Radar Receiver

The function of the receiver in early radar system was to extract the weak echo signals that appeared at the antenna terminals and amplify them to a level where they could be displayed to a radar operator who then make the decision as to ~~amplify~~ whether or not a target echo signal present. It employs a matched filter whose purpose is to maximize the peak signal to mean noise ratio and discriminate against unwanted signals whose waveform are different from those transmitted by the radar. In modern radars the decision wether a target is present or absent is seldom made by an operator viewing on a display the unprocessed output of a receiver. Information about a target's location in range and angle can also be extracted automatically instead of manually by an operator. In an operational air surveillance radar, tracking of targets is no longer performed by an operator making with a grease pencil on a radar display the location of blips (target) from scan to scan and calculating the target spe and estimating its direction.

When a radar can not remove all the clutter, echoes, const-ant false alarm rate (CFAR) circuitary is employed to prevent the tracking computer from becoming overloaded when trying to establish tracker using clutter echoes.

Thus in addition to detection and amplification of signals a radar receiver perfoms many other functions either directly as a part of receiver or in conjunction with it. Ther other functions include signal processing, information extraction, data processing, electromagnetic compatibility a

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Electronic Counter-Countermeter (The modern receiver might thought of as the receiver processor). Sometimes the display is considered part of receiver system.

The radar receiver is almost always a superheterodyne or superhet. The essential characteristic of superheterodyne is that it converts the RF input signal to an intermediate frequency where it is easier than at RF to acheive the necessary filter shape, bandwidth, gain, and stability.

The first stage, or front end, of a radar superheterodyne receiver can be an RF low-noise amplifier such as a transist

Before the availability of low-noise transistors, the receiver front end was the mixer stage without an RF amplifier preceding.

NOISE FIGURE

The noise figure of a linear network may be defined as either

$$F_n = \frac{N_{out}}{K T_o B_n G} \quad \text{or} \quad \frac{S_{in}/N_{in}}{S_{out}/N_{out}} \quad — ①$$

where $N_{out} \rightarrow$ Available O/P noise power

$K T_o B_o = N_{in} \rightarrow$ Available I/P noise power

$K \Rightarrow$ Boltzmann's Constant $= 1.38 \times 10^{-23}$ J/deg

$T_o \rightarrow$ Standard temprature of 290 K

$G = S_{out}/S_{in}$ = Available gain

$S_{out} \rightarrow$ Available O/P Signal Power

$S_{in} \rightarrow$ Available I/P Signal Power

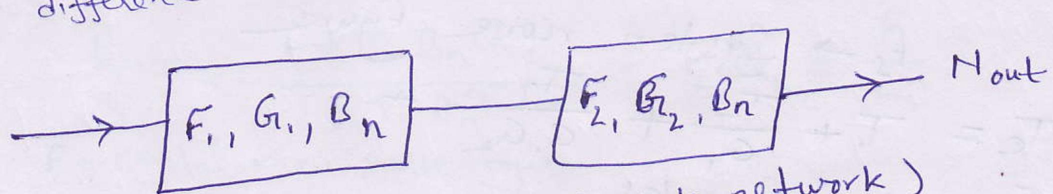
– The term available power refers to the power that would be delivered to a matched load.

Eqn ① permits two different, but equivalent interpretation of the noise figure. It may be considered as the degradation of the signal to noise ratio as the signal passes through the network.

$$\Rightarrow F_n = \frac{K T_o B_n G + \Delta N}{K T_o B_n G} = 1 + \frac{\Delta N}{K T_o B_n G}$$

Noise figure of network in Cascade :—

Considered two networks in cascade, each with the same noise bandwidth B_n, but with different noise figure and gain.



(Cascade network)

The problem is to find F_0, the overall noise-figure of the two networks in cascade.

