UNIT-VIII

RADAR RECEIVERS

8.1 Noise Figure

The noise figure of a receiver can be described as a measure of the noise produced by a practical receiver as compared with the noise of an ideal receiver. The noise figure F_n, of a linear network may be defined as

$$F_n = \frac{S_{in}/N_{in}}{S_{out}/N_{out}} = \frac{N_{out}}{kT_0 B_n G} \qquad 8.1$$

where
S_{in} = available input signal power
N_{in} = available input noise power (equal to kT_oB,)
S_{out} = available output signal power
N_{out} = available output noise power
$G = S_{out}/S_{in}$

"Available power" refers to the power which would be delivered to a matched load. The available gain G is equal to S_{out}/S_{in}, **k** = Boltzmann's constant = 1.38 x 10^{-23} J/deg, T_o = standard temperature of 290 K (approximately room temperature) and B_n, is the noise bandwidth . The product kT_o = 4 x 10^{-21} W/Hz**.** The purpose for defining a standard temperature is to refer any measurements to a common basis of comparison. Equation (9.1) permits two different but equivalent interpretations of noise figure**.** It may be considered as the degradation of the signal-to-noise ratio caused by the network (receiver), or it may be interpreted as the ratio of the actual available output noise power to the noise power which would be available if the network merely amplified the thermal noise. The noise figure may also be written

$$F_n = \frac{kT_0 B_n G + \Delta N}{kT_0 B_n G} = 1 + \frac{\Delta N}{kT_0 B_n G} \qquad 8.2$$

where ΔN is the additional noise introduced by the network itself. The noise figure is commonly expressed in decibels, that is, **10** log F_n. The term noise factor is also used at times instead of noise figure. The two terms are now synonymous.

The definition of noise figure assumes the input and output of the network are matched. In some devices, less noise is obtained under mismatched, rather than matched, conditions. In spite of definitions, such networks would be operated so as to achieve the maximum output signal-to-noise ratio.

$$\triangle N = (F_n - 1)\, kT_o B_n G$$

8.1.1. Noise figure of networks in cascade

Consider two networks in cascade, each with the same noise bandwidth Bn, but with different noise figures and available gain (Fig. 8.1). Let F_1 , G_1 be the noise figure and available gain, respectively, of the first network, and F_2 , G_2 be similar parameters for the second network. The problem is to find F_o the overall noise-figure of the two circuits in cascade. From the definition of noise figure [Eq. (9.1)] the output noise N_o of the two circuits in cascade is

$$N_o = F_o G_1 G_2 k T_0 B_n = \text{noise from network 1 at output of network 2} + \text{noise } \Delta N_2 \text{ introduced by network 2} \quad 8.3a$$

$$N_o = k T_0 B_n F_1 G_1 G_2 + \Delta N_2 = k T_0 B_n F_1 G_1 G_2 + (F_2 - 1) k T_0 B_n G_2 \quad 8.3b$$

Or

$$F_o = F_1 + \frac{F_2 - 1}{G_1} \quad 8.4$$

The noise figure of ***N*** networks in cascade may be shown to be

$$F_o = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \cdots + \frac{F_N - 1}{G_1 G_2 \cdots G_{N-1}} \quad 8.5$$

Similar expressions may be derived when bandwidths and/or the temperature of the individual networks are not the same.

8.1.2. Noise temperature

The noise introduced by a network may also be expressed as an ***effective Noise Temperature*** T_e, defined as that (fictional) temperature at the input of the network which would account for the noise ▲N at the output. Therefore ▲N = kT_eB_n G and

$$F_n = 1 + \frac{T_e}{T_0} \quad (8.6)$$

$$T_e = (F_n - 1) T_0 \quad (8.7)$$

The S***ystem noise temperature*** T_s, is defined as the effective noise temperature of the receiver system including the effects of antenna temperature T_a (It is also sometimes called the system operating noise temperature) if the receiver effective noise temperature is T_e, then

$$T_s = T_a + T_e = T_0 F_s \quad (8.8)$$

where F_s is the system noise-figure including the effect of antenna temperature.

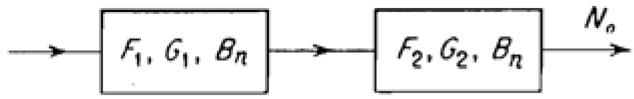

Fig8.1: Two Networks in cascade

The effective noise temperature of a receiver consisting of a number of networks in cascade is

$$T_e = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \cdots \qquad (8.9)$$

Where $\mathbf{T_i}$ and G_i are the effective noise temperature and gain of the i^{th} network. The effective noise temperature and the noise figure both describe the same characteristic of a network. In general, the effective noise temperature has been preferred for describing low-noise devices, and the noise figure is preferred for conventional receivers. For radar receivers the noise figure is the more widely used term, and is what is used in this text.

8.1.3. Measurement of noise figure

The monitoring of the noise figure can be accomplished either automatically or manually by the operator. The receiver noise-figure can be measured with a broadband noise source of known intensity, such as a gas-discharge tube or a solid-state noise source. The noise figure is determined by measuring

(1) The noise power output N_1, of the receiver when a matched impedance at temperature $\boldsymbol{T_o}$ = 290 $\boldsymbol{K}$ is connected to the receiver input and

(2) The noise power output N_2 when a matched noise generator of temperature T_2 is connected to the receiver input. The temperature $\boldsymbol{T_2}$ is the equivalent noise temperature of the broadband noise generator. The noise figure can be shown to be

$$F_n = \frac{T_2/T_0 - 1}{Y - 1} \qquad 8.10$$

where $Y = N_2 / N_l$

The measurement of noise figure can be made during radar operation without degrading the receiver sensitivity by pulse-modulating the noise source in synchronism with the radar trigger and injecting the noise into the receiver during the " flyback " or "dead time" of the radar, just prior to the triggering of the next transmitter pulse. The measurement of the receiver output with the noise source on ***(N_2)*** and the noise source off ***(N_1)*** can be made on alternate pulse periods.

In making a measurement of the receiver noise-figure, the noise source or signal generator is usually inserted by a directional coupler ahead of the duplexer and other RF components so that the overall noise-figure of the system is measured rather than that of the receiver alone.

8.2. Mixers

Many radar super heterodyne receivers do not employ a low-noise RF amplifier. Instead, the first stage is simply the mixer. Although the noise figure of a mixer front-end may not be as low as other devices that can be used as receiver front-ends, it is acceptable for many radar applications when other factors besides low noise are important. The function of the mixer is to convert RF energy to **IF** energy with minimum loss and without spurious responses. Silicon point-contact and Schottky-barrier diode based on the nonlinear resistance characteristic of metal-to-semiconductor contacts have been used as the mixing element. Schottky barrier diodes are made of either silicon or GaAs, with GaAs preferred for the higher microwave frequencies. The Schottky-barrier diodes have had lower noise figures and lower flicker noise than conventional point-contact diodes, but the silicon point-contact diode has better burnout properties. An integral part of the mixer is the local oscillator.

