Basic Radar System Block Diagram:

Basic Radar System Block Diagram consists of a transmitter and a receiver, each connected to a directional antenna. The transmitter is capable of sending out a large UHF or microwave power through the antenna. The receiver collects as much energy as possible from the echoes reflected in its direction by the target and then processes and displays this information in a suitable way. The receiving antenna is very often the same as the transmitting antenna. This is accomplished through a kind of time-division multiplexing arrangement, since the radio energy is very often sent out in the form of pulses.

Fundamentals of Basic Radar System:

Basic radar system: The operation of a Basic Radar System Block Diagram can be quite complex, but the basic principles are somewhat easy for the student to comprehend. Covered here are some fundamentals which will make the follow-up material easier to digest.

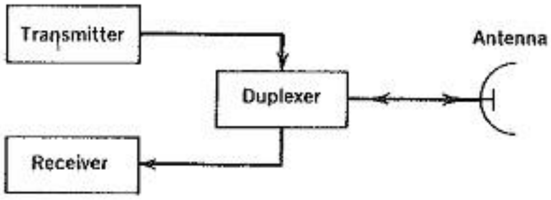


FIGURE 16-1 Block diagram of an elementary pulsed radar.

Refer to Figure 16-1 and the timing diagram (Figure 16-2). A master timer controls the pulse repetition frequency (PRF) or pulse repetition rate (PRR) (Figure 16-2.). These pulses are transmitted by a highly directional parabolic antenna at the target, which can reflect (echo) some of the energy back to the same antenna. This antenna has been switched from a transmit mode to a receive mode by a duplexer. The reflected energy is received, and time measurements are made, to determine the distance to the target.

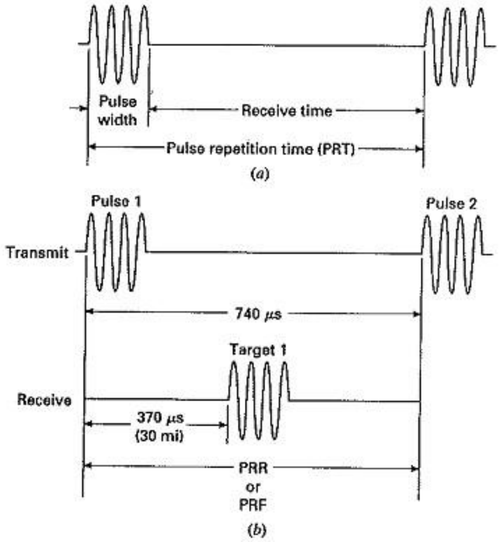


FIGURE 16-2 Timing diagram.

The pulse energy travels at 186,000 statute miles per second (162,000 nautical miles per second). For convenience, a radar mile (2000 yd or 6000 ft) is often used, with as little as 1 percent error being introduced by this measurement. The transmitted signal takes 6.16 µs to travel 1 radar mile; therefore the round trip for 1 mi is equal to 12.36µs. With this information, the range can be calculated by applying Equation (16-1).

$$\text{Range} = \frac{\Delta t}{12.36} \qquad \textbf{(16-1)}$$

Where

t = time from transmitter to receiver in microseconds

For higher accuracy and shorter ranges, Equation (16-2) can be utilized.

$$\text{Range (yards)} = \frac{328\ \Delta t}{2} = 164\ \Delta t \qquad \textbf{(16-2)}$$

After the radar pulse has been transmitted, a sufficient rest time (Figure 16-2a) (receiver time) must be allowed for the echo to return so as not to interfere with the next transmit pulse. This PRT, or pulse repetition time, determines the maximum distance to the target to be measured. Any signal arriving after the transmission of the second pulse is called a second return echo and would give an ambiguous indication.

The range beyond which objects appear as second return echoes is called the maximum unambiguous range (mur) and can be calculated as shown in Equation (16-3).

$$\text{mur} = \frac{\text{PRT}}{12.2} \qquad \textbf{(16-3)}$$

Range in miles; PRT in µs

Refer to the timing diagram (Figure 16-2). By calculation, maximum unambiguous distance between transmit pulse I and transmit pulse 2 is 50 mi. Any return pulse related to transmit pulse 1 outside this framework will appear as weak close-range pulses related to transmit pulse 2. The distance between pulse 1 and pulse 2 is called the maximum range.

