Radar Principles-Simplified

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Although radar is not one of the forms of communication generally used by radio amateurs, the author feels that amateurs should have a "speaking acquaintance" with this very important and fascinating phase of electronics. Possibly reading this article may capture your interest enough to cause you to investigate in detail what makes a radar "tick." In any case, we hope that this article will clear up some of the questions you may have had about radar.

Introduction

The word RADAR is made up by extractions from the phrase "RAdio Detection and Ranging." Basically, radar is the application of radio principles to detect unseen objects and to determine their direction and range. In special types of radar, elevation and speed may be indicated also.

Radar is one of the greatest scientific developments to come out of World War 2. Its basic principles are relatively simple, and the seemingly complicated circuits can be resolved into a series of functions that, when taken individually, will afford identification and understanding.

Basic Principles

The basic principle of radar operation is dependent on creating (transmitting) and picking up (receiving) an echo. A radar transmitter emits powerful, short bursts of rf energy. Some of this energy will strike objects within the range of the transmitted signal and be reflected back to the radar receiver. It is possible to determine the distance of the object causing the reflected signal to return by carefully measuring the time required for the energy to go to the object and to return, and then translating this information into a measure of distance.

Sound echoes or wave reflection is the principle used in radar operation. If a person shouts in the direction of a sound-reflecting surface 2200 feet away, he will hear his shout return in about 4 seconds. If a directional device was built to transmit and receive sound, the principles of echo and a knowledge of sound velocity could be used to determine the distance, the height, and the direction of an unseen object.

All radar sets work on principles much like these in the preceding paragraph except that a radio wave of extremely high frequency is used instead of a sound wave. The radar set transmits a short pulse of rf energy and receives its own echo signal, then transmits another pulse and receives these echoes. Depending on the design of the radar set, this cycle is repeated 60 to 4000 times each second. If the energy is sent into clear space, there will naturally be no returning echoes and the energy is lost. If the energy strikes an object such as a building, ship, airplane, or hill, some of the energy will be reflected back to the radar's antenna and receiver. If the object is large, a strong echo (but only a fraction of the radiated energy) is returned to the antenna. If the object is small, the echo will be weak. Radar waves travel at the speed of light, approximately 186,000 land miles per second or approximately 162,000 nautical miles per second. Radar signals have been directed to the moon and their echoes have been received approximately 2½ seconds later.

Because radar utilizes the uhf and the shf bands, the energy will travel in a straight line with very little effect from the earth's atmosphere. Consequently, there is a very short time interval between the transmission of a radar pulse and the reception of its echo. It is possible to measure the amount of elapsed time to an accuracy of one ten-millionth of one second (1×10^{-7} seconds). The forming, timing, and presentation of these pulses are accomplished by special circuitry and devices.

The antennas used by a radar set are designed with a sharply defined beam. When a signal is being received, the antenna will be rotated until the received signal is maximum. The direction of the target (object) is then determined by the position of the antenna.

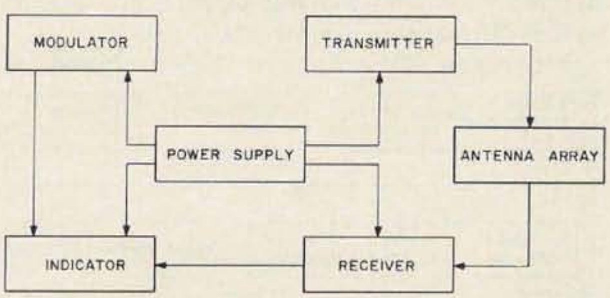

FIGURE 1
Fundamental elements of a radar system

The echoes received by the radar receiver are observed on an oscilloscope (built as part of the radar) as marks of light. This scope may be calibrated in miles, yards, or degrees. A radar operator can tell the bearing and range of a target by the position of the echo on the scope indicator.

Azimuth is the relative horizontal direction of a target with respect to some particular direction reference expressed in degrees. Elevation expresses the angular degrees that the target is above or below the radar set. Both azimuth and elevation must be considered in determining the direction of a target. The determination of both azimuth and elevation depend upon the directional characteristics of the radar antenna.

Types of Radar Systems

There are several radar systems in current use, each with major differences between them. They are the frequency modulation system, the frequency shift system, and the pulse modulation system (most commonly used today.)

Frequency Modulation System. Because each cycle of a frequency-modulated wave differs by a small increase in frequency from the others of that wave, a frequency-modulation system makes it possible to identify each cycle of the transmitted wave and to recognize it from all others when it returns to the receiver. If a transmitter is designed to produce a signal which regularly changes over a known range of frequencies, it is possible to identify any particular reflected signal cycle. Two separate signals are fed to the receiver and, when mixed, produce a beat note. The frequency of the beat note varies directly with the distance to the object, increasing as the distance increases. A device that measures frequency can be calibrated to indicate range (distance to object). A measurement of the difference in frequency between the transmitted and reflected energy determines the presence and speed of a moving target. The frequency-modulation system works well with stationary or slow-moving targets but not as well with fast-moving targets.