8.2.1. Conversion loss and noise-temperature ratio

The conversion loss L_c of a mixer is defined as

$$L_c = \frac{\text{available RF power}}{\text{available IF power}} \qquad (8.11)$$

It is a measure of the efficiency of the mixer in converting **RF** signal power into **IF.** The conversion loss of typical microwave crystals in a conventional single-ended mixer configuration varies from about 5 to 6.5 dB. A crystal mixer is called "broadband" when the signal and image frequencies are both terminated in matched loads. A signal impressed in the RF signal channel of a broadband mixer is converted in equal portions to the **IF** signal and the RF image. Therefore the theoretical conversion loss can never be less than 3 dB with this configuration. (The image frequency is defined as that frequency which is displaced from the local oscillator frequency $\mathbf{f_{LO}}$ by the IF frequency, and which appears on the opposite side of the local oscillator frequency as the signal frequency $\mathbf{f_{RF}}$. It is equal to 2 $\mathbf{f_{LO}}$ - $\mathbf{f_{RF}}$).

Short-circuiting or open-circuiting the image-frequency termination results in a" narrowband" mixer. The conversion loss is less in the narrowband than in the broadband mixer. In principle, it can be about 2 dB lower. The design of a broadband mixer has been simpler to achieve arid less critical than a narrowband mixer.

8.2.2. Balanced mixers

Noise that accompanies the local-oscillator (LO) signal can appear at the IF frequency because of the nonlinear action of the mixer. The LO noise must be removed if receiver sensitivity is to be maximized. One method for eliminating LO noise that interferes with the desired signal is to insert a narrow-band pass RF filter between the local oscillator and the mixer. The center frequency of the filter is that of the local oscillator, and its bandwidth must be narrow so that LO noise at the signal and the image frequencies do not appear at the mixer. Since the receiver is tuned by changing the LO frequency, the narrowband filter must be tunable also.

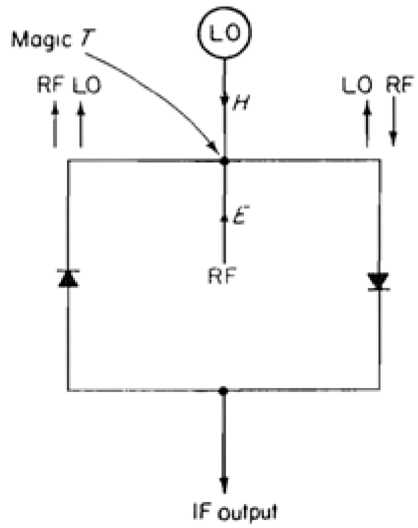

Fig 8.2: Balanced Mixer based on Magic-T

A method of eliminating local-oscillator noise without the disadvantage of a narrow bandwidth filter is the ***balanced mixer*** (Fig. 8.2***).*** A balanced mixer uses a hybrid junction, a magic T, or an equivalent. These are four-port junctions. Figure 8.2 illustrates a magic *T* in which the LO and RF signals are applied to two ports. Diode mixers are in each of the remaining two arms of the magic T. At one of the diodes the sum of the RF and LO signals appears, and at the other diode the difference of the two is obtained. (In a magic ***T*** the LO would be applied to the H-plane arm, and the RF signal would be applied to the E-plane arm. The diode mixers would be mounted at equal distances in each of the collinear arms.) The two diode mixers should have identical characteristics and be well matched. The IF signal is recovered by subtracting the outputs of the two diode mixers. In Fig. 8**.2** the balanced diodes are shown reversed so that the IF outputs can be added. Local-oscillator noise at the two diode mixers will be in phase and will be canceled at the output.

- It is only the AM noise of the local oscillator which is canceled. The FM noise inserted by the local oscillator is unaffected by the balanced mixer.

- **A** balanced mixer suppresses the even harmonics of the LO signal.
- **A** double balanced mixer is basically two single-ended mixers connected in parallel and **180"** out of phase. It suppresses even harmonics of both the RF and the LO signal.

8.2.3. Diode burnout.

A crystal diode which is subjected to excessive RF power may suffer burnout. This is a rather loosely defined term which is applied to any irreversible deterioration in the detection or conversion properties of a crystal diode as the result of electrical overload.

If excessive RF energy is applied to the diode the heat generated cannot **be** dissipated properly and the diode can be damaged. Excessive energy causes the diode to open-circuit or the semiconductor to puncture, resulting in failure of the device.

However, burnout of a diode can occur before the onset of physical destruction. An increase in the receiver noise due to the effects of excessive RF energy can be just as harmful as complete destruction; perhaps more so, for gradual deterioration of performance might not be noticed as readily as would catastrophic failure.

It is for this reason that some means of automatic monitoring of receiver noise-figure is necessary if the radar is to be maintained in prime operating conditions.

One of the causes of diode burnout in radar receivers has been the increased RF leakage through a conventional duplexer due to aging of the TR tube. When the transmitter fires, the TR tube breaks down. A finite time, usually on the order of several nanoseconds, must elapse before breakdown is complete. During this time, RF energy leaks into the receiver. This is called the ***spike-leakage*** energy. From 1 to 10 ergs of spike-leakage energy might be required to burn out microwave crystal diodes. The amount of energy contained within the remainder of the pulse after the initial spike is usually small and is not as serious as spike leakage.

8.3. Low-Noise Front-Ends

There are now a number of RF amplifiers that can provide a suitable noise figure. **Figure 8.4 plots noise figure as a function of frequency for the several receiver front-ends used in radar applications.** The parametric amplifier has the lowest noise figure of those devices described here, especially at the higher microwave frequencies. However, it is generally more complex and expensive compared to the other front -ends.

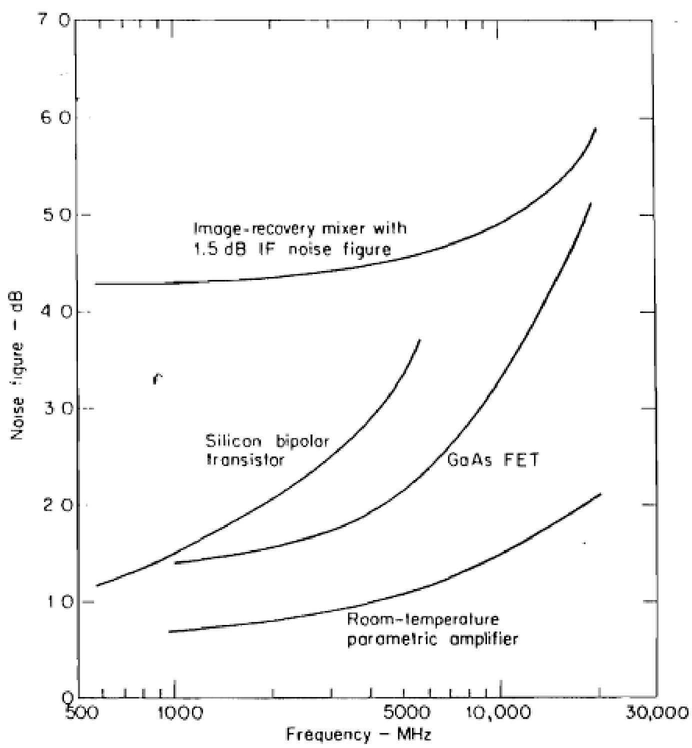

Figure 8.4 plots noise figure as a function of frequency for the several receiver front-ends used in radar applications.

