Microwave Engineering
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Lecture 35
Microwave Communication Systems and other application areas

So, we come to the last module of this course. Where we discuss some applications of microwave engineering particularly microwave communication systems and some other application areas.

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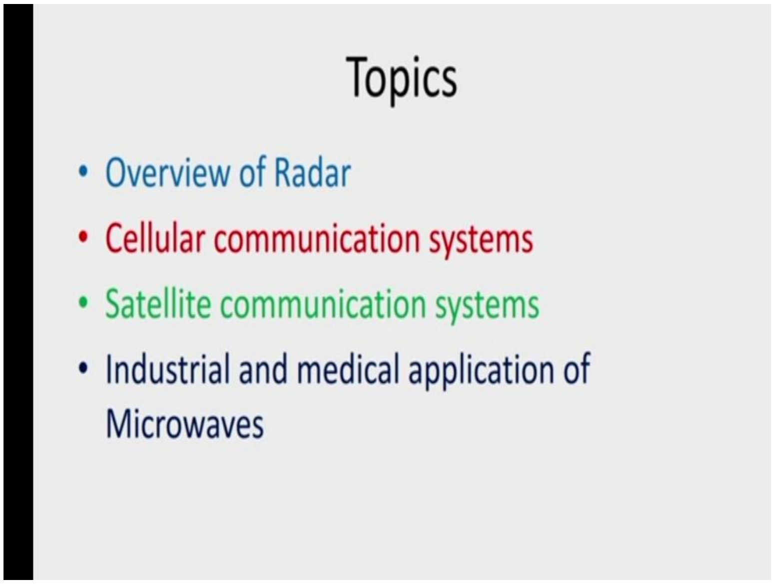

Topics

- Overview of Radar
- Cellular communication systems
- Satellite communication systems
- Industrial and medical application of Microwaves

So, in this module, we cover the following topics we give an overview of radar system then we discuss satellite communication systems in brief, and finally we discuss the industrial and medical applications of microwaves.

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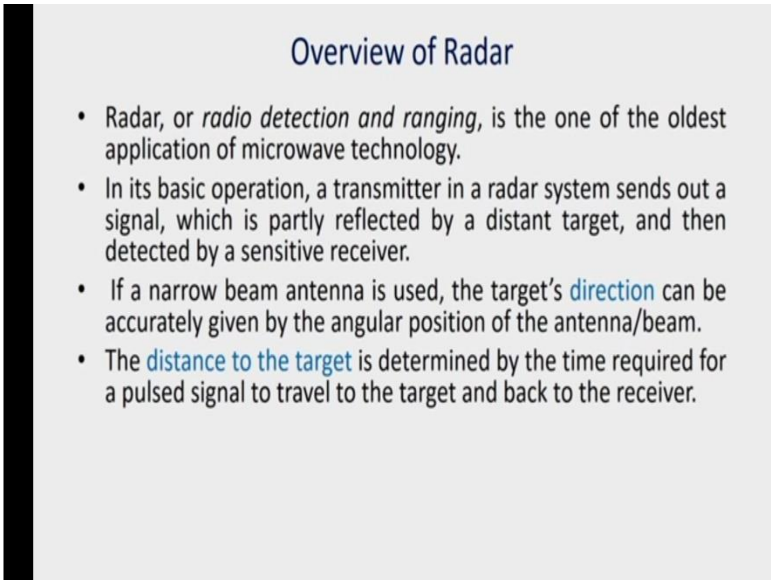

Overview of Radar

- Radar, or *radio detection and ranging*, is the one of the oldest application of microwave technology.
- In its basic operation, a transmitter in a radar system sends out a signal, which is partly reflected by a distant target, and then detected by a sensitive receiver.
- If a narrow beam antenna is used, the target's direction can be accurately given by the angular position of the antenna/beam.
- The distance to the target is determined by the time required for a pulsed signal to travel to the target and back to the receiver.

We start our discussion with radar, where we provide an overview of radar. Radar or radio detection and ranging are one of the oldest applications of microwave technology. So, in its basic form, it consists of a transmitter which sends out signal it is reflected by a distant target and then detected by a sensitive receiver. So, if we use a narrow beam antenna then this gives us the information about the direction of the target. So, it can be estimated from the angular position of the antenna or the beam. So, the next comes. Once we have found the direction of target. Next comes the distance to target and this is determined by the time required for a pulse signal to travel to target and back to the receiver.

