4 copies

UNIT - V

RADAR TRANSMITTER AND RECEIVER:

Linear beam power tubes - Solid state RF power sources - Solid state devices used in RADAR - Magnetron crossed field amplifiers - other aspects of radar transmitter - RADAR Receiver - Receiver noise figure - Superheterodyne receiver - dynamic range - RADAR Displays.

Linear Beam power tubes:

* There is no universal transmitter best suited for all radar appln.
* The transmitter must be of adequate power to obtain the desired radar range, but it must also satisfy other requirements imposed by the system appln.
* Choice of transmitter also depends on whether the radar operates from fixed land sites, mobile land vehicles, ships, aircrafts, or spacecraft.
* Other considerations include the size and weight, high vge and x-ray protection, modulation requirements and the method of cooling.
* The classical radar range eqn. shows that the transmitter power depends on the 4th power of the radar range.
* To double the range of a radar, the power has to be increased 16-fold.

* Transmitter includes the transmitter tubes, exciter, and driver amplifiers if a power amp., the power supply for generating the necessary voltages and currents needed by the tube, modulator, cooling for the tube, heat exchanges for the cooling

System if liquid, protection devices for arc discharges, safety interlocks, monitoring devices, isolators and x-ray shielding.

* The efficiency quoted for most tubes is the RF conversion efficiency, defined as the RF power o/p available from the tube to the dc i/p power of the electron stream

* Overall transmitter efficiency - ratio of RF power available from the transmitter to the total power needed to operate the transmitter.

* There are two basic radar-transmitter configuration - self-excited oscillator and power oscill-amplifier

* klystron, TWT, cross-field amp. are eg. of microwave power amp. tubes

* Transmitters that employ the magnetron power-osc. are usually smaller in physical size than transmitters that employ the power amp.

* Klyston amp - high power, high gain, good efficiency, and stability for MTI and pulse-compression appln.

* TWT - wider BW at expense of less gain.

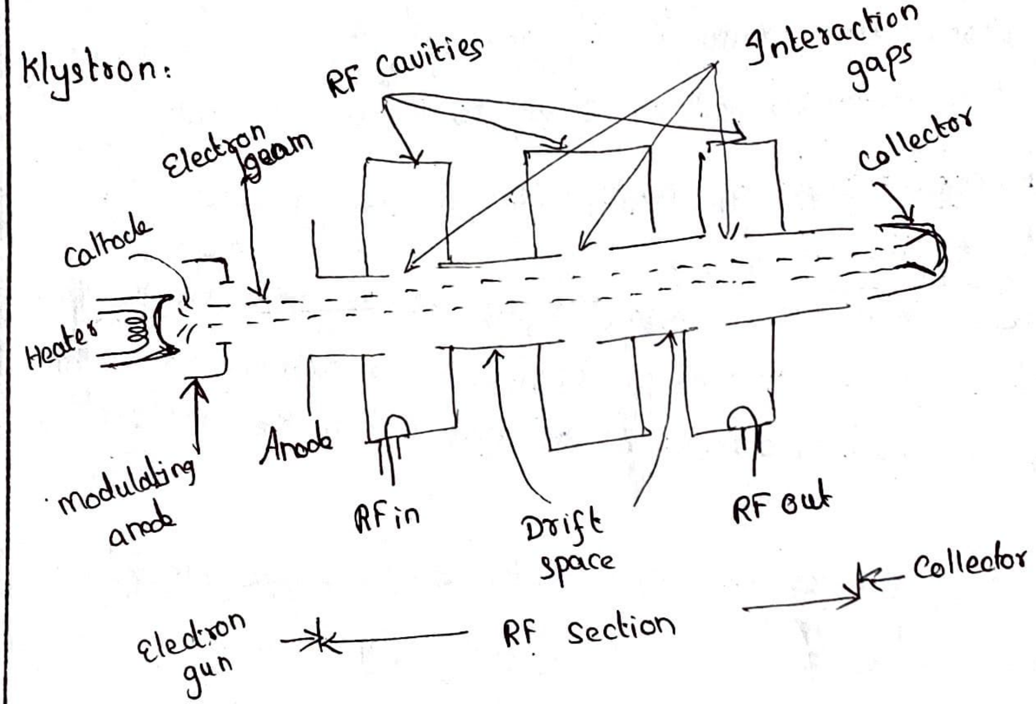
* magnetron - low cost, convenient size and weight and high efficiency and has an operating voltage low enough not to generate dangerous X-rays.

