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 \((1 \times 10^{-7} \text{ seconds})\). 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.
...and if the observer is moving with respect to the source of radio waves, the Doppler effect is experienced. If the observer is moving away from the source, the frequency of the received waves will be lower than the transmitted frequency. If the observer is moving toward the source, the frequency of the received waves will be higher than the transmitted frequency. The amount of change in frequency is proportional to the speed of the observer. If the change is not significant, (as in the case of radio waves) the Doppler effect is not noticeable. However, in the case of light waves, the change in frequency is significant and noticeable.

In the radar system, the frequency shift is used to distinguish between different objects. This is done by transmitting a frequency-modulated signal, and then measuring the change in frequency of the received signal. The difference in frequency can be used to determine the distance to the object.

The diagram below illustrates a simplified block diagram of a radar system.
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 is a dipole used in conjunction with parabolic reflectors. Ordinarily, one antenna is used for both the transmitter and the receiver and a switching device is used to connect it to the transmitter when a pulse is radiated, and to the receiver during the interval between pulses. The antenna is a rotatable array and continually searches for targets within its range.

The receiver is usually a superheterodyne type, is very sensitive, and is capable of accepting signals within a 1 to 10 megacycle bandwidth. It presents video pulses to the indicator.

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

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

Certain parameters are associated with all radar 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

\[ \frac{10^6}{250} = 4000 \text{ microseconds.} \]

For 12.4 microseconds per mile, the range will be

\[ \frac{4000}{12.4} \approx 322 \text{ miles.} \]

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.