So, this delay involved from the transmission of your pulse until it is received back that can be used to estimate the distance to the target or the range of the target. Another important parameter that we want to know about the target is the radial velocity. And if the target is moving then the Doppler sheet produced in the returned signal can be used to estimate this. So, we can see that on a radar we can know in which angle the target is located. Its range or distance from the transmitting antenna and as well as if the target is moving, what is the velocity. So we get all the information about a target.

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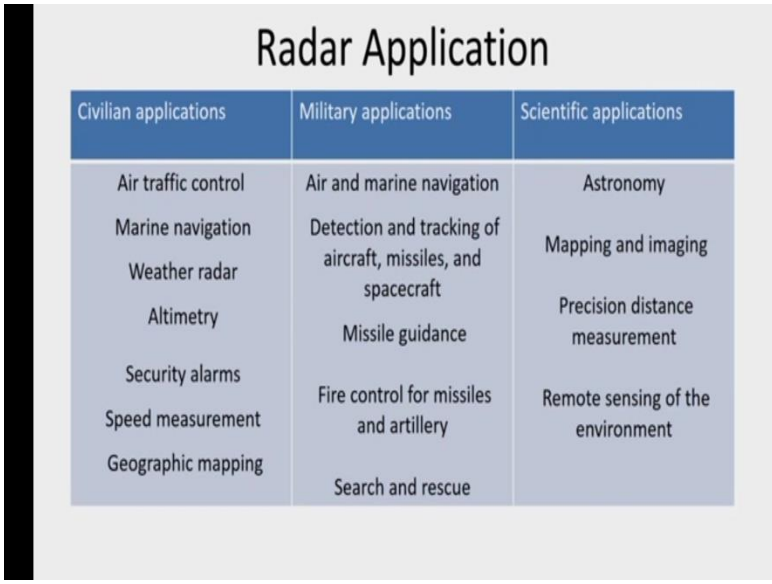

Radar Application

Civilian applications	Military applications	Scientific applications
Air traffic control Marine navigation Weather radar Altimetry Security alarms Speed measurement Geographic mapping	Air and marine navigation Detection and tracking of aircraft, missiles, and spacecraft Missile guidance Fire control for missiles and artillery Search and rescue	Astronomy Mapping and imaging Precision distance measurement Remote sensing of the environment

Now, radar has many application areas, So this has been put in 3 vertical civilian applications, military application, and scientific application. In civilian application one major application of radar is air traffic control then radar is used in marine navigation. Whether radar altimetry, security alarms, speed measurement, and geographic mapping. Military application is plenty just to name a few air and marine navigation, Detection and tracking of aircraft, missiles and spacecraft, Missile guidance, Fire control for missiles and artillery, search and rescue. Microwave astronomy is one of the scientific applications where radar is used, and then for mapping and imaging, then radar is used for precision distance measurement and also for remote sensing of the environment. So, we can see that there are a variety of areas where the radar finds application, and this list is not exhaustive. There are many other applications.

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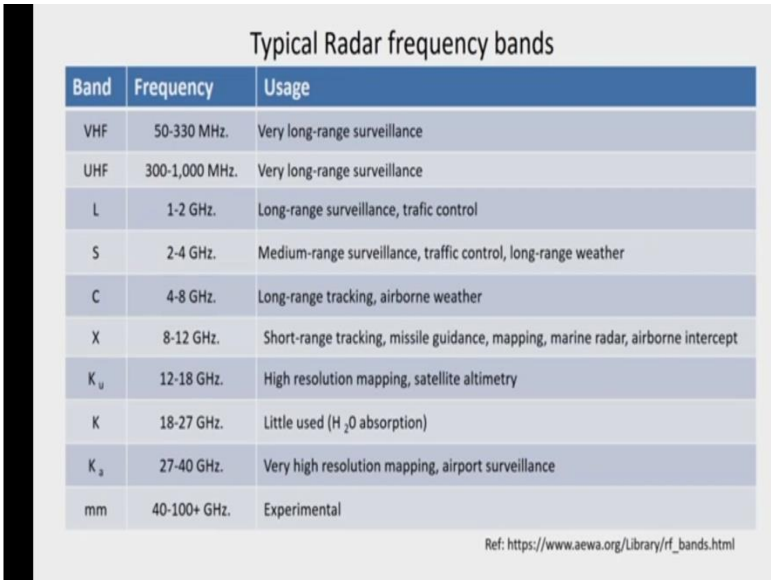