The transistor amplifier can be applied over most of the entire range of frequencies of interest to radar. The silicon bipolar-transistor has been used at the lower radar frequencies (below L band) and Gallium Arsenide field-effect transistor (GaAs FET) is preferred at the higher frequencies. The transistor is generally used in a multistage configuration with a typical gain per stage decreasing from 12 dB at VHF to 6 dB at $\mathbf{K_u}$band." In the GaAs FET, the thermal noise contribution is greater than the shot noise. Cooling the device will therefore improve the noise figure."

The tunnel-diode amplifier has been considered in the past as a low-noise front-end, with noise figures from 4 to 7 dB over the range 2 to 25 GHz." It has been supplanted by the improvements made in the transistor amplifier. The traveling-wave-tube amplifier has also been considered as a low-noise front-end, but it has been overtaken by other devices. Cryogenic parametric amplifiers and masers produce the lowest noise figures, but the added complexity of operating at low temperatures has tempered their use in radar.

There are other factors beside the noise figure which can influence the selection of a receiver front-end. Cost, burnout, and dynamic range must also be considered. The selection of a particular type of receiver front-end might also be influenced by its instantaneous bandwidth, tuning range, phase and amplitude stability, and any special requirements for cooling. The image-recovery mixer represents a practical compromise which tends to balance its slightly greater noise figure by its lower cost, greater ruggedness, and greater dynamic range."

There are, however, limitations to the use of a low-noise front-end in some radar applications.' As mentioned above, the cost, burnout, and dynamic range of low-noise devices might not be acceptable in some applications. Even if the low-noise device itself is of large dynamic range, there can be a reduction of the dynamic range of the receiver as compared to a receiver with a mixer as it's front-end. Dynamic range is usually defined as the ratio of the maximum signal that can be handled to the smallest signal capable of being detected. The smallest signal is the minimum detectable signal as determined by receiver noise, and the maximum signal is that which causes a specified degree of inter-modulation or a specified deviation from linearity (usually 1 dB) of the output-vs.-input curve.

8.4. Radar Displays

The purpose of the display is to visually present in a form suitable for operator interpretation and action the information contained in the radar echo signal. When the display is connected directly to the video output of the receiver, the information displayed is called ***raw video.*** This is the "traditional " type of radar presentation. When the receiver video output is first processed by an automatic detector or automatic detection and tracking processor (ADT), the output displayed is sometimes called ***synthetic video.***

The cathode-ray tube (CRT) has been almost universally used as the radar display. There are two basic cathode-ray tube displays. One is the ***dejection-modulated CRT,*** such as the A-scope, in which a target is indicated by the deflection of the electron beam. The other is the **Intensity modulated CRT**, such as the PPI, in which a target is indicated by intensifying the electron beam and presenting a luminous spot on the face of the CRT. In general, deflection-modulated displays have the advantage of simpler circuits than those of intensity modulated displays, and targets may be more readily discerned in the presence of noise or interference. On the other hand, intensity-modulated displays have the advantage of presenting data in a convenient and easily interpreted form. The deflection of the beam or the appearance of an intensity-modulated spot on a radar display caused by the presence of a target is commonly referred to as a ***blip.***

The focusing and deflection of the electron beam may be accomplished electro-statically, electro-magnetically, or by a combination of the two. Electro-static deflection CRTs use an electric field applied to pairs of deflecting electrodes, or plates, to deflect the electron beam. Such tubes are usually longer than magnetic tubes, but the overall size, weight, and power dissipation are less. Electromagnetic deflection CRTs require magnetic coils, or deflection yokes, positioned around the neck of the tube. They are relatively lossy and require more drive power than electrostatic devices. Deflection-modulated CRTs, such as the A-scope, generally employ electrostatic deflection. Intensity-modulated CRTs, such as the PPI, generally employ electromagnetic deflection. Magnetically focused tubes utilize either an electromagnet or a permanent magnet around the neck of the CRT to provide an axial magnetic field. Magnetic focus generally can provide better resolution, but the spot tends to defocus at the edge of the tube. The CRT display is by no means ideal. It employs a relatively large vacuum tube and the entire display is often big and can be expensive. The cost is not simply the tube itself, which is usually modest, but the various circuits needed to display the desired information and provide the operator with flexibility. The amount of information that can be displayed is limited by the spot size, which in a high-performance display is less than 0.1 percent of the screen diameter." In some high-range-resolution radars, however, the number of resolvable range cells available from the radar might be greater than the number of resolution cells available on the PPI screen. The result is a collapsing loss. Increasing the CRT diameter does not necessarily help, since the spot diameter varies linearly with the screen diameter. Another limitation is the dynamic range, or contrast ratio, of an intensity modulated display which is of the order of 10 dB. This might cause blooming of the display by large targets so as to mask the blips from nearby smaller targets.

The decay of the visual information displayed on the CRT should be long enough to allow the operator not to miss target detections, yet short enough not to allow the information painted on one scan to interfere with the new information entered from the succeeding scan. However, there is usually not sufficient flexibility available to the CRT designer to always obtain the desired phosphor decay characteristics. The brilliance of the initial " flash " from the CRT phosphor may be high, but the afterglow is dim so that it is often necessary to carefully control both the color and the intensity of the ambient lighting to achieve optimum seeing conditions. The conventional CRT usually requires a darkened room or the use of a viewing hood by the operator. In spite of the limitations of the conventional CRT display, it is almost universally used for radar applications. Many of its limitations can be overcome, but sometimes with a sacrifice in some other property.

The ability of an operator to extract information efficiently from a CRT display will depend on such factors as

- the brightness of the display,
- density and character of the background noise,
- pulse repetition rate,
- scan rate of the antenna beam,
- signal clipping,
- decay time of the phosphor,

- length of time of blip exposure,
- blip size,
- viewing distance,
- ambient illumination,
- dark adaptation,
- display size,
- Operator fatigue.

8.4.1. Types of display presentations

The various types of CRT displays which might be used for Surveillance and tracking radars are defined as follows:

A-scope. ***A*** deflection-modulated display in which the vertical deflection is proportional to target echo strength and the horizontal coordinate is proportional to range.

B-scope. An intensity-modulated rectangular display with azimuth angle indicated by the horizontal coordinate and range by the vertical coordinate.

C-scope. An intensity-modulated rectangular display with azimuth angle indicated by the horizontal coordinate and elevation angle by the vertical coordinate.

