

**Keywords.** Noise, Signal-to-noise ratio, PPI, Pulse radar

## 2.3 Radar Block Diagram and Operation

The block diagram given below (Fig. 2.5) shows the main components of pulse radar and their operation. The transmitter may be an oscillator, such as a magnetron, which is pulsed (turned on and off) by the modulator to generate a repetitive train of pulses of the kind shown in Fig.2.1. The waveform generated by the transmitter travels along a transmission line to the antenna, which is generally used for both transmitting and receiving. The duplexer consists of two devices, one known as TR (Transmit-Receive) and the other as ATR (Anti-Transmit-Receive). The TR protects the delicate circuits of the receiver from the high power of the transmitter during transmission and the ATR channels the returned echo signal to the receiver, and not to the transmitter, during reception. The first stage of the receiver is a low-noise RF (radio frequency) amplifier. The mixer and the local oscillator convert the RF signal to an IF (intermediate frequency) signal. This signal is passed through an IF amplifier which is designed to maximize the signal-to-noise ratio at its output. The pulse modulation of the echo signal is extracted by the detector and amplified by the video amplifier to a level at which the signal can be properly displayed on a CRT (Cathode Ray Tube). Timing signals are also supplied for range reference. Angle information is obtained from the pointing direction of the antenna.

The most common form of the CRT display is the PPI (Plan Position Indicator), which maps (in polar coordinates) the location of the target in azimuth and range. This is an intensity-modulated display in which the amplitude of the receiver output modulates the electron-beam intensity as the electron beam is made to sweep outward from the center of the tube. The beam rotates in angle in response to the antenna position.

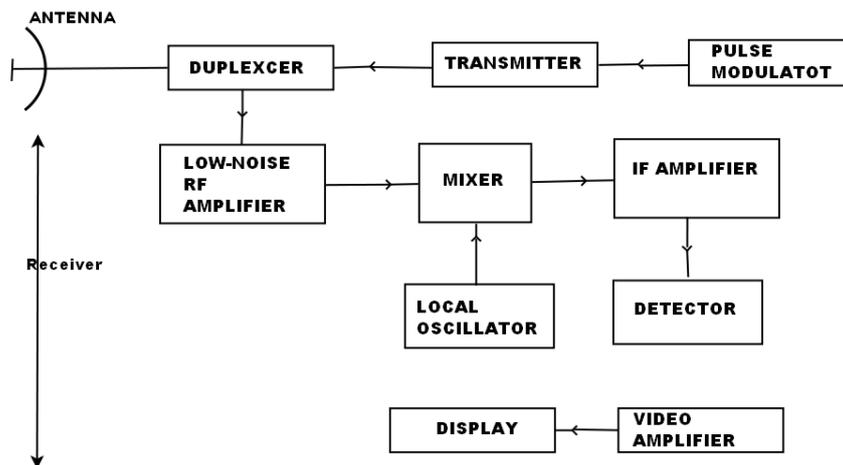


Figure 2.5: Block diagram of a pulse radar

A B-scope display is similar to the PPI except that it utilizes rectangular, rather than polar, coordinates and displays range vs. angle. Both the B-scope and the PPI, being intensity modulated, have limited dynamic range. (see figures in Skolnik's book)

Another form of display is the A-scope display, which plots target amplitude vs. range, for some fixed direction. This is a deflection-modulated display. It is more suited for tracking radar application than for surveillance radars.

The block diagram in Fig.2.5 is a simplified version which omits many im-

portant details like devices which automatically compensate the receiver for changes in frequency (AFC - Automatic Frequency Controller), gain (AGC - Automatic Gain Controller), receiver circuits for reducing interference from other radars and from unwanted signals, rotary joints in the transmission lines to allow movement of the antenna, circuitry for discriminating between moving targets and unwanted stationary objects, and pulse compression for achieving the resolution benefits of a short pulse but with the energy of a large pulse. Similarly, there are many other devices, used according to requirement, which have not been discussed here.