Typical Radar frequency bands

Band	Frequency	Usage
VHF	50-330 MHz.	Very long-range surveillance
UHF	300-1,000 MHz.	Very long-range surveillance
L	1-2 GHz.	Long-range surveillance, trafic control
S	2-4 GHz.	Medium-range surveillance, traffic control, long-range weather
C	4-8 GHz.	Long-range tracking, airborne weather
X	8-12 GHz.	Short-range tracking, missile guidance, mapping, marine radar, airborne intercept
K_u	12-18 GHz.	High resolution mapping, satellite altimetry
K	18-27 GHz.	Little used (H_2O absorption)
K_a	27-40 GHz.	Very high resolution mapping, airport surveillance
mm	40-100+ GHz.	Experimental

Ref: https://www.aewa.org/Library/rf_bands.html

Now, the typical frequency bands which are used for radar are we VHF 50 to 330 megahertz. This is for long-range surveillance. Similarly, 300 megahertz to 1 gigahertz this is also for very long-range surveillance, 1 to 2 gigahertz long-range surveillance and traffic control, 2 to 4 gigahertz medium range surveillance, traffic control long-range weather monitoring, 4 to 8 gigahertz long range tracking, airborne weather monitoring systems, 8 to 12 gigahertz short-range tracking, missile guidance, mapping, marine radar, airborne intercept, 12 to 18 gigahertz high resolution mapping and satellite altimetry, 18 to 27 gigahertz band is not used very much because of H_2O absorption, 27 to 40 gigahertz very high-resolution mapping, airport surveillance and 40 to 100 plus gigahertz it is experimental.

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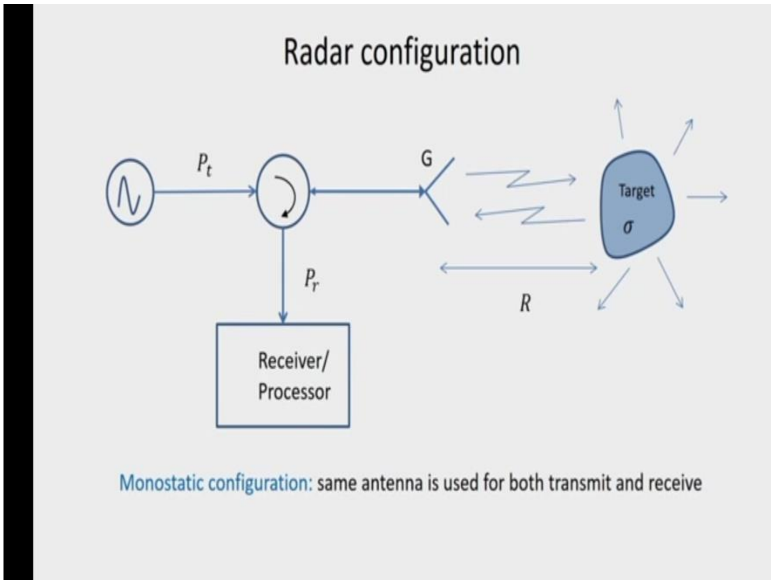

Radar configuration

Monostatic configuration: same antenna is used for both transmit and receive

We now look into the configurations of radar. One particular configuration is called monostatic configuration, and in this configuration, we use the same antenna as for both transmit and receive. So, we have a signal transmitted, and here you can see a circulator. So, it will connect that signal to the antenna; the signal will be radiated. Now we have a target, and this target will scatter the signal, and this backscattered signal will be picked up by the antenna, and this signal, when it goes to the circulator it will be delivered to the receiver, and then it will be further processed. So, this type of configuration which uses only 1 antenna for transmitting and receive these are called monostatic configuration.

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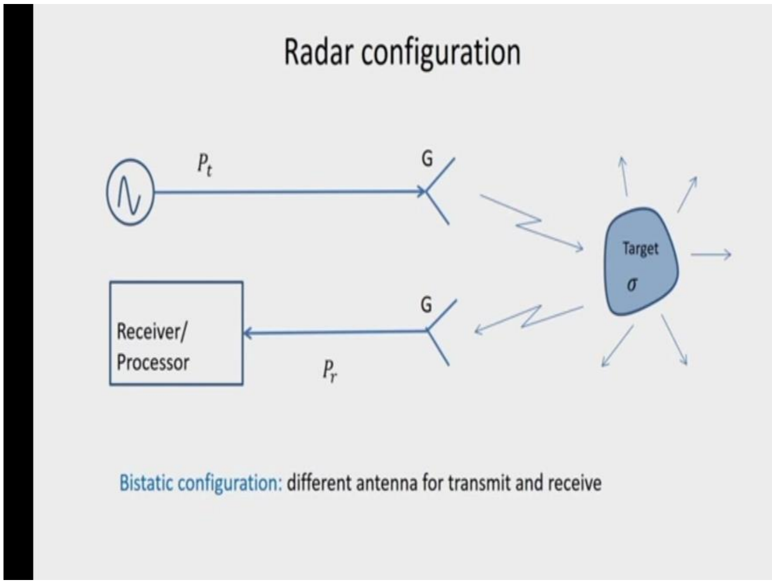