* In the linearbeam tube the electrons emitted from the cathode are formed into a long cylindrical beam that receives the full potential energy of the electric field before the beam enters the RF interaction region.

eg) klystron, traveling wave tube, Twystron

* An axial magnetic field is used in linear-beam tubes to confine the electron beam and keep electrons from hitting the RF structure.

Klystron:



* At the left is the cathode which emits a stream of electrons that is formed into a narrow cylindrical beam by the electron gun.

* Electron gun consist of the cathode that is the source of electrons, a modulating anode or other beam-control electrode to provide

a means of the beam on and off to generate pulses and the anode.

* The electron emission density at the surface of the cathode is less than that required for the electron beam, so a large area cathode surface is used and the emitted electrons are caused to converge to a narrow beam of high electron density.

* The multiple RF cavities, which correspond to the LC resonant circuits of conventional lower-frequency amplifiers are at anode potential.

* Electrons are removed by the collector electrode after the beam has given up its RF energy to the o/p RF cavity.

* RF i/p signal is applied across the interaction gap of the 1st cavity.

* Those electrons which arrive at the gap when the i/p signal voltage is a maximum experience a voltage greater than those electrons which arrive at the gap when the i/p is at a minimum.

* The process whereby some electrons are speeded up and others slowed down is called velocity modulation of the electron beam.

* In the drift space, electrons that are speeded up during the peak of one cycle catch up with those slowed down during the previous cycle.

* The result is that the electrons of the velocity-modulated beam become "bunched" or density modulated, after traveling through the drift space.

* Klystron has one or more appropriately placed intermediate cavities to enhance the bunching of the electron beam which increases the gain.

* If the interaction gap of the output cavity is placed at the point of maximum bunching, power can be extracted from the density-modulated beam.

* Gain of klystron might be 15 to 20 dB per stage

* After the bunched electron beam delivers its RF power to the o/p cavity, the energy of the electron beam that remains is dissipated when the spent electrons are removed by the collector.

* A long solenoid with iron shielding around its outside diameter surrounds the high-power klystron to provide an axial magnetic field that confines the electron to a relatively long, thin beam and prevents the beam from dispersing.

Bandwidth of a klystron:-

* freq. of a klystron is determined by its resonant cavities.

* When all the cavities are tuned to the same frequency the gain of the tube is high but the BW is narrow - Synchronous tuning

* To maximize the klystron's efficiency the next to last cavity is tuned upward in freq. and it is outside the passband.

* Although gain reduced, increased bunching results in greater efficiency and more o/p power.

Frequency Charging or Tuning:

* Conventional narrowband klystrons may have their freq. changed mechanically over a relatively wide freq. range.

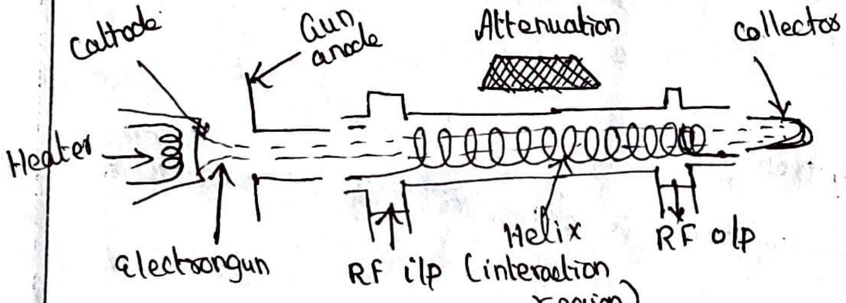
* Individual cavities of a klystron can be changed in freq. by having a flexible wall in the resonant cavity by a movable capacity element in the cavity. or by a sliding contact movable cavity wall.

Traveling Wave Tubes (TWT)

* The traveling wave tube is a linear beam tube with the cathode, RF circuit and collector separated from one another.

* In TWT, there is continuous interactions of the electron beam and the RF field over the entire length of the propagating structure of the TWT.

* It has wide bandwidth.



* The electron beam is similar to that of the klystron and both use velocity modulation to cause the electron beam current to be periodically bunched

* The electron beam passes through the RF interaction circuit known as the slow-wave structure or periodic delay line.

* The velocity of propagation of the RF signal is slowed down by the periodic delay line so that it is nearly equal to the velocity of the electron beam.