## 2.4 Radar Frequencies

Conventionally, radars are usually operated at frequencies between 220 MHz and 35 GHz, a spread of more than 7 octaves. However, they can also be operated at other frequencies outside this range. For example, skywave HF over-the-horizon (OTH) radars might operate at frequencies as low as 4 to 5 MHz and ground wave F radars as low as 2 MHz. Millimeter wave radars may operate at 94 GHz. Laser radars have been known to operate at even higher frequencies (Refer to Skolnik, pages 7-8, for details).

## 2.5 Applications of Radars

On ground : Detection, location, and tracking of aircraft and space targets.

In the air : Detection of other aircraft, ships, or land vehicles; mapping of land; storm avoidance, terrain avoidance, and navigation.

On the sea : Navigation aid and safety device to locate buoys, shore lines, other ships, and for observation of aircraft.

In space : Guidance of spacecraft; remote sensing of land and sea.

Some specific applications are as follows:

Air traffic control : Controlling of air traffic in the vicinity of airports; and also for automated landing.

Aircraft navigation : Weather avoidance to indicate regions of severe precipitation; terrain following/terrain avoidance (TF/TA); radio altimeter and doppler navigator are also radars.

Ship safety : Collision avoidance; detection of navigation buoys.

Space : Rendezvous and docking; landing on the moon and other planets; detection and tracking of satellites.

Remote sensing: Sensing of geophysical object, or the "environment" like weather, cloud cover, earth resources, water resources, agriculture, forests, geological formation, etc. This is usually done from aircraft or satellites.

Law enforcement : To monitor speed of vehicles in traffic.

Military : Surveillance and navigation; control and guidance of weapons. The largest use of radars occurs here.

## 2.6 Range Performance of Radars

In Section 2.2 we had derived the maximum range  $R_{max}$  (in meters) of a radar as,

$$R_{max} = \left[ \frac{P_t G A_e \sigma}{(4\pi)^2 S_{min}} \right]^{1/4} \quad (2.31)$$

where,  $P_t$  = Transmitted power, in watts,

$G$  = Antenna gain,

$A_e$  = Antenna effective aperture, in  $m^2$ .

$\sigma$  = Radar cross-section of the target, in  $m^2$ .

$S_{min}$  = Minimum detectable signal, in watts.

All the above parameters, except  $\sigma$ , are to some extent under the control of the radar designer.

In practice, the simple radar equation does not predict the range performance of actual radar equipments to a satisfactory degree of accuracy. In many cases the actual range might be half of that predicted by the above equation. Some of the major reasons for this are the following:

- Failure of the equation to explicitly include various losses that can occur throughout the system.
- Loss of performance usually experienced when electronic equipment are operated in the field, as against when they are operated under laboratory conditions.
- Statistical and unpredictable nature of the various parameters in the radar equation.

Both  $S_{min}$  and  $\sigma$  are statistical in nature and must be expressed as such in statistical terms. other statistical factors which affect radar performance are meteorological conditions along the propagation path and performance of the radar operator, if one is employed.

In view of the above, specification of radar range is usually given as the probability that the radar will detect a certain type of target at a particular range.

## 2.7 Minimum Detectable Signal

The ability of a radar receiver to detect a weak echo signal is limited by the noise energy occupying the portion of the frequency spectrum which is also occupied by the signal energy. The weakest signal the receiver can detect is  $S_{min}$  (minimum detectable signal). But the specification of the minimum detectable signal is usually difficult because of the presence of noise and because the criterion for deciding whether a target is present or not may not be too well-defined.

Detection is usually done by specifying a threshold at the output of the receiver. If the signal exceeds this threshold then a target is assumed to be present. This is known as threshold detection. Consider Fig. 2.6 below which shows the output of a typical radar receiver on an A-scope display.

Here the signal at A (see Fig.2.6) crosses the threshold level and indicates the presence of a target. Obviously, too high a threshold level might cause a signal to be missed and too low a threshold level might produce spurious signals due to noise. It ought to be noted that noise sometimes has a beneficial effect since it enhances some weak signals so that they cross the threshold (as in the case of the signal at B in Fig.2.6).

The harmful effect of noise arises from the fact that the threshold level has to be raised to avoid spurious signals, thus causing nondetection of signal which might have been otherwise detected. The signal at C (Fig.2.6) illustrates this point. If the threshold level had been lower the receiver would have detected the signal.