Frequency Shift System. This is based on

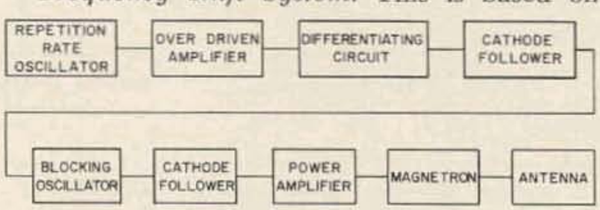

FIGURE 2
Simplified block diagram of a modulator and Transmitter

the Doppler effect. If the source of radio energy (an aircraft from which radio waves are reflected) is moving rapidly, the frequency of the echo return signal will change provided that the object is moving toward or away from the receiving antenna. The circling of an aircraft (or cross-wise movement) will not change the frequency. The amount of frequency change is proportional to the speed at which the object is moving toward or away from the receiving point. The detector in the receiver responds to the difference in frequency. If the object is not moving, or if it is moving crosswise, the detector response is zero. In a mountainous area where the echo return signals are stronger than the echo return signals from an aircraft, the frequency shift principle is sometimes combined with a pulsed radar system. The moving objects are differentiated from the stationary ones, the stationary objects are eliminated, and the operator sees only the moving objects. In this type of system, the frequency shift detector device is supplementary equipment attached to the radar set and is called a moving target indicator.

Pulse Modulation System. Most radar sets employ the pulse system of deflection. In this system, the transmitter is turned on for short periods and off for long periods. When the transmitter is on, it radiates a short burst of energy called a pulse. This pulse will strike an object, part of the reflected energy is returned to the receiver, and is displayed on a cathode-ray tube. As the transmitter is turned off after every pulse, it does not interfere with the receiver. Complete location of an object in space depends on the range or distance of the target from the antenna and the direction including both the azimuth and elevation directions. The primary purpose of a radar set is its ability to measure distance in terms of time. In useful terms for radar, radio waves travel one nautical mile in 6.2 microseconds, or one radar mile (out and back) in 12.4 microseconds. If a pulse of energy was transmitted toward a target and the echo returned 620 microseconds later, the distance of the target would be 50 miles.

$$\frac{620}{12.4} = 50 \text{ miles}$$

In the pulse system, the time duration of the pulses may vary from 0.1 to 50 microseconds. If the transmitter is turned off before the reflected energy returns from the target, the receiver can distinguish between the transmitted pulse and the reflected pulse. After the reflections have returned, the transmitter can

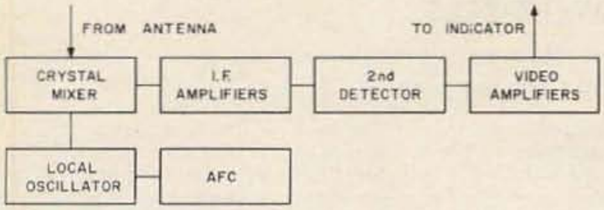

FIGURE 3

Simplified block diagram of a radar receiver

be turned on again and the process repeated. The receiver output is applied to an indicator that measures the time interval between the transmission of the energy and its return as a reflection.

Fundamental Radio Concepts

The fundamental elements of a radar system consist of the transmitter, modulator, antenna, receiver, indicator, and power supply. A functional diagram of a simple radar system is shown in Figure 1. Figure 2 shows a simplified block diagram of a transmitter and modulator and Figure 3 shows a simplified block diagram of a receiver.

The transmitter provides extremely high-power pulses of rf energy for a very short time. The frequency must be very high to allow many cycles to get into the short pulse.

The modulator produces the synchronizing signals that trigger the transmitter the required number of times each second. It triggers the indicator sweep and coordinates the other associated circuits.

The antenna is very directional and usually s a dipole used in conjunction with parabolic eflectors. Ordinarily, one antenna is used for oth the transmitter and the receiver and a witching device is used to connect it to the ransmitter when a pulse is radiated, and to he receiver during the interval between ulses. The antenna is a rotatable array and ontinually searches for targets within its ange.

The receiver is usually a superheterodyne ype, is very sensitive, and is capable of acepting signals within a 1 to 10 megacycle andwidth. It presents video pulses to the inlicator.

The indicator presents necessary information o locate a target on the indicator screen. The nethod of presentation is called "scan." There re about 15 types of scan used in radar eceivers but the most common ones are: type , B, PPI, and E.

The power supply furnishes all ac and dc oltages to the radar system.

Certain parameters are associated with all adar systems. These parameters consist of carrier frequency, pulse-repetition frequency (PRF) (the number of pulses sent out each second), pulse width (in microseconds), and power relation (relationship of peak and average power).

The carrier frequency is the frequency at which the rf energy is generated.

The range of a radar set depends upon the pulse-repetition rate provided the power is sufficient. For example, if the repetition rate is 250 pulses per second, the period of time is $\frac{10^6}{250} = 4000$ microseconds. At 12.4 microseconds per mile, the range will be $\frac{4000}{12.4} =$ approx. 322 miles.

The minimum range at which a target can be detected is determined largely by the width of the transmitted pulse. For example, a pulse width of one microsecond will have a minimum range of 164 yards. A target within this range will be blocked out on the indicator. For radar navigation work, the pulse width is normally in the order of 0.1 microsecond. For long range work, the pulse width is normally from 1 to 5 microseconds.

The transmitter's useful power contained in the radiated pulses is called peak power. The transmitter's average power is low compared with the peak power. The greater the pulse width, the higher will be the average power. The longer the pulse-repetition time, the lower will be the average power. Duty cycle is the fraction of the total time that rf energy is radiated. This is represented as

$$\text{duty cycle} = \frac{\text{pulse width}}{\text{pulse-repetition time}}$$

High peak power is desirable to produce a strong echo return and low average power is desirable to keep the equipment compact.

Summary

Throughout the years that radar has been in use, it was pioneered and developed primarily by the various military services. In addition to being used by the military, it is used by civilian organizations for:

1. Determination of vehicle speeds on highways,
2. Radar weather prediction,
3. Commercial air navigation, and
4. Safeguarding aircraft and merchant ships from collision hazards.

Radar equipments are grouped into many classes, but in general it can be said that some of the classes are air search, surface search, fire control, identification, ground and carrier-controlled aircraft approach, range rate or speed, and height finding. . . . W1MEG