* The synchronism between the electromagnetic wave propagating along the slow-wave structure and the d-c electron beam propagating inside the helix results in a cumulative interaction which transfers d-c energy from the electron beam to increase the energy of the RF wave, causing the wave to be amplified.

* After delivering their d.c energy to the RF field on the slow-wave structure, the electrons are removed by the collector.

* The helic TWT is limited to voltages of about 10kV and a peak power o/p of a few kilowatts.

Solid State RF Power Sources:

* The Solid-State RF power generation device is the ~~transmit~~ transistor amplifier, both silicon bipolar and gallium arsenide FET.

* An individual transistor amplifier device is inherently of low power and Low gain, but it operates with low voltages and has high reliability.

* A single microwave transistor might have an average power capability from a few watts to over a hundred watts depending on the frequency and the duty cycle.

* Lower the freq, the greater the power can be.

* To increase the power, transistors may be operated in parallel and with more than one stage to increase the gain.

* Solid-state power devices of a given average power cannot be operated at high peak powers as can vacuum tubes.

* When solid-state amplifiers devices are employed in radar transmitters they have long pulsewidths and require pulse compression, to obtain useful range resolution.

* There are at least 4 ways that solid-state device can be employed in radar

1) as a transmitter for a low-power appln

2) as a high-power transmitter where a large no. of individual transistors are combined with microwave circuitry.

3) With many modules distributed on a mechanically steered planar array

4) With a module at each of the many elements of an electronically scanned phased array

Low. Power Transmitter:

* The solid-state device is used as a direct replacement for a vacuum tube when the radar waveform is of low power and of high duty cycle or CW.

eg) FM-CW altimeter, doppler speedmeter, airborne doppler navigator.

High. Power Transmitter:

* The solid state transmitter has replaced the high-power vacuum tube in some air-surveillance radars.

* A large no. of transistors are combined to produce a single o/p that feeds a conventional antenna.

eg) AN/SPS-40 - shipboard air-surveillance radar

Ramp radar system - air-traffic Control Primary Surveillance

Modules Arranged on a Mechanically Scanned Planar Array:

* Individual transmitter modules can be arranged on a mechanically scanning array antenna by placing one module at each element.

* It has been more usual in such a radar to employ one module at each element.

* At each row is a transceiver, which is a miniature radar containing transmitter, receiver preamplifier, duplexer, phase shifter for steering in elevation, logic control, cooling and power supply.

Active Apeture, Electronically Steered Phased Array:

THAAD Ground Based Radar:

Solid state Devices used in Radar.

* The transistor amp has been the device usually used for radars with high-power solid state transmitters.

* At the lower microwave frequencies, the silicon bipolar transistor is usually used and at the higher microwave frequencies gallium arsenide (GaAs) FET transistors are used.

* At the higher frequencies, the solid-state power device can also be incorporated as part of a microwave monolithic integrated circuit (MMIC).

* Silicon bipolar transistor used at microwave frequencies below about 3 GHz.

* Power o/p of the silicon bipolar transistor decreases with increasing frequency.

* At higher microwave frequencies, the gallium arsenide FET is capable of greater power than the silicon bipolar transistor.

* At high μ-wave frequencies, where compactness in size is desired, the microwave monolithic integrated circuit (MMIC) is used.

Advantages of solid state.

i) Individual solid-state devices have long MTBF (mean time between failures)

ii) Maintenance is relatively easy with the modular constrn. of solid state.

iii) Very wide bandwidths can be obtained

iv) No cathode heater is required.