PPI, or ***Plan Position Indicator*** (also called ***P-scope).*** An intensity-modulated circular display on which echo signals produced from reflecting objects are shown in plan position with range and azimuth angle displayed in polar (rho-theta) coordinates, forming a map-like display. An ***offset,*** or ***off center, PPI*** has the zero position of the time base at a position other than at the center of the display to provide the equivalent of a larger display for a selected portion of the service area. A ***delayed PPI*** is one in which the initiation of the time base is delayed.

CRT screens. A number of different cathode-ray-tube screens are used in radar applications. They differ primarily in their decay times and persistence. The properties of some of the phosphors which have been used in radar CRTs are listed in Table 9.1. The degree of image persistence required in a cathode-ray-tube screen depends upon the application. A long persistence screen such as the PI9 is appropriate for **PPI** presentations where the frame times are on the order of several seconds. On the other hand, where no persistence is needed, as when the frame time is less than the response time of the eye (0.1 s or less), a P1 phosphors might be used. The P1 phosphor is commonly found in most A-scope presentations.

Table 8.1 Radar CRT phosphor characteristics

Phosphor	Fluorescent color	Phosphorescent color	Persistence*
P1	Yellowish green	Yellowish green	Medium
P7	Blue Yellowish	green,	Blue, medium short; yellow, long
P12	Orange	Orange	Long
P13	Reddish orange	Reddish orange	Medium
P14	Purplish blue	Yellowish orange	medium short; yellowish orange,

		Blue,	medium
P17	Blue	Yellow	Blue, short; yellow, long
P19	Orange	Orange	Long
P21	Reddish orange	Reddish orange	Medium
P25	Orange	Orange	Medium
P26	Orange	Orange	Very long
P28	Yellowish green	Yellowish green	Long
P32	Purplish blue	Yellowish green	Long
P3 3	Orange	Orange	Very long
P34	Bluish green	Yellowish green	Very long
P38	Orange	Orange	Very long
P39	Yellowish green	Yellowish green	Long

* Persistence to 10 percent level:
short = 1 to 10 ps;
medium short = 10 ps to I ms;
medium = 1 to 100 ms;
long = 100 ms to 1 **s;**
very long = > 1 s.

8.5. Duplexers and Receiver Protectors

The duplexer is the device that allows a single antenna to serve both the transmitter and the receiver. On transmission it must protect the receiver from burnout or damage, and on reception it must channel the echo signal to the receiver. Duplexers, especially for high-power applications, sometimes employ a form of gas-discharge device. Solid-state devices are also utilized. In a typical duplexer application the transmitter peak power might be a megawatt or more and the maximum safe power that can be tolerated at the receiver might be less than a watt. Therefore, the duplexer must provide, in this example, more than 60 dB of isolation between the transmitter and receiver with only negligible loss of the desired signal. In addition, during the interpulse period or when the radar is shut down, the receiver must be protected from high-power radiation, as from nearby radars, that might enter the radar antenna with less power than that needed to activate the duplexer, but with greater power than can be safely handled by the receiver.

There have been two basic methods employed that allow the use of a common antenna for both transmitting and receiving. The older method is represented by the '**branch-type duplexer'** and the '**balanced duplexer'** which utilize gas TR-tubes for accomplishing the necessary switching actions. The other method uses a ferrite circulator to separate the transmitter and receiver, and a receiver protector consisting of a gas TR-tube and diode limiter.

8.5.1. Branch-type duplexers

The branch-type duplexer, diagrammed in Fig. 8.5 was one of the earliest duplexer configurations employed. It consists of a TR (transmit-receive) switch and an ATR (anti-transmit receive) switch, both of which are gas-discharge tubes. When the transmitter is turned on, the TR and the ATR tubes ionize; that is, they break down, or fire. The TK in the fired condition acts as a short circuit to prevent transmitter power from entering the receiver. Since the TR is located a quarter wavelength from the main transmission line, it appears as a short circuit at the receiver but as an open circuit at the transmission line so that it does not impede the flow of transmitter power. Since the ATR is displaced a quarter wavelength from the main transmission line, the short circuit it produces during the fired condition appears as an open circuit on the transmission line and thus has no effect on transmission.

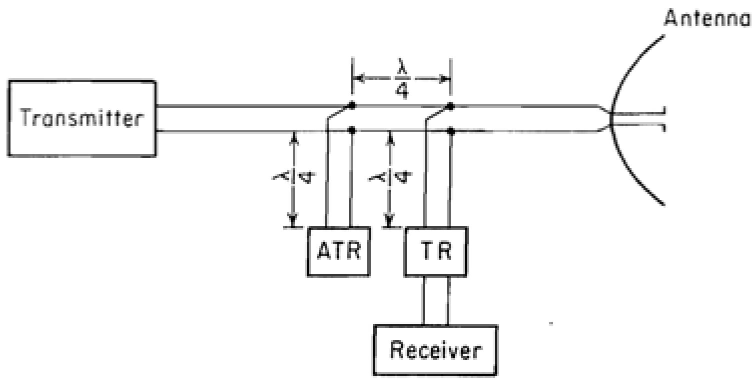

Fig 8.5. Principle of branch type Duplexer

During reception, the transmitter is off and neither the TR nor the ATR is fired. The open circuit of the ATR, being a quarter wave from the transmission line, appears as a short circuit across the line. Since this short circuit is located a quarter wave from the receiver branch-line, the transmitter is effectively disconnected from the line and the echo signal power is directed to the receiver. The diagram of Fig. 8.5 is a parallel configuration. Series or series-parallel configurations are possible. The branch-type duplexer is of limited bandwidth and power-handling capability, and has generally been replaced by the balanced duplexer and other protection devices. It is used, in spite of these limitations, in some low-cost radars.

8.5.2. Balanced duplexers

The balanced duplexer, Fig. 8.6, is based on the short-slot hybrid junction which consists of two sections of waveguides joined along one of their narrow walls with a slot cut in the common narrow wall to provide coupling between the two. The short-slot hybrid may he considered as a broadband directional coupler with a coupling ratio of 3 dB. In the transmit condition (Fig. 8.6a) power is divided equally into each waveguide by the first short slot hybrid junction. Both TR tubes break down and reflect the incident power out the antenna arm as shown. The short-slot hybrid has the property that each time the energy passes through the slot in either direction, its phase is advanced 90". Therefore, the energy must travel as indicated by the solid lines. Any energy which leaks through the TR tubes (shown by the dashed lines) is directed to the arm with the matched dummy load and not to the receiver, In addition to the attenuation provided by the TR tubes, the hybrid junctions provide an additional 20 to 30 dB of isolation.