The output noise N_{out} of the two network in cascade is

N_{out} = noise from network 1 at O/P of network 2 + noise ΔN_2 introduced by network 2.

$$N_{out} = F_0 K T_0 B_n G_1 G_2 = F_1 K T_0 B_n G_1 G_2 + \Delta N_2 \Rightarrow$$

$$N_{out} = F_1 K T_0 B_n G_1 G_2 + (F_2 - 1) K T_0 B_n G_2$$

$$\Rightarrow F_0 = F_1 + \frac{F_2 + 1}{G_1}$$

The noise figure of N networks in cascade may be given by

$$F_0 = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \cdots + \frac{F_N - 1}{G_1 G_2 \cdots G_{N-1}}$$

Noise temprature: — The noise introduced by a network may also be expressed as the effective noise temprature T_e,

It is given $\Rightarrow$ $\Delta N = K T_e B_n G$

$$F_n = 1 + \frac{T_e}{T_0}$$

$$\Rightarrow T_e = (F_n - 1) T_0$$

The system noise temprature T_s is defined as the effective noise temprature of the receiver including the effects of antenna temprature T_a. If the receiver effective noise temprature is T_e then

$$T_s = T_a + T_e = (F_s - 1) T_0$$

$F_s \rightarrow$ System noise figure

$$T_e = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \cdots$$

For N- networks

MIXERS

Many radar Superheterodyne 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 ~~sup~~ spurious responses. An integral part of the mixer is the local oscillator. The IF amplifier is also of importance in mixer design because of the its influence on the overall noise figure.

Conversion loss and noise temprature ratio:—

The conversion loss of a mixer is defined as

$$L_c = \frac{\text{available RF power}}{\text{available IF power}}$$

It is the measure of efficiency of the mixer in converting RF signal power into IF. The conversion loss of typical microwave crystals in a conventional ~~sig~~ 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.

Short circuting or open circuting the image frequency terminals results in narrow band mixer.

The noise temprature ratio of a crystal mixer is defined by

$$t_r = \frac{\text{actual available IF noise power}}{\text{available noise power from an equivalent resistance}}$$

$$t_r = \frac{F_c K T_0 B_n G_c}{K T_0 B_n} = F_c G_c = \frac{F_c}{L_c}$$

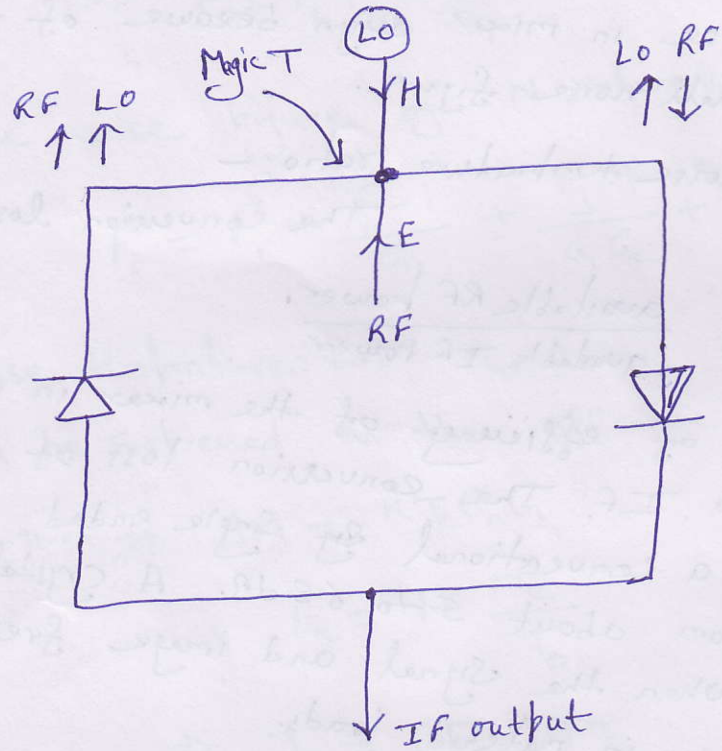
F_c = Crystal mixer noise figure

$L_c = 1/G_c$ = Conversion loss

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 bandpass RF filter b/w the local oscillator and the mixer.