Thus, the choice of threshold level is a compromise between the importance given to

- Probability of missing a signal

- Probability of a false alarm.

The Signal-to-Noise Ratio (SNR) necessary to provide adequate detection is one of the important parameters that must be determined in order to compute the minimum detectable signal. Although the detection decision is made based on the output of the video, it is easier to maximize the SNR at the output of the IF (Intermediate Frequency) amplifier. It has been proved that maximizing SNR at the output of IF amplifier is equivalent to maximizing the video output.

## 2.8 Noise

Noise is unwanted electromagnetic energy which interferes with the ability of the receiver to detect the desired signal. It may originate within the receiver itself, or it may enter via the receiving antenna along with the desired signal. If the radar were to operate in a perfectly noise-free environment so that no external sources of noise accompanied the desired signal, and if the receiver itself were so perfect that it did not generate any excess noise, there would still exist an unavoidable component of noise generated by the thermal motion of the conduction electrons in the ohmic portions of the receiver input stages. this is called thermal noise, or Johnson noise, and is directly proportional to the temperature of the ohmic portions of the circuit, and also to the receiver bandwidth.

In fig.2.7 we show some of the parameters used to determine the effect of noise on threshold detection. Probability of false alarm is the probability that noise will cross the threshold. The average time interval between crossings of the threshold by noise alone is defined as the false alarm time  $T_{fa}$ ,

and is given by

$$T_{fa} = \lim_{N \rightarrow \infty} \left( \frac{1}{N} \right) \sum_{k=1}^N T_k \quad (2.32)$$

where,  $T_k$  is the time between crossings of the threshold  $V_T$  by the noise envelope. Usually the time between peaks is taken, or one may take the time between two crossings when the slope is positive. The false alarm probability, denoted by  $P_{fa}$ , may be defined as the ratio of the duration of time the envelope is actually above the threshold to the total time it could have been above the threshold.

$$P_{fa} = \frac{\sum_{k=1}^N t_k}{\sum_{k=1}^N T_k} = \frac{\langle t_k \rangle_{av}}{\langle T_k \rangle_{av}} = \frac{1}{T_{fa} B} \quad (2.33)$$

EXAMPLE 2.3 : The noise profile in a threshold detector, when displayed on an A-scope, reveals the following information recorded over a period of time from 0 to 90 secs.

A → 2 6 12 14 17 29 35 40 48 50 62 68 73 79 86  
 B → 10 9 8 12 5 6 10 3 4 8 2 11 9 13 7

where, A=time in sec at which the noise amplitude crosses the threshold with positive slope, and B=time duration in msec for which the noise remains above the threshold. Find the approximate value of the probability of false alarm based on the above data.

ANSWER

From Eqn. (2.17) we can rewrite the probability of false alarm as

$$P_{fa} = \frac{\text{signal is above the threshold}}{\text{Total time duration of the experiment}} \quad (2.34)$$

$$= \frac{117 \times 10^{-3}}{90} = 1.3 \times 10^{-3} \quad (2.35)$$

Since the average duration of the noise pulse is approximately the reciprocal of the bandwidth  $B$ , which in the case of the envelope detector is  $B_{IF}$ , and since

$$P_{fa} = \exp\left[\frac{-V_T^2}{2\psi_0}\right] \quad (2.36)$$

Which is derived from the Rayleigh probability density function, we have

$$T_{fa} = \frac{1}{B_{IF}} \exp\left[\frac{V_T^2}{2\psi_0}\right] \quad (2.37)$$

where,  $\psi_0$  is the variance or the mean square value of the noise voltage.

### PROBLEMS AND EXERCISES

1. If all targets are known to be within a distance of 75 km from a certain radar then what is the maximum pulse repetition frequency which will not cause ambiguities in range measurement? What is the maximum expected time difference between transmitting a signal and receiving its echo?

2. Consider a radar with antenna gain of 4000 and radiated power 90 Mw. The wavelength of the transmitted energy is 0.05m and the minimum detectable signal is  $10^{14}$  watts. If an object is located 150 kms from the radar, what should be the minimum radar cross-section of this object for detection to be possible? for this kind of object what is the factor of reduction of the received power with respect to the transmitted power?