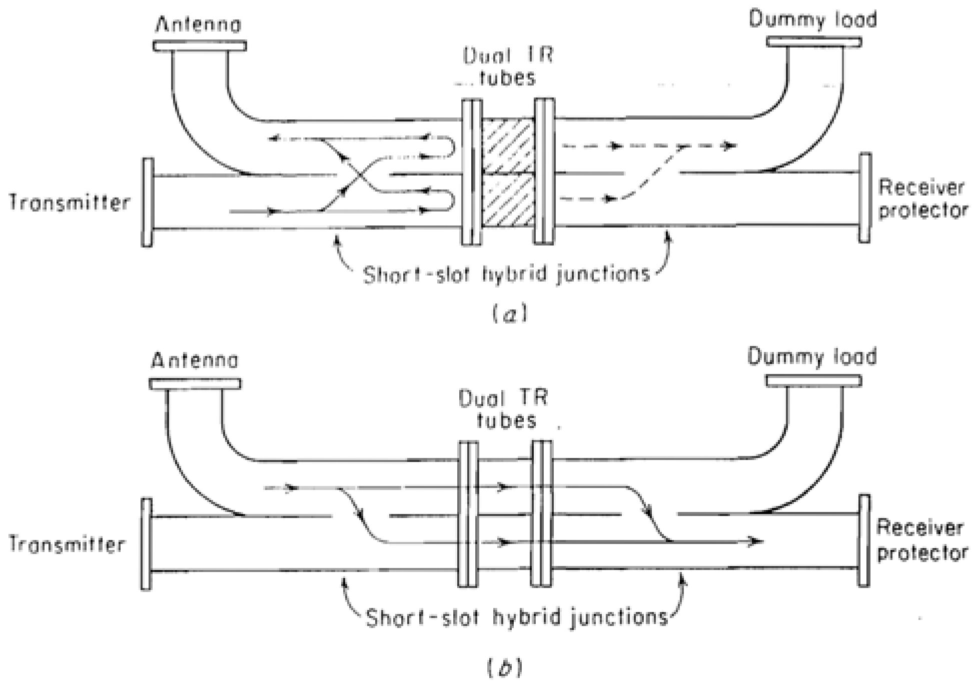

Fig 8.6: Balanced Duplexer using TR tubes and two short-slot junctions. (a) Transmit condition (b) Receive condition

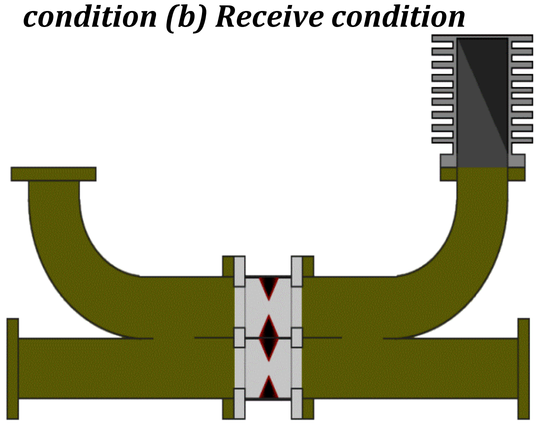

Fig 8.7: Balanced Duplexer using TR tubes and two short-slot junctions, descriptive figure

On reception the TR tubes are unfired and the echo signals pass through the duplexer and into the receiver as shown in Fig. 8.6b. The power splits equally at the first junction and because of the **90"** phase advance on passing through the slot, the energy recombines in the receiving arm and not in the dummy-load arm.

The power-handling capability of the balanced duplexer is inherently greater than that of the branch-type duplexer and it has wide bandwidth, over ten percent with proper design. ***A receiver protector,*** to be described later, is usually inserted between the duplexer and the receiver for added protection.

TR tubes: The TR tube is a gas-discharge device designed to break down and ionize quickly at the onset of high RF power, and to deionize quickly once the power is removed. One common construction of a TR consists of a section of waveguide containing one or more resonant filters and two glass-to-metal windows to seal in the gas at low pressure. A noble gas like argon in the TR tube has a low breakdown voltage, and offers good receiver protection and relatively long life. Pure-argon-filled tubes, however, have relatively long deionization times and are not suitable for short-range applications. The deionization process can be speeded up **by** the addition of water vapor or a halogen. The life of TR tubes filled with a mixture of a noble gas (argon) and a gas with high electron affinity (water vapor) is less than the life of tubes filled with a noble gas only.

Receiver protectors

Since the keep-alive in the TR is not usually energized when the radar is turned off, considerably more power is needed to break down the TR than when it is energized. Radiations from nearby transmitters may therefore damage the receiver without firing the TR. To protect the receiver under these conditions, a mechanical shutter can be used to short circuit the input to the receiver whenever the radar is not operating. The shutter might be designed to attenuate a signal by 25 to 50 dB.

Solid-state limiters. Solid-state PN and PIN diodes can be made to act as RF limiters and are thus of interest as receiver protectors. Ideally, a limiter passes low power without attenuation, but above some threshold it provides attenuation of the signal so as to maintain the output power constant. This property can be used for the protection of radar receivers in two different implementations depending on whether the diodes are operated unbiased (self actuated) or with a d-c forward-bias current. Unbiased operation is also known as ***passive.*** It is used for low-power applications. Biased operation is also known as ***active*** and is capable of switching high power. Biased PIN diodes can replace the gas-tube TRs of the balanced duplexer configuration of Fig. 8.6 or they may be used as receiver protectors.

Passive TR-limiter. The passive diode-limiter also finds important application when used with a radioactive-primed gas tube TR. The combination is known as a ***passive TR-limiter.*** The passive TR-limiter protects the receiver from nearby transmissions even when the radar is shut off since it requires no active voltages for either the radioactive-primed TR tube or the diode limiter. The presence of the diode limiter following the TR tube considerably reduces the spike leakage, increasing the life of the device itself as well as the receiver front-end it is supposed to protect. The passive TR-limiter, however, has a higher insertion loss than the TR tube but it generate no excess noise because it does not employ a keep-alive discharge. Its recovery time is superior to the conventional TR tube, but inferior to the diode limiter acting alone or the ferrite diode limiter.

Ferrite limiter. The ferrite limiter46 followed by a diode limiter, has also been employed as a solid-state receiver protector. The diode is necessary to reduce the spike leakage to a safe level since the ferrite acting alone does not offer sufficient suppression of the spike leakage at high peak power. The ferrite diode limiter has fast recovery time (can be as low as several tens of nanoseconds), and if the power rating is not exceeded, the life should be essentially unlimited.

8.6. Phased Array Antennas

The phased array is a directive antenna made up of individual radiating antennas, or elements, which generate a radiation pattern whose shape and direction is determined by the relative phases and amplitudes of the currents at the individual elements. By properly varying the relative phases it is possible to steer the direction of the radiation. The radiating elements might be dipoles pen-ended waveguides, slots cut in waveguide, or any other type of antenna. The inherent flexibility offered by the phased-array antenna in steering the beam by means of electronic control is what has made it of interest for radar. It has been considered in those radar applications where it is necessary to shift the beam rapidly from one position in space to another, or where it is required to obtain information about many targets at a flexible, rapid data rate. The full potential of a phased-array antenna requires the use of a computer that can determine in real time, on the basis of the actual operational situation, how best to use the capabilities offered by the array.

8.6.1. Basic Concepts of Phased Array Antennas

An array antenna consists of a number of individual radiating elements suitably spaced with respect to one another. The relative amplitude and phase of the signals applied to each of the elements are controlled to obtain the desired radiation pattern from the combined action of all the elements. Two common geometrical forms of array antennas of interest in radar are the linear array and the planar array.