Radar configuration

Bistatic configuration: different antenna for transmit and receive

Another radar configuration is bistatic. Where we use different antenna for transmitting and receive. And here the signal is transmitted from the first antenna. It is scattered back by the target, and the backscattered signal is picked up by the receiver antenna, which is given to the receiver for further processing. Nowadays there are some advance versions are also there like multi-static and even multi-dynamic radar are also being tried.

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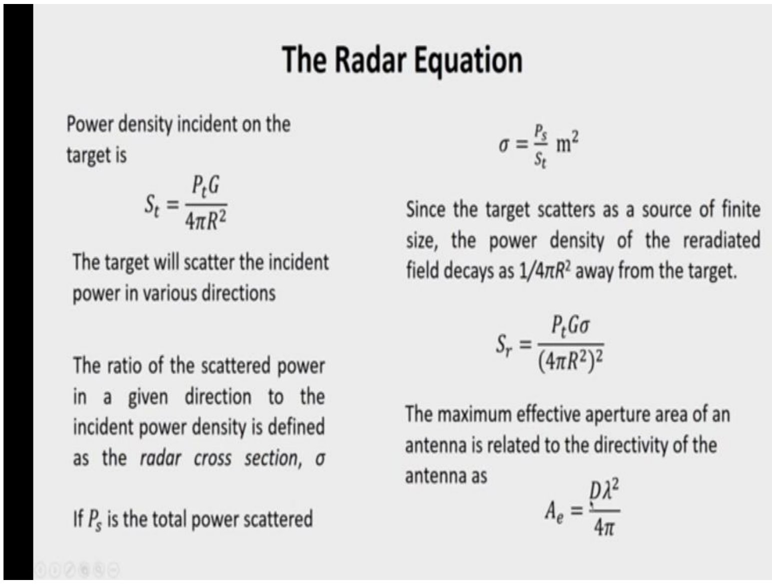
$$S_t = \frac{P_t G}{4\pi R^2}$$

$$\sigma = \frac{P_s}{S_t}\ \mathrm{m}^2$$

$$S_r = \frac{P_t G \sigma}{(4\pi R^2)^2}$$

$$A_e = \frac{D\lambda^2}{4\pi}$$



The Radar Equation

Power density incident on the target is

$$S_t = \frac{P_t G}{4\pi R^2}$$

The target will scatter the incident power in various directions

The ratio of the scattered power in a given direction to the incident power density is defined as the *radar cross section*, σ

If P_s is the total power scattered

$$\sigma = \frac{P_s}{S_t}\ \mathrm{m}^2$$

Since the target scatters as a source of finite size, the power density of the reradiated field decays as $1/4\pi R^2$ away from the target.

$$S_r = \frac{P_t G \sigma}{(4\pi R^2)^2}$$

The maximum effective aperture area of an antenna is related to the directivity of the antenna as

$$A_e = \frac{D\lambda^2}{4\pi}$$

Let us now see the basic equation that is involved with radar. So, we have if you considered the power transmitted by an antenna then if Pt is the power. The power density that is radiated is Pt by 4pi R square at a distance R from the transmit antenna. Since the antenna has a gain G the power density in that particular direction where the antenna has maximum gain, it will be given by St equal to Pt into G by 4pi R square. Now we have seen that this incident power is scattered by the target in various directions. The ratio of the scattered power to a given direction to the incident power density is defined as the radar cross-section and it is denoted by sigma. That is why in the earlier 2 diagrams we use this sigma while representing the targets.

So, targets will be characterized by its radar cross-section sigma. If Ps is the total power scattered, then we can write sigma is equal to Ps by St and it has a dimension of meter square. Now since the target scattered as a source of finite size, the power density of the reradiated field decays as 1 by 4 pi r square. And therefore we can write Sr the received power density it is Pt G divided by 4 pi r square multiplied by sigma that will give us Ps and divided by 4 pi r square that means 4pi r square square that will give us, the received power density. Now, this power density is incident on the receiving antenna depending upon the effective aperture of the antenna will receive power the maximum effective aperture area of an antenna is related to the directivity of the antenna as effective aperture is equal to D lambda square by 4pi where lambda is the operating wavelength.