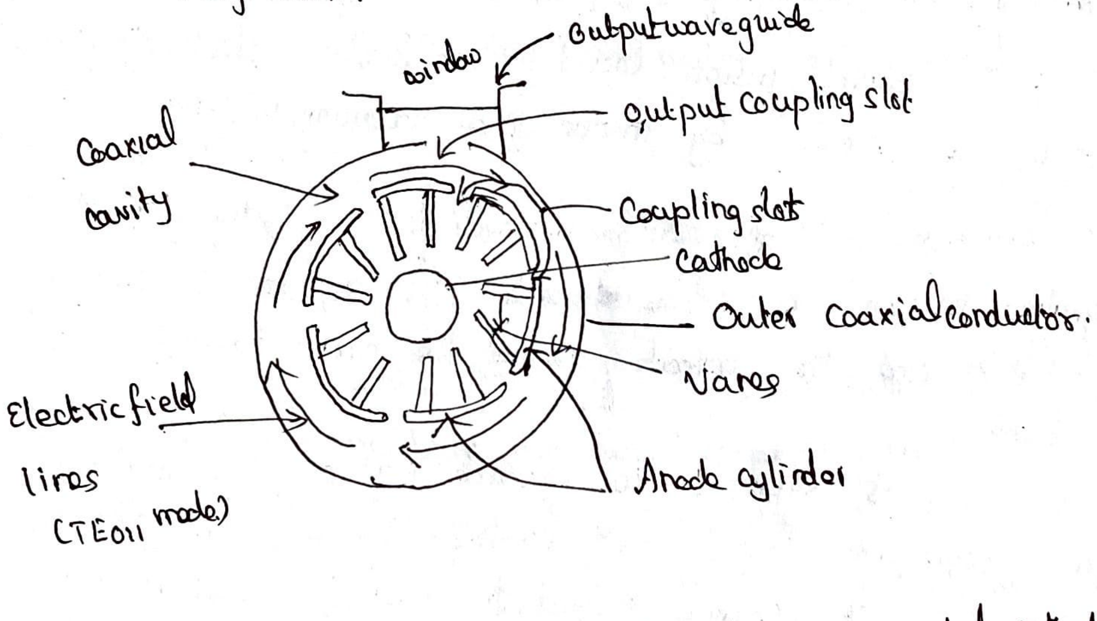
v) Operate at much lower voltages

vi) have low noise and good stability.

Magnetron:

* It is the only high-power RF power source used for radar that is a power oscillator rather than a power amplifier.
* It is a crossed-field device in that its electric field and its magnetic field are perpendicular to one another.
* The compact size and efficient operation of the magnetron at microwave frequencies allowed radars to be small enough to fly in military aircraft, be mobile for ground warfare and even be used on submarines.

Co-axial magnetron:



* At the center is the 'fat' oxide-coated cathode.
* Surrounding the cathode are a number of RF resonant cavities defined by the radial vanes.
* Between the cathode and the resonant cavities is the interaction space where the electrons interact with the d-c electric field and the static magnetic field in such a manner

that the electrons give up their d.c energy to the RF field.

* The crossed electric and magnetic fields cause the electrons to be "bunched" almost as soon as they are emitted from the cathode.

* After bunching, the electrons move along in a traveling wave field that is almost the same speed as that of free electrons.

* The frequency of a coaxial magnetron can be changed by mechanically moving one of the end plates, called a tuning piston of the stabilizing cavity.

* The tuning piston can be positioned mechanically from outside the vacuum by means of a vacuum bellows.

* There is also an inverted form of the coaxial magnetron version with the anode and resonant cavities in the center and the cathode around the outer perimeter of the tube.

* It is supposed to provide better performance at higher frequencies when the cavity becomes small and the regular type of coaxial magnetron would result in a small cathode.

* A magnetron can oscillate at a number of different, closely spaced frequencies due to various possible configurations of the RF field that can exist between the cathode and the resonant cavities.

* These RF field configurations, along with coupling among the many cavity resonators of the magnetron, result in different modes of oscillation.

* The magnetron can shift from one mode to another as the voltage changes or as the input impedance that the magnetron sees changes.

* The shift from one mode to another is called moding and is especially bad since it can occur when the radar antenna scans and views different environments.

* The preferred magnetron mode of operation is the so-called π-mode that occurs when the RF field configuration is such that the RF phase alternates 180° b/w adjacent cavities.

Adv. of π mode:

i) * Its freq. can be more readily separated from the frequencies of the other possible modes.

ii) * π mode oscillates at only a single frequency, but the other modes can oscillate at two different frequencies.

In general * An N cavity magnetron can oscillate at N-1 different frequencies

Crossed-Field Amplifiers:

* The crossed-field amplifiers resembles the magnetron in that it employs a magnetic and electric field that are $\perp^{ar}$ to one another.

* Here the RF circuit is interrupted to provide the input and output connections.

Adv:

i) High efficiency
ii) Use lower voltage than linear-beam tubes
iii) lighter in weight, smaller in size
iv) Wide bandwidth (10 to 20%)
v) High peak and average power
vi) Good phase stability
vii)

Disadv:

Gain is low.

CFA Operation:

* The CFA uses slow-wave circuits, cathode, and input and output ports.