(a **A** linear array consists of elements arranged in a straight line in one dimension.

(b) Planar array is a two-dimensional configuration of elements arranged to lie in a plane. The planar array may be thought of as a linear array of linear arrays.

© **A** ‘broadside’ array is one in which the direction of maximum radiation is perpendicular, or almost perpendicular to the line (or plane) of the array.

(d) An ‘endfire’ array has its maximum radiation parallel to the array.

The linear array generates a fan beam when the phase relationships are such that the radiation is perpendicular to the array. When the radiation is at some angle other than broadside the radiation pattern is a conical-shaped beam. The broadside linear-array antenna may be used where broad coverage in one plane and narrow beam width in the orthogonal plane are desired. The linear array can also act as a feed for a parabolic-cylinder antenna. The combination of the linear-array feed and the parabolic cylinder generates a more controlled fan beam than is possible with either a simple linear array or with a section of a parabola. The combination of a linear array and parabolic cylinder can also generate a pencil beam.

The endfire array is a special case of the linear or the planar array when the beam is directed along the array. Endfire linear arrays have not been widely used in radar applications. The two-dimensional planar array is probably the array of most interest in radar applications since it is fundamentally the most versatile of all radar antennas. An array whose elements are distributed on a non-planar surface is called a *conformal array.*

An array in which the relative phase shift between elements is controlled by electronic devices is called an *electronically scanned array.* In an electronically scanned array the antenna elements, the transmitters, the receivers, and the data-processing portions of the radar are often designed as a unit.

8.6.2. Radiation pattern.

Consider a linear array made up of N elements equally spaced a distance ***d*** apart (Fig. 8.8). The elements are assumed to be isotropic point sources radiating uniformly in all directions with equal amplitude and phase. The array is shown as a receiving antenna for convenience, but because of the reciprocity principle, the results obtained apply equally well to a transmitting antenna. The outputs of all the elements are summed via lines of equal length to give a sum output voltage *E,* Element 1 will be taken as the reference signal with zero phase. The difference in the phase of the signals in adjacent elements is $\Psi = 2\pi(d/\lambda)\sin\theta$, where θ is the direction of the incoming radiation. It is further assumed that the amplitudes and phases of the signals at each element are weighted uniformly. Therefore the amplitudes of the voltages in each element are the same and, for convenience, will be taken to be unity. The sum of all the voltages from the individual elements, when the phase difference between adjacent elements is Ψ, can be written

$$E_a = \sin \omega t + \sin(\omega t + \psi) + \sin(\omega t + 2\psi) + \cdots + \sin[\omega t + (N-1)\psi] \qquad (8.1)$$

where ω is the angular frequency of the signal. The sum can be written

$$E_a = \sin\left[\omega t + (N-1)\frac{\psi}{2}\right]\frac{\sin(N\psi/2)}{\sin(\psi/2)} \qquad (8.2)$$

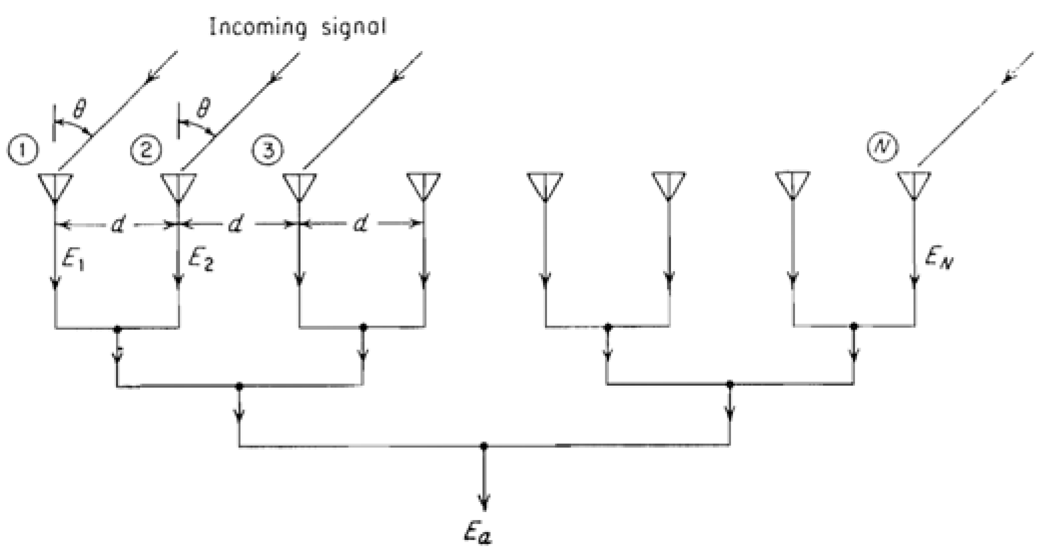

Fig 8.8: N-element linear array

The first factor is a sine wave of frequency ***w*** with a phase shift (N - l) Ψ /2 (if the phase reference were taken at the center of the array, the phase shift would be zero), while the second term represents an amplitude factor of the form sin (N Ψ /2)/sin (Ψ /2). The field intensity pattern is the magnitude of equation (8.2), or

$$G(\theta) = \frac{\sin^2[N\pi(d/\lambda)(\sin\theta - \sin\theta_o)]}{N^2\sin^2[\pi(d/\lambda)(\sin\theta - \sin\theta_o)]} \qquad (8.9)$$

The maximum of the radiation pattern occurs when $\sin\theta = \sin\theta_o$. Equation (8.9) states that the main beam of the antenna pattern may be positioned to an angle θ_o, by the insertion of the proper phase shift Φ, at each element of the array. If variable, rather than fixed, phase shifters are used, the beam may be steered as the relative phase between elements is changed (Fig. 8.9).

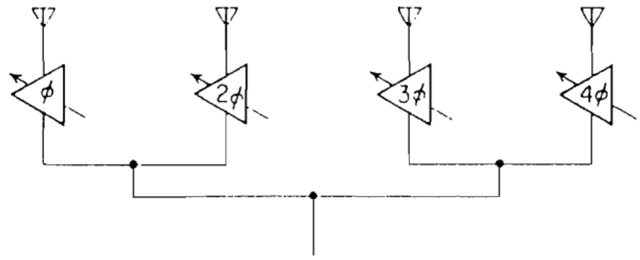

Figure 8.9 Steering of an antenna beam with variable phase shifters (parallel-fed array).

Using an argument similar to the non-scanning array described previously, grating lobes Appear at an angle θ_g, whenever the denominator is zero, or when

$$\pi \frac{d}{\lambda}(\sin \theta_g - \sin \theta_0) = \pm n\pi \tag{8.10a}$$

Or

$$|\sin \theta_g - \sin \theta_0| = \pm n \frac{\lambda}{d} \tag{8.10b}$$

If a grating lobe is permitted to appear at -90°when the main beam is steered to +90°, it is found from the above that $d = \lambda/2$. Thus the element spacing must not be larger than a half wavelength if the beam is to be steered over a wide angle without having undesirable grating lobes appear. Practical array antennas do not scan ± 90°. If the scan is limited to ±60° Eq. (8.10) states that the element spacing should be less than 0.54 λ. Note that antenna elements used in arrays are generally comparable to a half wavelength in physical size.