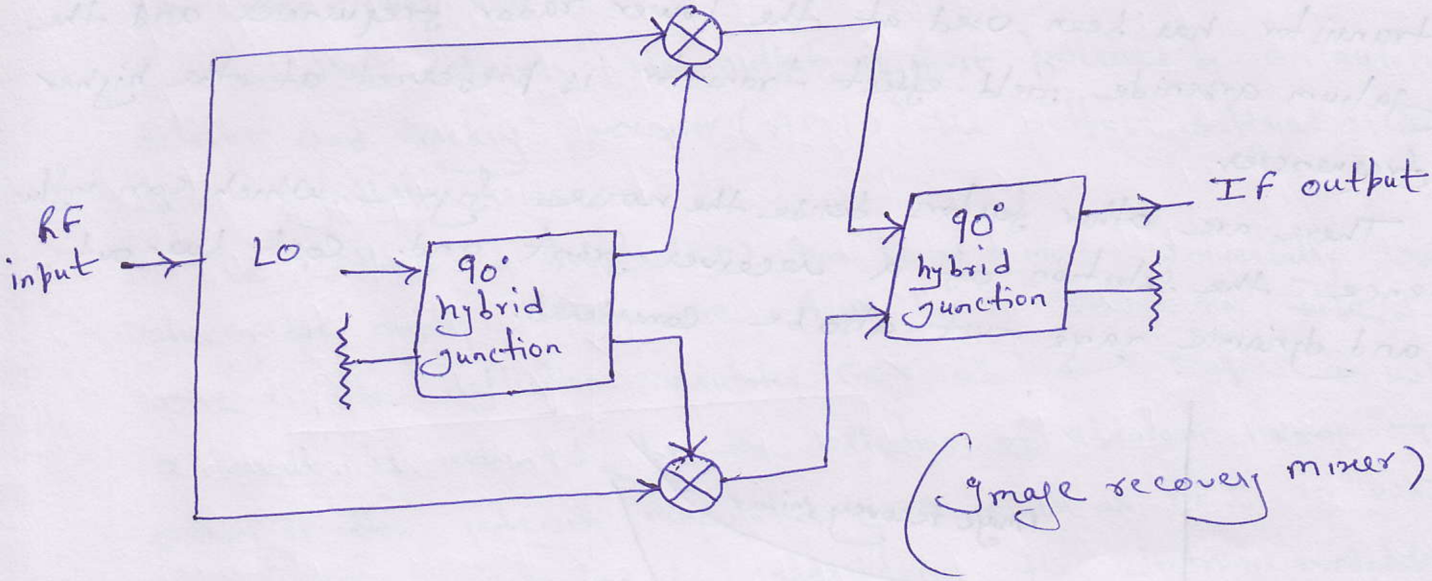
A method of eliminating local oscillator noise without the disadvantage of a narrowbandwidth filter is the balanced mixer. A balanced mixer uses a hybrid junction, a magic T, or an equivalent. These are the four port junctions.



(Balanced mixer)

In a single ended mixer, the mixing action generates all harmonics of the RF and LO frequencies, and combination thereof. The output is designed to filter out the frequency of interest, usually the difference frequency. A balanced mixer supresses 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 supresses even harmonics of both the RF and the LO signals.

Reactive image termination:— If the image frequency of a mixer is presented with the proper reactive termination, the conversion loss and the noise figure can be 1 or 2 dB less than with a broad band mixer in which the image frequency is terminated in the matched load.



(Image recovery mixer)

A method for achieving a reactive termination without bandwidth components is the image recovery mixer.

Diode burnout:- One of the cause of diode burnout in radar receivers has been the increased RF leakage through conventional duplexer due to aging of the TR tube.