If a large reflective object is very close, the echo may return before the complete pulse can be transmitted. To eliminate ambiguity, the receiver is blocked, or turned off. Blocking of the receiver during the transmit cycle is common in most Basic Radar System Block Diagram.

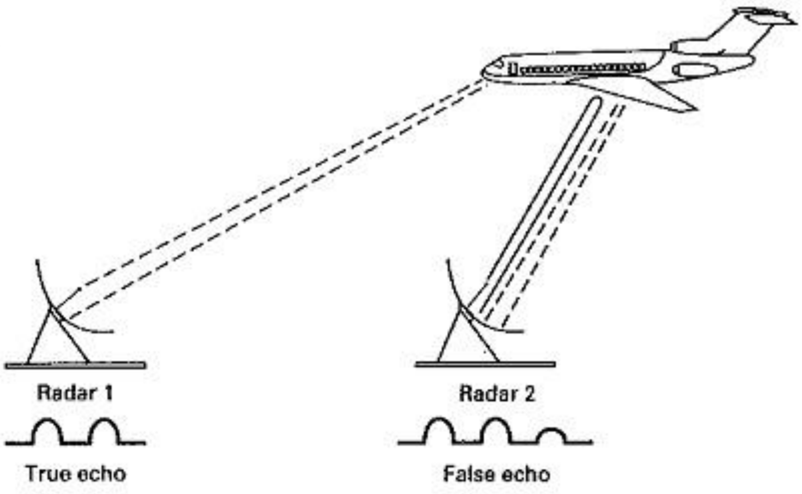


FIGURE 16-3 Double-range echoes.

A second problem arises-with large objects at close range. The transmitted pulse may be reflected by the target for one complete round trip (see Figure 16-3). It may then, because of its high energy level, be reflected by the transmitter antenna and bounced back to the target for a second round trip. This condition is called double range echoes. To overcome this form of ambiguity, Equation (16-4) is used to determine the minimum-effective range.

$$\text{Minimum range} = 164\ \text{PW} \qquad (16\text{-}4)$$

Range = yards
PW = μs

Other terms sometimes discussed in conjunction with the radar transmitter are duty cycle, peak power, and average power. To calculate duty cycle the following equation may be employed.

$$\text{Duty cycle} = \frac{\text{PW}}{\text{PRT}} \qquad (16\text{-}5)$$

The ratio of peak power and average may also be expressed in terms of “duty cycle.”

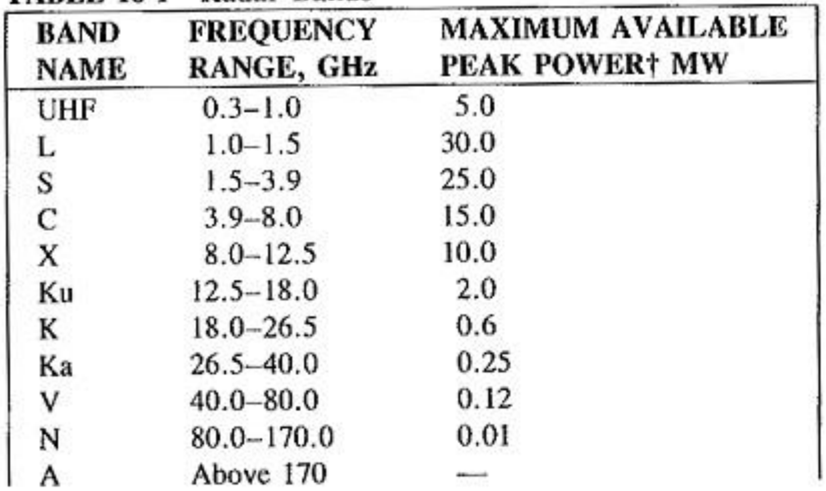
To complete this section on fundamentals, we can conclude that in order to produce, a strong echo over a maximum range, high peak power is required. In some situations, size and heat are important factors (radar in aircraft) and low average power is a requirement. We can easily see how low duty cycle is an important consideration.

Commenting briefly on the other aspects of the radar set, we find that pulse-modulated magnetrons, klystrons, TWTs or CFAs are normally used as transmitter output tubes, and the first stage of the receiver is often a diode mixer. The antenna generally uses a parabolic reflector of some form.

Frequencies and Powers used in Radar:

The frequencies employed by Basic Radar System Block Diagram lie in the upper UHF and microwave ranges. As a result of wartime security, names grew up for the various frequency ranges, or bands, and these are still being used. One such term has already been discussed (the X band), and the others will now be identified. Since there is not a worldwide agreement on radar band nomenclature, the names used in Table 16-1 are the common American designations.