8.6.3. Change of beam width with steering angle.

The half-power beam width in the plane of scan increases as the beam is scanned off the broadside direction. The beam width is approximately inversely proportional to cos θ_0, where θ_0 is the angle measured from the normal to the antenna. This may be proved by assuming that the sine in the denominator of Eq. (8.9) can be replaced by its argument, so that the radiation pattern is of the form $(\sin^2 u) / u^2$, where $u = N\pi(d/\lambda)(\sin\theta - \sin\underline{\theta_0})$. The $(\sin^2 u) / u^2$ antenna pattern is reduced to half its maximum value when $u = \pm 0.443\pi$ **d**enoted by θ+ the angle corresponding to the half-power point when $\theta > \theta_0$ **,** and θ-, the angle corresponding to the half-power point when $\theta < \theta_0$; that is, θ+ corresponds to $u = +0.443\pi$ **an**d θ-to $u = -0.443\pi$ **.** The $\sin\theta - \sin\underline{\theta_0}$, term in the expression for u can be written'

$$\sin\theta - \sin\theta_0 = \sin(\theta - \underline{\theta_0})\cos\theta_0 - [1 - \cos(\theta - \underline{\theta_0})]\sin\underline{\theta_0} \tag{8.11}$$

The second term on the right-hand side of Eq. (8.11) can be neglected when $\underline{\theta_0}$ is small (beam is near broadside), so that

$$\sin\theta - \sin\theta_0 \approx \sin(\theta - \underline{\theta_0})\cos\theta_0 \tag{8.11}$$

Using the above approximation, the two angles corresponding to the 3-dB points of the antenna pattern are

$$\theta_+ - \theta_0 = \sin^{-1} \frac{0.443\lambda}{Nd \cos \theta_0} \approx \frac{0.443\lambda}{Nd \cos \theta_0}$$

$$\theta_- - \theta_0 = \sin^{-1} \frac{-0.443\lambda}{Nd \cos \theta_0} \approx \frac{-0.443\lambda}{Nd \cos \theta_0}$$

The half-power beam width is

$$\theta_B = \theta_+ - \theta_- \approx \frac{0.886\lambda}{Nd \cos \theta_0} \quad (8.13)$$

Therefore, when the beam is positioned an angle θ_o off broadside, the beam width in the plane of scan increases as $(\cos \theta_o)^{-1}$. The change in beam width with angle θ_o**,** as derived above is not valid when the antenna beam is too far removed from broadside. It certainly does not apply when the energy is radiated in the endfire direction.

Equation 8.13 applies for a uniform aperture illumination. With a cosine-on-a-pedestal aperture illumination of the form $A_n = \alpha_0 + 2\,\alpha_1 \cos 2\pi n/N$, the beam width is

$$\theta_B \simeq \frac{0.886\lambda}{Nd \cos \theta_0} [1 + 0.636(2a_1/a_0)^2] \quad (8.14)$$

The parameter n in the aperture illumination represents the position of the element. Since the illumination is assumed symmetrical about the center element, the parameter n takes on values of $n = 0, \pm 1, \pm 2, \ldots, \pm (N - 1)/2$. The range of interest is $0 \leq 2\alpha_1 \leq \alpha_0$ which covers the span from uniform illuminations to a taper so severe that the illumination drops to zero at the ends of the array. (The array is assumed to extend a distance *d /2* beyond each end element.)

The above applies to a linear array. Similar results apply to a planar aperture;"." that is, the beam width in the plane of the scan varies approximately inversely as $\cos \theta_o$**,** provided certain assumptions are fulfilled.

Essay type Questions

1. Discuss Radar CRT phosphor characteristics. [JNTU May 2012]
2. Explain about Color CRTs. [JNTU May 2012]
3. Why might a double-conversion super heterodyne receiver be used instead of a single-conversion receiver. What limitation might there be in using double-conversion receiver? [JNTU May 2012]
4. Explain in detail about N-element linear array and derive its Radiation pattern expression. [JNTU May 2012]
5. Explain in detail about different types of phased array radars and list out their advantages and disadvantages. [JNTU May 2012]
6. What effect does the local oscillator have on the receiver's dynamic range? [JNTU May 2011]
7. Distinguish between electrostatic and electromagnetic detection. ? [JNTU May 2011]
8. List the major difficulties occasioned by the use of moving radar antennas. How can phased arrays overcome these difficulties? [JNTU May 2011]
9. Describe the functions of the more important controls that may be provided with an A - scope radar display. [JNTU May 2011]

10. Explain the terms: side lobe radiation and aperture efficiency, as applicable to radar antennas. [JNTU May 2010]
11. Explain the significance and effects of uniform excitation and tapered excitation of parabolic reflectors. [JNTU May 2010]
12. Explain the effect of noise figure on the radar receiver? [JNTU Jan 2010]
13. Write the principle of branch type duplexer? [JNTU Jan 2010]
14. Write about the following: [JNTU Jan 2010]
    (a) zero – crossing detector (b) Envelope detector (c) logarithmic detector.
15. Discuss about the mixers in the radar receiver? [JNTU Jan 2010]
16. Compare series feeds and parallel feeds? [JNTU Jan 2010]
17. Explain the principle of the balanced mixer? [JNTU Jan 2010]
18. Write about CRT screens for display in radar systems. [JNTU Jan 2010]
19. Write about the following: [JNTU Jan 2010]
    a) Receiver protectors (b) passive TR limiter (c) low noise front ends.
20. Explain the following: [JNTU Jan 2009]
    i) Branch type duplexer
    ii) Balanced type duplexer
    iii) Receiver protectors.
21. Write notes on various displays. [JNTU Jan 2009]
22. Explain the operation of branch type duplexer with neat sketch. [JNTU Jan 2009]
23. Write notes on: [JNTU Jan 2009]
    i) noise figure
    ii) noise temperature.
    b) Any two types of mixers.
24. What is low noise front end? What are its applications? [JNTU Jan 2009]
25. Explain the following: [JNTU Jan 2009]
    i) Balanced type duplexer
    ii) Branch type duplexer.