Noise figure due to RF losses:- The noise figure due to RF losses may be derived from

$$F_n = \frac{N_{out}}{kT_0 B_n G}$$

The noise figure of a receiver with noise figure F_2, preceded by RF losses equal to L_{RF} is

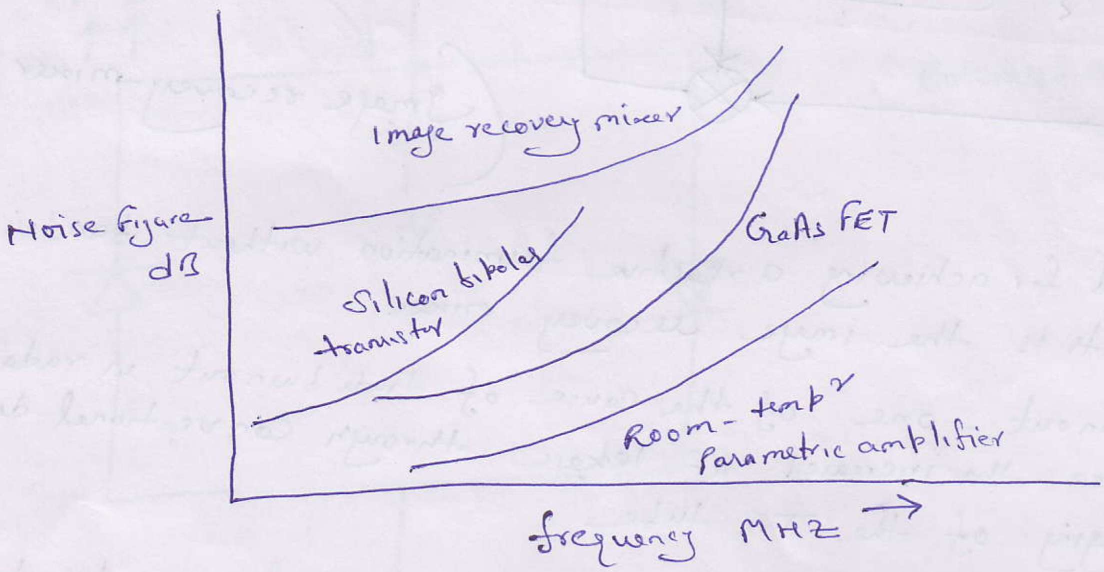
$$F_0 = F_1 + \frac{F_2 - 1}{G_1} = L_{RF} + (F_2 - 1) L_{RF} = F_2 L_{RF}$$

Low Noise Front Ends

The parametric amplifier has the lowest noise figure as compare to other amplifiers, especially at the higher microwave frequencies

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 and the galium arsenide field-effect transistor is preferred at the higher frequencies.

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 image recovery mixer represents a practical compromise which tends to balance its slightly greater noise figure by its lower cost, greatest ruggedness, and greater dynamic range.

The lower the noise figure of the radar receiver, the less need be the transmitter power and/or the antenna aperture. Reduction in the size of transmitter and antenna are always desirable if there are no concomitant reductions in performance. A few decibels improvement in receiver noise figure can be obtained at a relatively low cost as compared to cost and complexity of adding the same few decibels to a high power transmitter.

DISPLAYS: →

The purpose of 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 video output of the receiver, the information displayed is called raw video.

When the receiver video output is first processed by an automatic detector 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 deflection modulated CRT, such as A scope in which a target is indicated by the deflection of electron beam. The other is the intensity modulated CRT, such as PPI in which the target is indicated by intensifying the electronic 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 advantages 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 refered as a blip.

Electrostatic deflection CRT's use an E-field applied to pairs of deflection electrods, 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 CRT's require magnetic coils, or deflection yokes positioned around the neck of the tube.

Types of display presentation:- The various types of CRT displays which might be used for surveillance and tracking radars are defined as follow.

A-Scope:- A deflection modulated display in which the vertical deflection is proportional to target echo strength and the horizontal co-ordinate is proportional to range.