3. Consider a radar with a maximum range of 200 kms. Suppose due to some modifications made in the system components.

(i) the wavelength of the transmitted energy doubles while the antenna gain become half.

(ii) the antenna effective aperture becomes half while the antenna gain triples.

(iii) the antenna effective aperture doubles while the wavelength of the transmitted energy remains constant. Find the new radar range in all the three cases.

4. In Example 2.3 plot the probability of false alarm against the number of samples. Can you comment on whether the number of samples considered is adequate or not?

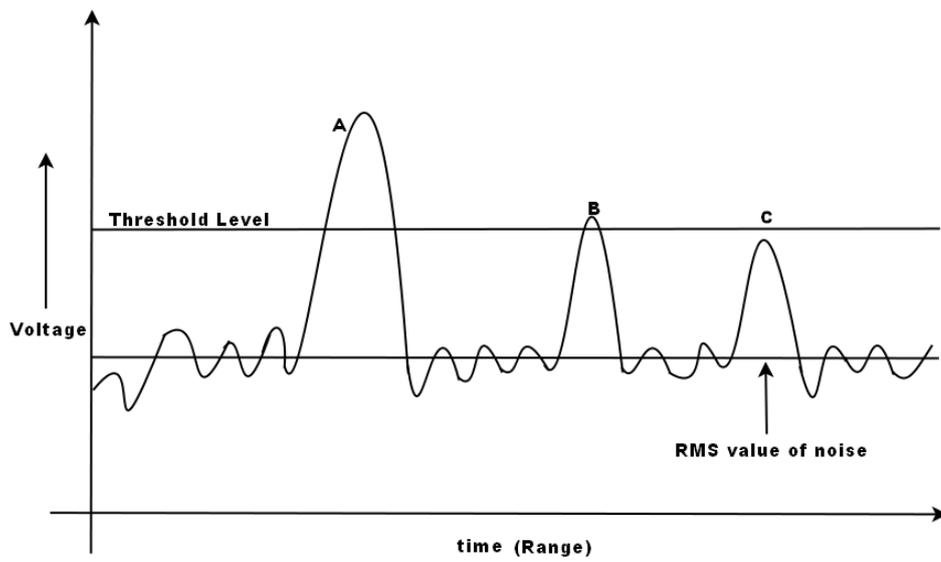


Figure 2.6: Output of a typical radar receiver on an A-scope display

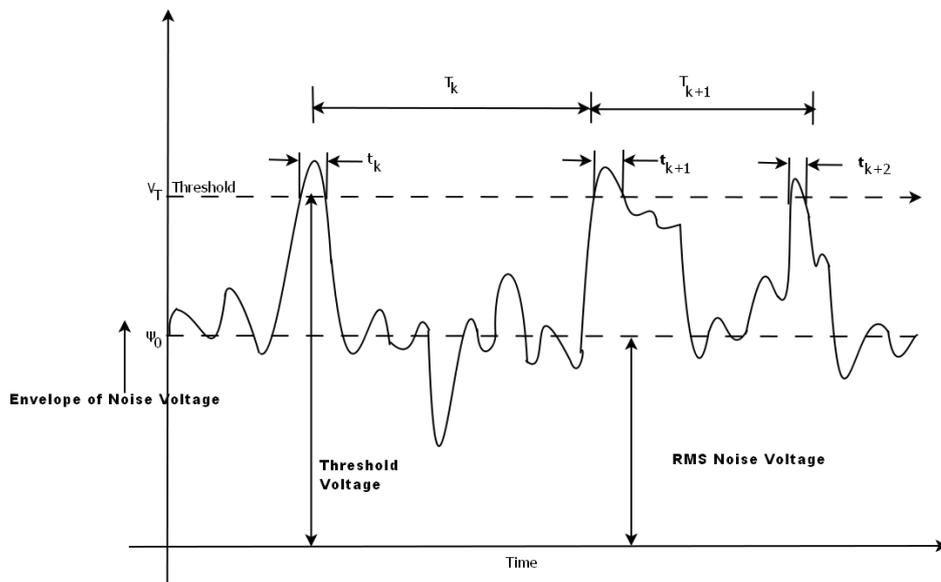


Figure 2.7: Receiver output illustrating false alarm due to noise