Objective type questions

1. If the receive effective noise temperature is Te, then operating noise temperature is

a. T_oFs b. $T_o/F s$ c. $T_o/1+Fs$ d. T_o / 1-Fs

2. Effective noise temperature is defined as

a. Te = (Fn -1)T0 b. Te = F n T0

c. Te = Fn-1/T 0 d. Te = (Fn +1)T0

3. It is defined as the effective noise temperature of the receiver system including the effects of antenna temperature

a. Effective noise temperature b. Noise figure

c. System noise temperature d. Antenna noise

temperature

4. System noise temperature is given by

a. Ts = T_a + T f **b. Ts =** T_a **+ Te**

c. $Ts = T_a - T f$ d. $Ts = T_a - T e$

5. The noise figure is commonly expressed in

a. Hertzs b. Decibels c. Hz/W d. W/Hz

6. When a long persistence is needed the required phosphor is

a. P7 b. P19 c. P1 d. P39

7. This is universally used as the radar display

a. Raw Video b. Blip display

c. CRT display d. Synthetic display

8. Where no persistence is needed as when the frame time is less than the response time of the eye.
This phosphor is commonly used

a. P7 b. P19 c. P1 d. P39

9. It is appropriate for PPI presentations where the frame times are several seconds

a. P19 b. P39 c. P29 d. P7

10. When the display is connected directly to the video output of the receiver the information displayed is called

a. Raw video b. Synthetic video

c. CRT video d. Blip video

11. In this type of video, receiver video output is processed by automatic detection and tracking processor

a. Synthetic Video b. Raw Video c. CRT Video d. Blip Video

12. An intensity modulated rectangular display with azimuth angle indicated by horizontal coordinate and elevation angle by the vertical coordinate is

a. A Scope b. B Scope c. C Scope d. R Scope

13. This is the device that allows a single antenna to serve both the transmitter and the receiver

a. Dual Pulse generator b. Duplexer

c. Multiplexer d. Demultiplexer

14. This is based on the short-slot Hybrid function

a. Balanced Demodulator b. Balanced Duplexer

c. Unbalanced Duplexer d. ATR Tube

15. The power handling capability is greater in the

a. Balanced Duplexer b. Branch Duplexer

c. ATR Tube d. Receiver protector

16. Phased array is made up of

a. Non radiating antennas b. Radiating Antennas

c. Loop Arrays d. Non Resonant arrays

17. The linear array generates a fan beam such that radiation of pattern

a. Perpendicular to array b. Parallel to array

c. Lies in same plane as array d. Not lies in array plane

18. It offers separation of transmitter and receiver without need for conventional duplexer configurations

a. ATR Tube b. Ferrite Circulator c. TR Tube d. Diode Limiter

19. The ferrite circulator with receiver protector is attractive for radar applications because of its

a. Narrow Bandwidth b. Long life

c. Solid state configuration d. Low VSWR

20. The ferrite circulator have

a. Less life time b. Narrow bandwidth

c. Wider bandwidth d. Complex designing

21. The phased array is a

a. Directive Antenna b. Resonant Antenna

c. Non Resonant Antenna d. Non Directive Antenna

22. It consists of elements arranged in a straight line in one dimension

a. Non linear array b. Loop Array

c. Linear Array d. Planar Array

23. It is a two dimensional configuration

a. Non linear array b. Loop Array c. Linear Array d. Planner Array

24. The VSWR is a measure of the amount of power

a. Incident by Antenna b. Radiated by Antenna

c. Reflected by Antenna d. Isolated by Antenna

25. It is a good absorber device as compared to gas tube TR

a. Reflective limiter b. Circulator

c. Ferrite limiter d. TR limiter

26. When directive elements are used, the resultant array antenna radiation pattern is

a. $G(\theta) = Ge(\theta)\ Ga(\theta)$ b. $G(\theta) = Ge(\theta)+Ga(\theta)$

c. $G(\theta) = Ge(\theta) - Ga(\theta)$ d. $G(\theta) = 2G\,e(\theta) + Ga(\theta)$

27. If the radiation patterns in the two principal planes are $G1(\theta e)$ and $G2(\theta a)$ the two dimensional antenna pattern is

a. $G1(\theta e) + G2(\theta a)$ b. $2G1(\theta e) + G2(\theta a)$

c. $G1(\theta e)\ G2(\theta a)$ d. $G1(\theta e)/G2(\theta a)$

28. Grating lobes caused by a widely spaced array be eliminated with

a. Directive elements b. End fire arrays

c. Array elements d. Lobe factors

29. Radiate little or no energy in the directions of the undesired lobes

a. Non radiative elements b. Non directive elements

c. Directive elements d. Non resonant elements

30. An array whose elements are distributed on a non planar surface is called

a. Electronically scanned array b. Conformal Array

c. Linear array d. Loop array

31. The array factor has also been called

a. Lobe factor b. Radiation factor c. Space factor d. Element factor

32. This is the pattern of an array composed of Isotropic elements

a. Directive factor b. Lobe factor

c. Element factor d. Space factor

33. As the beam is scanned off the broad side direction. The half power beam width in the plane of scan

a. Decreases b. Remains constant

c. Reduced to zero d. Increases

34. If the same phase is applied to all elements the relative phase difference between adjacent elements is

a. 90^0 b. 180^0 c. 45^0 d. zero

35. If the spacing between antenna elements is λ/2, the pattern of uniformly illuminated array is

a. Similar to pattern of continuously illuminated uniform array

b. Different from pattern of continuously illuminated uniform array

c. Same as pattern of non uniform array

d. Similar to pattern of discontinuous illuminated array

36. In this array the energy to be radiated is divided between the elements by a power splitter

a. Serial feed array b. Parallel fed array

c. Corporate feed d. Circular feed

37. The maximum phase change required of each phase shifter in the parallel feed array is

a. π Radians b. Radians

c. Many times 2π radians d. 2π radians

38. A two dimensional parallel feed array of MN elements requires

a. M+N separate control signals b. control signals

c. M+N-2 separate control signals d. separate control signals

39. When a series of power splitters are used to create a tree like structure is called

a. Series feed b. Parallel feed

c. Corporate feed d. Tree feed

40. In the series feed where the signal is fed from one end the position of the beam will

a. Remains constant b. Vary with signal strength

c. Vary with frequency d. Vary with phase shift

41. Each phase shifter in the series fed linear array has

a. Phase shift - 37π Radians b. Same value of phase shift

c. Phase shift greater than 2π radians d. Variation in phase with frequency

42. Phase shifter in a series feed array must be of

a. Higher loss compared to parallel feed array

b. Lower loss compared to parallel feed array

c. Loss same as that of parallel feed array

d. Zero

43. The proper phase change for beam steering is introduced by

a. Power splitters b. Phase shifters

c. Phase splitters d. Corporate feed

44. In the parallel feed array energy to be radiated is

a. Divided by a power splitter b. Obtained by phase shifter

c. Obtained by corporate feed d. Divided by a phase splitter

Answers

Q	A	Q	A	Q	A	Q	A	Q	A	Q	A	Q	A
1	A	**2**	A	**3**	C	**4**	B	**5**	B	**6**	B	**7**	C
8	C	**9**	A	**10**	A	**11**	A	**12**	C	**13**	B	**14**	B
15	A	**16**	B	**17**	A	**18**	B	**19**	B	**20**	C	**21**	A
22	C	**23**	D	**24**	C	**25**	C	**26**	A	**27**	C	**28**	A
29	C	**30**	B	**31**	C	**32**	D	**33**	D	**34**	D	**35**	A
36	B	**37**	C	**38**	C	**39**	C	**40**	C	**41**	B	**42**	B
43	B	**44**	B										

*****