B-Scope:- An intensity modulated rectangular display with azimuth angle indicated by the horizontal co-ordinate and range by vertical co-ordinate.

C-Scope:- An intensity modulated rectangular display with azimuth angle indicated by the horizontal co-ordinate and elevation angle by the vertical co-ordinate

D-Scope:- A C-Scope in which blips extend vertically to give a rough estimate of distance.

E-Scope:- A intensity modulated rectangular display with distance indicated by the horizontal co-ordinate and elevation angle by the vertical co-ordinate.

F-Scope:- A rectangular display in which a target appears as a centera-zed blip when the radar antenna is aimed it.

G-Scope:- A rectangular display in which a target appear at a laterally centralized blip when radar antenna is aimed at it in azimuth.

H-Scope:- A B-Scope modified to include indication of angle of elevation.

I-Scope:- A display in which a target appears as a complete circle when the radar antenna is pointed at it and in which the radius of the circle is proportional to target distance.

J-Scope:- A modified A-Scope in which the time base is a circle and target appear as radial deflections from the time base.

K-Scope:- A modified A-Scope in which a target appears as a pair of vertical deflection.

L-Scope:- A display in which a target appears as two horizontal blips, one extending to the right from a central vertical time base and other to the left.

M-Scope:- A type of A-Scope in which the target distance is determined by moving an adjustable pedestal signal along the baseline until it coincides with horizontal position of target signal deflection.

N-Scope:- A K-Scope having adjustable pedestal signal.

O-Scope:- An A-Scope modified by the inclusion of an adjustable notch for measuring distance.

PPI:- Plane 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 co-ordinate, forming a map-like display.

R-Scope:- An A-Scope with a segment of the time base expanded near the blip for greater accuracy in distance measurement.

RHI:- Range height indicator:- An intensity modulated display with height as the vertical axis and range as horizontal axis.

CRT Screens:- A number of different cathode ray tubes screens are used in radar application. we also have color CRT's that provides another dimension for the display of target information.

Bright displays:→ There are applications where it is not possible or convenient to use the conventional CRT display that requires a darkened environment; such as in cockpit of an aircraft or an air-field control tower. One form of bright display is the direct view storage tube.

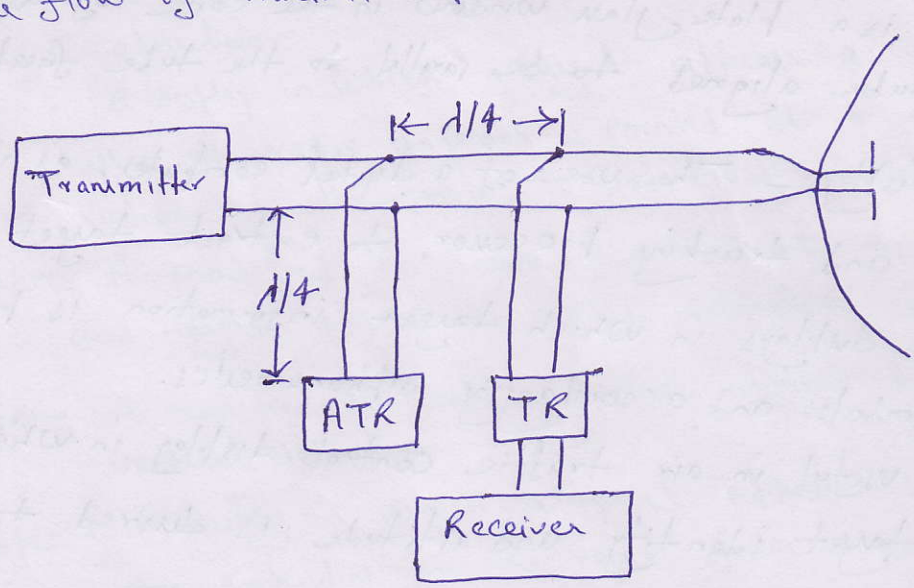
Rear port:- This is a plate glass window in the cone of a cathode ray tube aligned to be parallel to the tube faceplate.