TABLE 16-1 Radar Bands



BAND NAME	FREQUENCY RANGE, GHz	MAXIMUM AVAILABLE PEAK POWER† MW
UHF	0.3–1.0	5.0
L	1.0–1.5	30.0
S	1.5–3.9	25.0
C	3.9–8.0	15.0
X	8.0–12.5	10.0
Ku	12.5–18.0	2.0
K	18.0–26.5	0.6
Ka	26.5–40.0	0.25
V	40.0–80.0	0.12
N	80.0–170.0	0.01
A	Above 170	—

Doppler Effect in Radar:

The apparent frequency of electromagnetic or sound waves depends on the relative radial motion of the source and the observer. If source and observer are moving away from each other, the apparent frequency will decrease, while if they are moving toward each other, the apparent frequency will increase. This was postulated in 1842 by Christian Doppler and put on a firm mathematical basis by Armand Fizeau in 1848, The Doppler Effect in Radar is observable for light and is responsible for the so-called **red shift** of the spectral lines from stellar objects moving away from the solar system. It is equally noticeable for sound, being the cause of the change in the pitch of a whistle from a passing train. It can also be used to advantage in several forms of radar.

Consider an observer situated on a platform approaching a fixed source of radiation, with a relative velocity $+v_r$. A stationary observer would note f_t wave crests (or troughs) per second if the transmitting frequency were f_t. Because the observer is moving toward the source, that person of course encounters more than f_t crests per second. The number observed under these conditions is given by

$$f_t + f'_d = f_t\left(1 + \frac{v_r}{v_c}\right) \qquad \textbf{(16-18)}$$

Consequently,

$$f'_d = \frac{f_t v_r}{v_c} \tag{16-19}$$

where

$f_t + f'_d$ = new observed frequency

f'_d = Doppler frequency difference

Note that the foregoing holds if the relative velocity, v_r, is less than about 10 percent of the velocity of light, v_c. If the relative velocity is higher than that (most unlikely in practical cases), relativistic effects must be taken into account, and a somewhat more complex formula must be applied. The principle still holds under those conditions, and it holds equally well if the observer is stationary and the source is in motion. Equation (16-19) was calculated for a positive radial velocity, but if v_r is negative, f'_d in Equation (16-19) merely acquires a negative sign. In radar involving a moving target, the signal undergoes the Doppler shift when impinging upon the target. This target becomes the “source” of the reflected waves, so that we now have a moving source and a stationary observer (the radar receiver). The two are still approaching each other, and so the Doppler Effect in Radar is encountered a second time, and the overall effect is thus double.

Hence the Doppler frequency for radar is

$$\begin{aligned} f_d = 2f'_d &= \frac{2f_t v_r}{v_c} \\ &= \frac{2v_r}{\lambda} \end{aligned} \tag{16-20}$$

since $f_t/v_c = 1/\lambda$, where λ is the transmitted wavelength.

The same magnitude of Doppler shift is observed regardless of whether a target is moving toward the radar or away from it, with a given velocity. However, it will represent an increase in frequency in the former case and .a reduction in the latter. Note also that the Doppler Effect in Radar is observed only for radial motion, not for tangential motion. Thus no Doppler Effect in Radar will be noticed if a target moves across the field of view of a radar.

However, a Doppler shift will be apparent if the target is rotating, and the resolution of the radar is sufficient to distinguish its leading edge from its trailing edge. One example where this has been employed is the measurement of the rotation of the planet Venus (whose rotation cannot be observed by optical telescope because of the very dense cloud cover).

On the basis of this frequency change, it is possible to determine the relative velocity of the target, with either pulsed or CW radar, as will be shown. One can also distinguish between stationary and moving targets and eliminate the blips due to stationary targets. This may be done with pulsed radar by using moving-target indication.

Pulsed Radar System Block Diagram:

A very Pulsed Radar System Block Diagram set was shown in Figure 16-1. A more detailed block diagram will now be given, and it will then be possible to compare some of the circuits used with those treated in other contexts and to discuss in detail those circuits peculiar to radar.

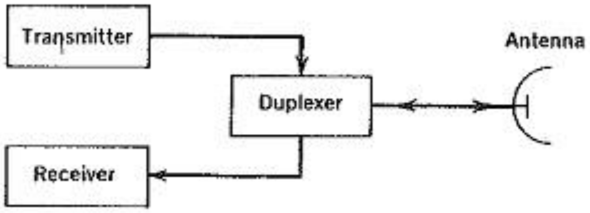


FIGURE 16-1 Block diagram of an elementary pulsed radar.