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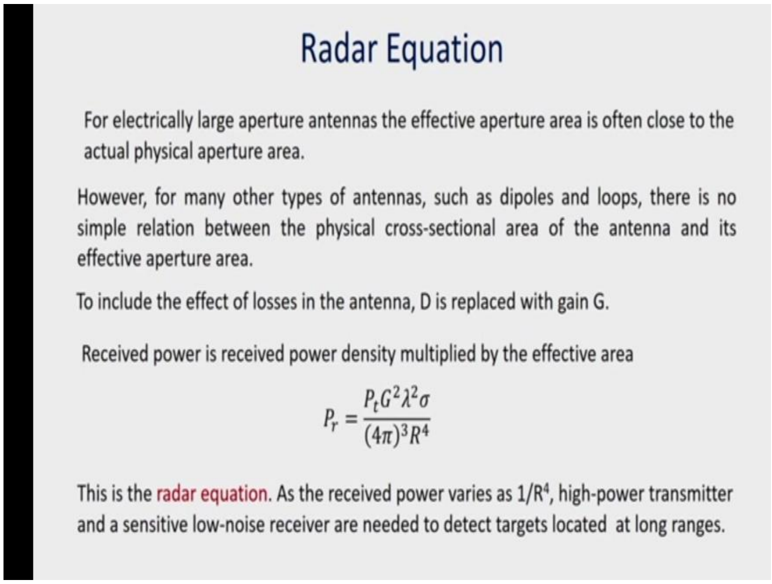
$$P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$$



Radar Equation

For electrically large aperture antennas the effective aperture area is often close to the actual physical aperture area.

However, for many other types of antennas, such as dipoles and loops, there is no simple relation between the physical cross-sectional area of the antenna and its effective aperture area.

To include the effect of losses in the antenna, D is replaced with gain G.

Received power is received power density multiplied by the effective area

$$P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$$

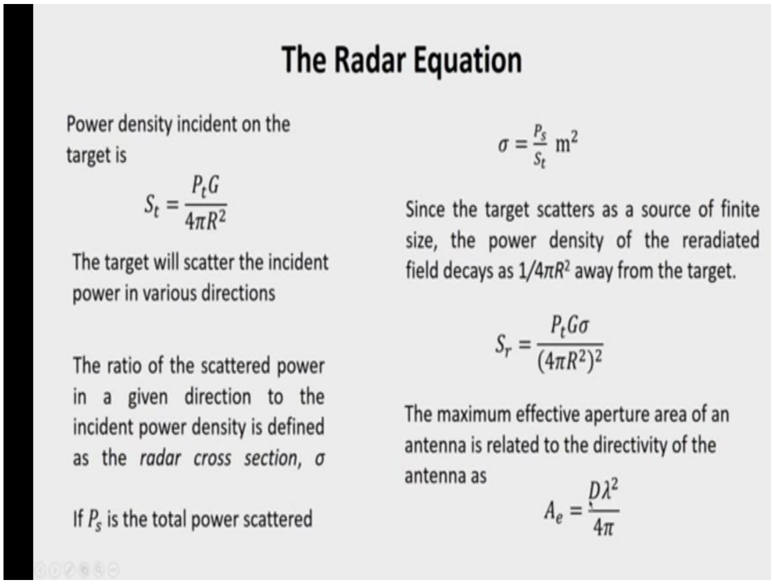
This is the radar equation. As the received power varies as $1/R^4$, high-power transmitter and a sensitive low-noise receiver are needed to detect targets located at long ranges.

$$S_t = \frac{P_t G}{4\pi R^2}$$

$$\sigma = \frac{P_s}{S_t}\ \mathrm{m}^2$$

$$S_r = \frac{P_t G \sigma}{(4\pi R^2)^2}$$

$$A_e = \frac{D\lambda^2}{4\pi}$$



The Radar Equation

Power density incident on the target is

$$S_t = \frac{P_t G}{4\pi R^2}$$

The target will scatter the incident power in various directions

The ratio of the scattered power in a given direction to the incident power density is defined as the *radar cross section*, σ