Synthetic-video Displays:- The use of a digital computer, as in an automatic detection and tracking processor, to extract target information results in synthetic displays in which target information is presented with standard symbols and accompanying alphanumerics. This is especially useful in air traffic control display in which such information as target identity and altitude is desired to be displayed.

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. Duplexer especially for high-power applications, sometimes employ a form of gas discharge device.

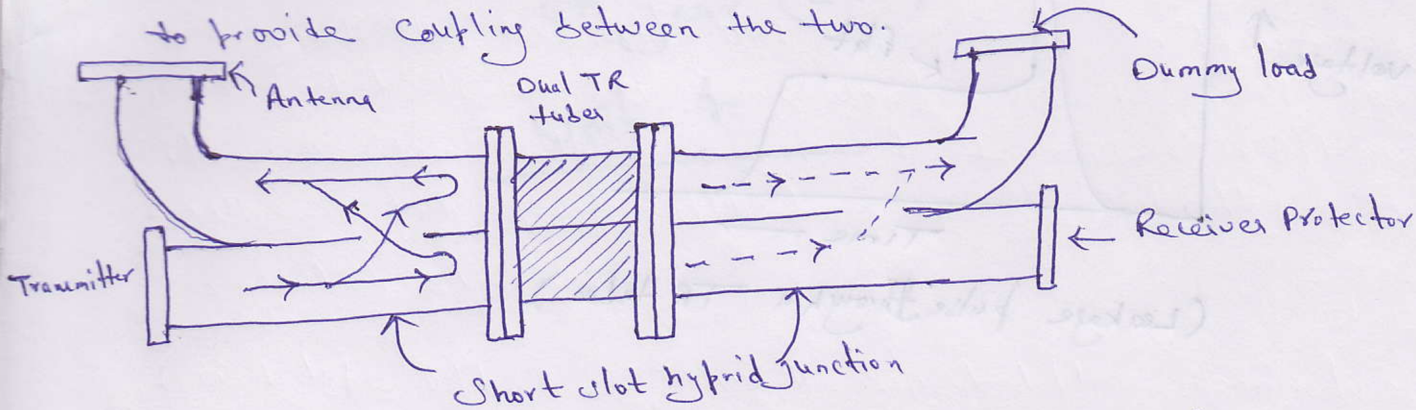
Branch type duplexer:— This the earliest duplexer configuration employed. It consist of a TR (transmit-receiver) switch and an ATR (anti transmit receiver) switch, both of which are gas discharged tube. When the transmitter is turned on, the TR and ATR tubes ionize; that is they break down, or fire. The TR in the fired condition acts as a short circuit to prevent transmitter power from entire the receiver. Since the TR is located a quater wavelength from the main transmission line so that it does not impede the flow of transmitted power.



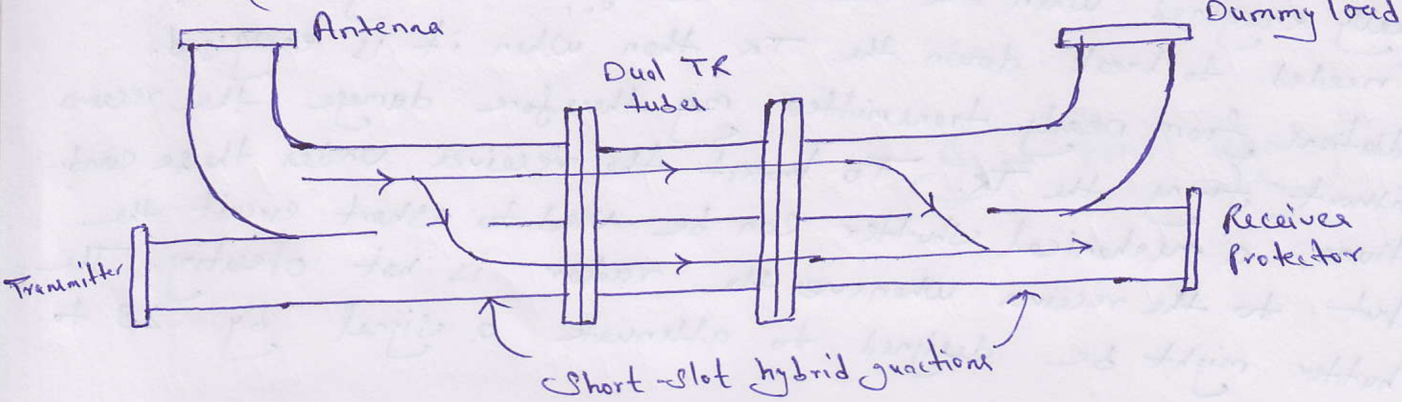
(Branch type duplexer)