Block diagram and description:

The block diagram of Figure 16-4 shows the arrangement of a typical high-power Pulsed Radar System Block Diagram. The trigger source provides pulses for the modulator. The modulator provides rectangular voltage pulses used as the supply voltage for the output tube, switching it ON and OFF as required. This tube may be a magnetron oscillator or an amplifier such as the klystron, traveling-wave tube or crossed-field amplifier, depending on specific requirements. If an amplifier is used, a source of microwaves is also required. While an amplifier may be modulated at a special grid, the magnetron cannot. If the radar is a low-powered one, it may use IMPATT or Gunn oscillators, or TRAPATT amplifiers. Below C band, power transistor amplifiers or oscillators may also be used. Finally, the transmitter portion of the radar is terminated with the duplexer, which passes the output pulse to the antenna for transmission.

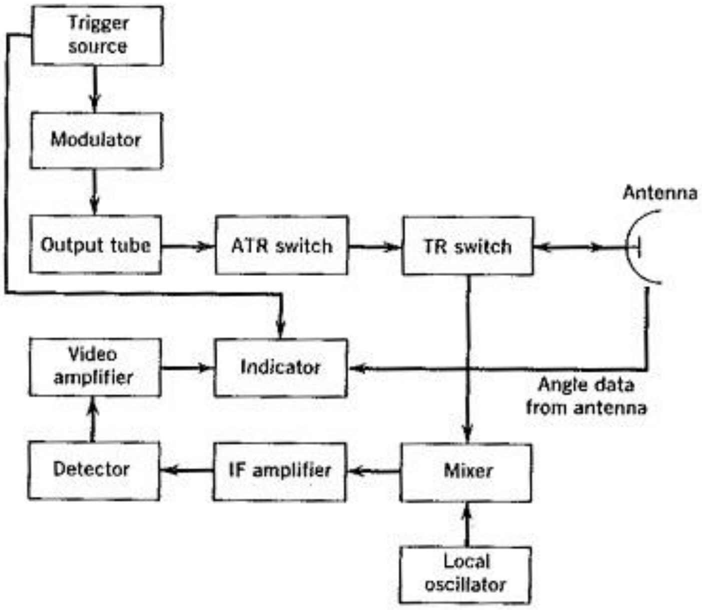


FIGURE 16-4 Pulsed radar block diagram.

The receiver is connected to the antenna at suitable times in the Pulsed Radar System Block Diagram (i.e., when no transmission is instantaneously taking place). As previously explained, this is also done by the duplexer. As shown here, a (semiconductor diode) mixer is the most likely first stage in the receiver, since it has a fairly low noise figure, but of course it shows a conversion loss. An RF amplifier can also be used, and this would most likely be a transistor or IC, or perhaps a tunnel diode or paramp. A better noise figure is thus obtained, and the RF amplifier may have the further advantage of saturating for large signals, thus acting as a limiter that prevents mixer diode burnout from strong echoes produced by nearby targets. The main receiver gain is provided at an intermediate frequency that is typically 30 or 60 MHz. However, it may take two or more down-conversions to reach that IF from the initial microwave RF, to ensure adequate image frequency suppression.

If a diode mixer is the first stage, the (first) IF amplifier must be designed as a low-noise stage to ensure that the overall noise figure of the receiver does not deteriorate. A noisy IF amplifier would play havoc with the overall receiver performance, especially when it is noted that the “gain” of a diode mixer is in fact a conversion loss, typically 4 to 7 dB. A cascode connection is quite common for the transistor amplifiers used in the IF stage, because it removes the need for **Neutralization** to avoid the **Miller effect**.

Another source of noise in the receiver of Figure 16-4 may be the local oscillator, especially for microwave radar receivers. One of the methods of reducing such noise is to use a varactor or step-recovery diode multiplier. Another method involves the connection of a narrowband filter between the local oscillator and the mixer to reduce the noise bandwidth of the mixer. However, in receivers employing automatic frequency correction this may be unsatisfactory. The solution of the oscillator noise problem may then lie in using a balanced mixer and/or a cavity-stabilized oscillator. If used, AFC may simply consist of a phase discriminator which takes part of the output from the IF amplifier and produces a dc correcting voltage if the intermediate frequency drifts. The voltage may then be applied directly to a varactor in a diode oscillator cavity.