The RADAR Receiver:

* The function of the radar receiver is to detect desired echo signals in the presence of noise, interference or clutter.
* It must separate wanted from unwanted signals and amplify the wanted signals to a level where target information can be displayed to an operator or used in an automatic data processor.
* The design of the radar receiver will depend not only on the type of waveform to be detected, but on the nature of the noise, interference and clutter echoes with which the desired echo signals must compete.

* Noise can enter the receiver via the antenna terminals along with the desired signals or it might be generated within the receiver itself.

* At μ-wave frequencies, used for radar, the external noise which enters via the antenna is generally quite low so that the receiver sensitivity is usually set by the internal noise generated within the receiver.

* The measure of receiver internal noise is the noise-figure.
* Good receiver design is based on maximizing the o/p SNR.
* Noise must be reduced in the input stages.
* Receiver design also must be concerned with achieving sufficient gain, phase and amplitude stability, dynamic range, tuning, ruggedness and simplicity.

Noise Figure:

* is a measure of the noise produced by a practical receiver as compared with the noise of an ideal receiver.
* Noise figure $F_n = \dfrac{S_{in}/N_{in}}{S_{out}/N_{out}} = \dfrac{N_{out}}{K T_0 B_n G}$.

S_{in} → available input signal Power

N_{in} → available input noise power (kT_oB_n)

S_{out} → " o/p signal power

N_{out} → " o/p noise power.

$$G = \frac{S_{out}}{S_{in}}$$ – available gain

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

T_o : Standard temperature 290 K.

B_n = noise BW.

$kT_o = 4 \times 10^{-21}$ w/Hz.

* Noise Figure may be considered as the degradation of the SNR caused by the n/w or it may be interpreted as the ratio of the actual available o/p noise power which would be available if the n/w merely amplified the thermal noise.

$$F_n = \frac{kT_oB_nG + \Delta N}{kT_oB_nG} = 1 + \frac{\Delta N}{kT_oB_nG}.$$

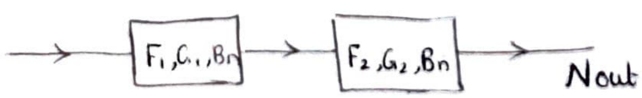
ΔN → additional noise introduced by the n/w itself.

* Noise Figure expressed in dB's is $10 \log F_n$.

Noise figure of networks in Cascade.

* Consider 2 n/w in cascade each with the same noise bandwidth B_n but with different noise figures and available gain.

* Let F_1, G_1 be the noise figure and available gain of the 1st n/w and F_2, G_2 for the 2nd n/w



* The problem is to find F_o, the overall noise figure of the two n/ws in cascade.

* From the above defns.,

N_{out} = noise from n/w 1 at o/p of network 2 + noise ΔN_2 introduced by n/w 2.

$$N_{out} = F_o k T_o B_n G_1 G_2 = F_1 k T_o B_n G_1 G_2 + \Delta N_2$$

$$= F_1 k T_o B_n G_1 G_2 + (F_2 - 1) k T_o B_n G_2$$

which results in, $F_o = F_1 + \frac{F_2 - 1}{G_1}$

* It is not sufficient that the 1st stage of a low-noise receiver have a low noise figure. The 2nd stage must also have a low noise figure or, if not, the gain of the 1st stage needs to be large.

* Too large 1st stage gain, always not desirable since dynamic range gets ↓.

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

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

Noise figure due to Loss in the Transmission line:

* Any losses in the RF portion ahead of the receiver front-end result in an increase in the apparent overall noise figure.

* Such losses can be due to the transmission line b/w antenna and receiver, the duplexer, receiver protector, rotary joint, preselector filter, monitoring devices and the Radome.

* Noise figure due to these RF losses, obtained from the second part of the is equal to the RF loss L_{RF}.

L_{RF} : loss in SNR as the signal travels from the antenna to the receiver.

* Noise out of a lossy transmission line is KT_0B_n and

$$G = \frac{1}{L_{RF}}.$$

Noise Temperature:

* The noise introduced by a n/w may also be expressed as the effective noise temperature T_e, defined as the temperature at the input of the network that accounts for the additional noise ΔN at the o/p.

$$\therefore \Delta N = kT_eB_nG$$

We know,

$$F_n = 1 + \frac{\Delta N}{kT_0B_nG}$$

$$= 1 + \frac{kT_eB_nG}{kT_0B_nG}$$

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

$$(F_n - 1) = \frac{T_e}{T_0}$$

$$T_e = (F_n - 1)T_0.$$

* System noise temperature T_s is defined as the effective noise temperature of the receiver including the effects of the antenna temperature T_a. ~~and receiver~~

15

* If the receiver effective noise temperature is T_e, then

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

$f_s \rightarrow$ System noise figure.