The branch type duplexer is of limited bandwidth and power handling capability, and has generally been replaced by the balanced duplexer and other protecting devices. It is used in spite of these limitation, in some low cost radar.

Balanced duplexer:— It is based on short slot hybrid junction which consist of two sections of waveguide joined along on of their narrow walls with a slot cut in common narrow wall to provide coupling between the two.



(Balanced duplexer using TR tubes Transmit condition)



(Receiver condition)

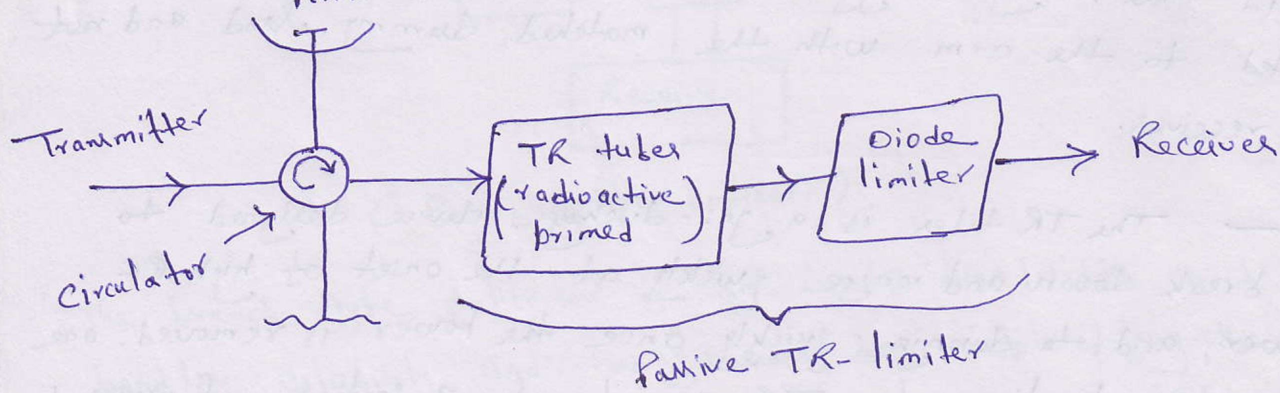
Both TR tubes break down and reflect the incident power out the antenna arm. The short-slot hybrid has the property that each time the energy passes through slot in their either direction, its phase is advanced 90°. Therefore the energy must travel as indicated by the solid lines. Any energy which leaks through the TR tubes is directed to the arm with the matched dummy load and not to the receiver.

TR tubes:— The TR tubes 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 contruction of a TR consists of a section of waveguide contained one or more resonant filters and two glass to metal window to seal in the gas at the low pressure.

(Leakage pulse through a TR tuber)

Receiver Protectors:→ Since the keep alive in the TR is not usually energized when the radar 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.

Circulator and receiver protector:→ The ferrite circulator is a three or four port device that can in principle, offer separation of the transmitter and receiver without the need for the conventional duplexer configurations.



(Circulator and receiver protector)