The IF amplifier is broadband, to permit the use of fairly narrow pulses. This means that cascaded rather than single-stage amplifiers are used. These can be synchronous, that is, all tuned to the same frequency and having identical bandpass characteristics. If a really large bandwidth is needed, the individual IF amplifiers may be stagger-tuned. The overall response is achieved by overlapping the responses of the individual amplifiers, which are tuned to nearby frequencies on either side of the center frequency. The detector is often a Schottky-barrier diode, whose output is amplified by a video amplifier having the same bandwidth as the IF amplifier. Its output is then fed to a display unit, directly or via computer processing and enhancing.

Modulators:

In a Pulsed Radar System Block Diagram transmitter, the modulator is a circuit or group of circuits whose function it is to switch the output tube ON and OFF as required. There are two main types in common use: **Line-Pulsing Modulators** and **Active-Switch Modulators**. The latter are also known as **Driver-Power-Amplifier Modulators** and were called **Hard-Tube Modulators** until the advent of semiconductor devices capable of handling some modulator duties.

The line-pulsing modulator corresponds broadly to the high-level modulator. Here the anode of the output tube (or its collector, depending on the tube used) is modulated directly by a system that generates and provides large pulses of supply voltage. This is achieved by slowly charging and then rapidly discharging a transmission line. The charging is made slow to reduce the current requirements and is generally done through an inductance. The transmission line is able to store energy in its distributed inductance and capacitance. If the line is charged to a voltage V from a high-impedance source, this voltage will drop to 1/2V when a load is connected (the output tube) whose impedance is equal to the characteristic impedance of the line. However, at the instant of load connection the voltage across the line is 1/2V only at the input; it is still V everywhere else. The voltage drop now propagates along the line to the far end, from which it is reflected to the input terminals. It is thus seen that a voltage 1/2V will be maintained across the load for a time 2t, where t is the time taken by an electromagnetic wave to travel from one end of the line to the other.

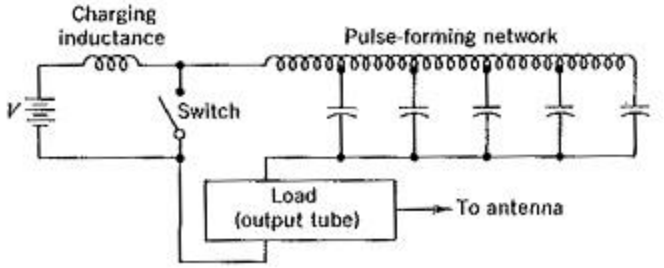


FIGURE 16-5 Simple line-pulser using a pulse-forming network.

If the pulse duration (2t) is to be 1 µs, the line length must be 150 m. This is far too long for convenience, and consequently a **Pulse Forming Network** (PFN) is almost always substituted for the transmission line. As shown in Figure 16-5, which illustrates a very basic modulator, the PFN looks just like the equivalent circuit of a transmission line. It also behaves identically to the transmission line for frequencies below $f = 1/\pi\sqrt{LC}$, where L and C are the inductance and capacitance, respectively, per section. In high-power radars, the device most likely for use as a switch is a hydrogen thyratron, because it is capable of switching very high powers and of rapid deionization. **Silicon-Controlled Rectifiers** (SCRs) may also be used to good advantage.

The advantages of the line modulator are that it is simple, compact, reliable and efficient. However, it has the disadvantage that the PFN must be changed if a different pulse length is required. Consequently, line modulators are not used at all in radars from which variable pulse widths are required, but they are often used otherwise. The Pulsed Radar System Block Diagram that are produced have adequately steep sides and flat tops.

The active-switch modulator is one that can also provide high-level modulation of the output tube, but this time the pulses are generated at a low power level and then amplified. The driver is often a blocking oscillator, triggered by a timing source and driving an amplifier. Depending on the power level, this may be a transistor amplifier or a powerful tube such as a shielded-grid triode. The amplifier then controls the dc power supply for the output RF tube. This type of modulator is less efficient, more complex and bulkier than the line modulator, but it does have the advantage of easily variable pulse length, repetition rate or even shape. It is often used in practice.

Finally, low-level modulation is also sometimes possible. This may be done in UHF radar, which uses orthodox vacuum tubes, or at higher frequencies if a velocity-modulated amplifier is used.