* The effective noise temperature of a receiver consisting of a number of n/ws in cascade is

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

$T_i, G_i \rightarrow$ effective noise temperature and gain of the ith n/w.

T_i is used to describe the noise performance of very low-noise receivers

Superheterodyne Receiver:

* The radar receiver is always a superheterodyne receiver.
* Essential characteristics of a superheterodyne is that it converts the RF i/p signal to an intermediate frequency (IF) where it is easier to achieve the necessary filter shape, BW, gain and stability.
* Adv: of superheterodyne receiver is that its frequency can be readily changed by changing the frequency of the local oscillator.
* 1st stage or frontend of a radar superheterodyne receiver can be an RF low-noise amplifier (LNA) such as a transistor

* A receiver with mixer as the front end can also be desired and has a greater dynamic range.

* A radar receiver has to have sufficient gain to increase the level of the weak echo signal.

* Should have adequate dynamic range so that large clutter echoes do not cause the receiver to saturate and reduce the MTI improvement factor.

Low-Noise Front-End

* RF amplifiers with suitable noise figure are employed as low-noise front-ends.

* The parametric amplifier has the lowest noise figure of those devices, at μ-wave frequencies.

* The transistor amplifier can be applied over most of the entire range of frequencies.

* Silicon bipolar transistor has been used at the lower radar frequencies and galium arsenide field-effect transistor (GaAsFET) is preferred at higher frequencies.

* The transistor is used in a multistage configuration with a typical gain per stage decreasing from 12dB at VHF to 6dB at Ku band.

* The tunnel-diode amplifier has a noise figure from 4 to 7dB over the range 2 to 2.5 GHz.

* TWT has also been considered as low noise front-ends

* Cryogenic parametric amplifiers and maser produce the lowest noise figures, but the added complexity of operating at low temperatures has tempered their use in radar.

* Cost, burnout, and dynamic range, instantaneous bandwidth, tuning range, phase and amplitude stability and any special requirements for cooling also influence the selection of a receiver front end.

Utility of low-noise front-ends:

* 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 the transmitter and the antenna are always desirable.

Dynamic range:

* 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 capable of
* The maximum signal is that which causes a specified degree of intermodulation or a specified deviation from linearity of the o/p vs i/p curve.

Mixers:

* mixer is the key element in the receiver since it is the means by which the incoming RF signal is converted to IF (intermediate frequency).
* When down conversion from RF to IF is performed in one step, it is called single conversion.
* If down convesion is done in two steps, with a mixers and IF amplifiers, then it is called dual conversion.
* This is used to avoid some forms of interference and electronic countermeasures.

* mixer should have low conversion loss, introduce little additional noise of its own, minimize spurious responses and not be susceptible to burnout.

Noise Figure of a Mixer Used as a Front End:

* determined by its conversion loss and noise temperature ratio.

* Conversion loss of a mixer is defined as

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

* It is a measure of the efficiency of the mixer in converting RF signal power into IF.
* Typical μ-wave diodes L_c is 5 to 6.5 dB.

* Noise-temperature is

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

$$t_r = \frac{F_m k T_0 B G_c}{k T_0 B} = F_m G_c = \frac{F_m}{L_c}.$$

$F_m \rightarrow$ mixer noise figure

$L_c \rightarrow$ conversion loss $= 1/G_c$.

$F_m = L_c t_r$.

(1)

* overall noise figure does not depend on the mixer stage, but also on the noise figure of the IF amp.

* noise figure of 1st stage (mixer) $F_1 = L_c t_r$, gain $G_1 = 1/L_c$.

2nd n/w (IF), $F_2 = F_{IF}$.

* The receiver noise figure with a mixer front-end is then the IF amp.

$$F_R = F_1 + \frac{F_2 - 1}{G_1}$$

$$= L_c t_r + (F_{IF} - 1) L_c$$

$$= L_c(t_r + F_{IF} - 1)$$

Types of Mixers:

* An ideal mixer is one whose o/p is proportion to the product of the RF echo signal and the local oscillator (LO) signal.

* The mixer provides two o/p frequencies that are the sum and difference of the two i/p frequencies or $f_{RF} \pm f_{LO}$, assuming $f_{RF} > f_{LO}$.