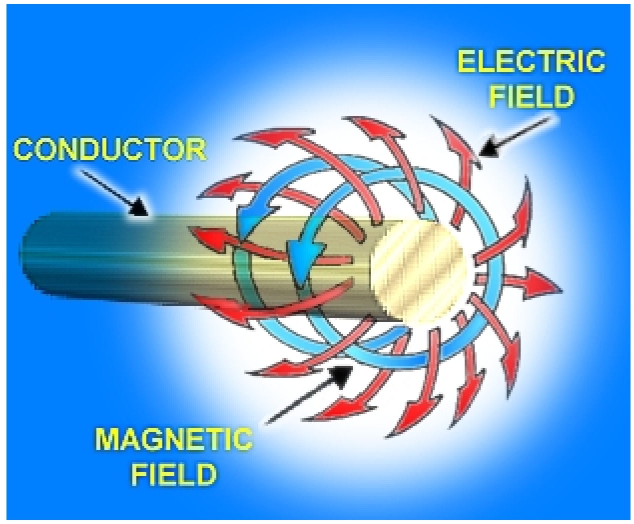

Figure 2-3 Electromagnetic field around a conductor (Wagner/Gallawa)

The electric and magnetic waves that combine to form an electromagnetic wave travel at right angles to each other and to the direction of motion. In Figure 2-4, imagine this electromagnetic wave front traveling right off the page and directly toward you. The *electric* field in this illustration consists of waves that rise and fall in a *vertical* plane, while the waves of the *magnetic* field vibrate back and forth on a *horizontal* plane. These waves, vibrating perpendicularly to each other, are inseparable and cannot be defined individually. In other words, an oscillating field of electrical energy will always create a magnetic field, and a moving magnetic field will always create an electrical field; one causes and depends on the other. Together they form electromagnetic radiation. (In reference to electromagnetic energy, the terms *vibrations*, *oscillations*, *radiations*, *waves*, *field*, and *radio frequency* [RF] *energy* are all used interchangeably to illustrate various and common terminologies.)

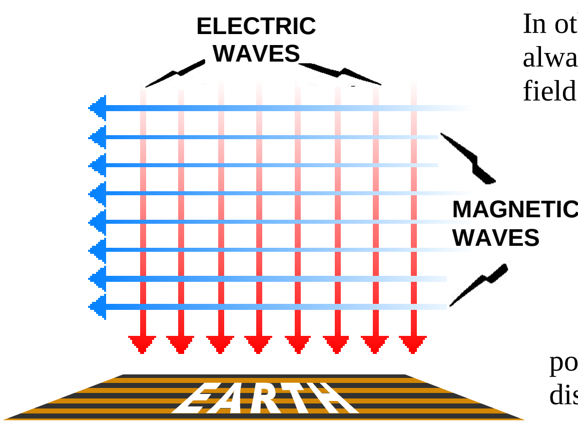

Figure 2-4 Electromagnetic Wavefront.

Figure *2-5* illustrates how the waves in the pond may be likened to electromagnetic energy. The distance between the crests or peaks of two successive waves would be called the *WAVELENGTH.* The distance between the top of the crest and the level surface of the water would be called the *AMPLITUDE.* If you could watch the floating leaf in slow motion as the ripple passes, you would observe it beginning at the level surface of the pond (or zero *amplitude);* then as the ripple approached, it would rise (in a *positive* direction or *alternation)* to the crest (or *positive peak).* Then, descending back through the "zero" point (in a *negative* direction or *alternation)* it reaches the lowest point of the trough (or *negative peak)*, and finally returns upward to its starting (or *zero)* position. The section of wave producing this motion would equal *ONE CYCLE*. The number of times the leaf completes one cycle in *one second* is called the *FREQUENCY*, which is measured in *CYCLES PER SECOND* or, more commonly *HERTZ* (HZ), in honor of German physicist Heinrich Hertz. The distance from the top of the crest to the bottom of the trough, taken in a straight vertical line, would represent the *PEAK-TO-PEAK* value of the wave. These are all terms that are used in describing electromagnetic waves.

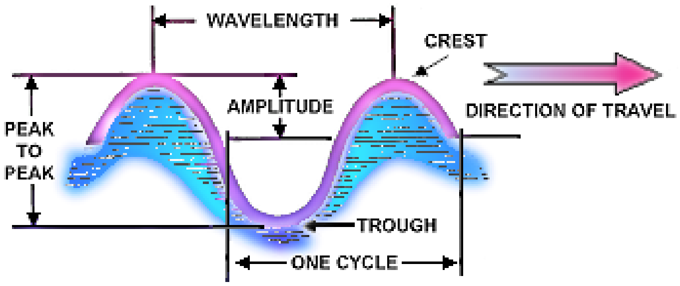

Figure 2-5 Elements of a wave.
(Michael Wagner/Kimberly Dennis)

What are some common forms of electromagnetic radiation? Figure 2-6 is a frequency spectrum chart showing the range of electromagnetic radiation from the slower, non-electromagnetic oscillations (or vibrations) of sound waves, up through the electromagnetic vibrations (or radiations) of radio, television, *microwaves*, radar, infrared (or radiant heat), and visible light. Beyond the visible is a band of ultraviolet light, then up into the X-rays, gamma and cosmic rays. Light and heat (infra-red) waves, as well as microwaves used in radar equipment for detecting aircraft, ships, speeding motorists, and microwaves used for cooking, and in telephone, television and radio communication, are *all* different forms of the *same* kind of electromagnetic energy. The difference is mainly in the frequency and the wavelength.

What is the difference, and why? Notice again in Figure 2-6, just above the visible light spectrum, the division between *non-ionizing* and *ionizing* types of radiation. These are the two main categories of electromagnetic radiation, and, as the terms indicate, there are very important differences.

2.2 IONIZING RADIATION

The frequency of *ionizing radiation* is measured in millions of trillions of hertz (cycles per second). The energy contained in a given photon is proportional to its frequency, which means that the higher the frequency, the higher the energy. The tremendous photon energy of X-rays and gamma rays (because of their extremely high frequencies) is capable of changing the internal structure of atoms and molecules, as well as being immensely penetrating. This is the sort of radiation we associate with radioactive substances such as uranium, radium, and radiation emitted during atomic and thermonuclear explosions. Ionizing radiation has sufficient energy to cause actual chemical changes to take place within the molecular structure of matter, damaging the cells of living tissues by creating electrically charged, or "ionized," molecules, and causing genetic mutations. These deadly rays are particularly dangerous because they are initially imperceptible, causing little or no temperature rise within the exposed matter, and since their damaging effects are cumulative, even slight exposure is hazardous.

2.3 NON-IONIZING RADIATION

Non-ionizing radiation covers all of the lower-frequency radiations. Because of their significantly lower frequencies, and therefore lower energy, they do not have the same damaging and cumulative properties as ionizing radiation. *Microwave radiation* is non-ionizing, and in sufficient intensity will simply cause the molecules in matter to vibrate, causing *friction*, which produces heat.

The danger from microwave radiation, then, exists in the cooking or heating effect. *(Note:* Recent studies suggest that microwaves can also result in effects that cannot be explained by

More samples coming soon…