If P_s is the total power scattered

$$\sigma = \frac{P_s}{S_t}\ \text{m}^2$$

Since the target scatters as a source of finite size, the power density of the reradiated field decays as $1/4\pi R^2$ away from the target.

$$S_r = \frac{P_t G \sigma}{(4\pi R^2)^2}$$

The maximum effective aperture area of an antenna is related to the directivity of the antenna as

$$A_e = \frac{D\lambda^2}{4\pi}$$

For electrically large antennas effective aperture area is often close to the actual physical area. But for many other types of antennas, the common ones say dipoles or loops antenna. There is no simple relation between the physical cross-sectional area of the antenna and its effective aperture. So, suppose we will have a loop antenna of radius R. So, the physical cross-section is pi r square what we are talking is an effective aperture. This effective aperture is different from the physical aperture, and when the incident power density at the antenna is multiplied by the effective aperture, we get the power that is intercepted by the antenna.

To include the effect of losses in antenna, D is replaced by gain G and therefore Pr becomes Sr into Ae with D replaced by G and when these terms are substituted we get Pr is equal to Pt G square lambda square sigma (4pi) r divided by 4pi cube into R to the power of 4 and this equation is the radar equation. As the received power varies as 1 by R to the power 4, high power transmitter and a very sensitive low noise receiver are needed to detect the targets if they are located at long distances.

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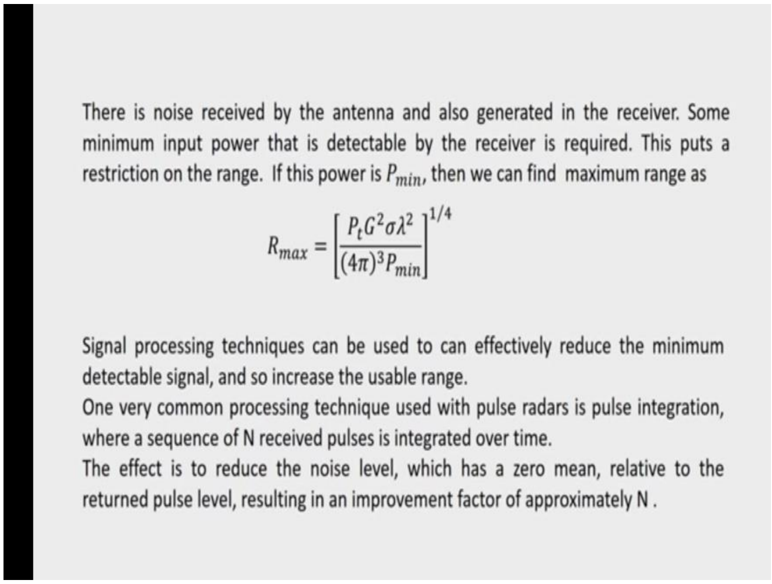
$$R_{max} = \left[\frac{P_t G^2 \sigma \lambda^2}{(4\pi)^3 P_{min}}\right]^{1/4}$$



There is noise received by the antenna and also generated in the receiver. Some minimum input power that is detectable by the receiver is required. This puts a restriction on the range. If this power is P_{min}, then we can find maximum range as

$$R_{max} = \left[\frac{P_t G^2 \sigma \lambda^2}{(4\pi)^3 P_{min}}\right]^{1/4}$$

Signal processing techniques can be used to can effectively reduce the minimum detectable signal, and so increase the usable range.

One very common processing technique used with pulse radars is pulse integration, where a sequence of N received pulses is integrated over time.

The effect is to reduce the noise level, which has a zero mean, relative to the returned pulse level, resulting in an improvement factor of approximately N .

As there is noise received by the antenna and also generated in the receiver. Some minimum input power that is detectable by the receiver is required. Because we require some minimum Snr and this puts a restriction on the range. If this power that is required at the receiver input is denoted by Pmin then we can find the maximum range or the distance as Rmax equal to Pt G square sigma lambda square divided by 4pi cube into Pmin all raise to the power 1 4th so this gives the maximum target distance from where if we get a backscattered signal that can be processed by the radar and can be detected.

Signal processing techniques can be used to effectively reduce the minimum detectable signal. So, this Pmin that we require can be very low when we employ a very advanced signal processing technique, and if Pmin reduces then it increases the Rmax. One very common processing technique used with pulse radar is pulse integration, where a sequence of N received pulses is integrated over time. So, here we know that the noise is essentially 0 mean. So, if we integrate the received signal over N number of pulses we can improve the Snr. And this Snr improvement is approximately by a factor of N.

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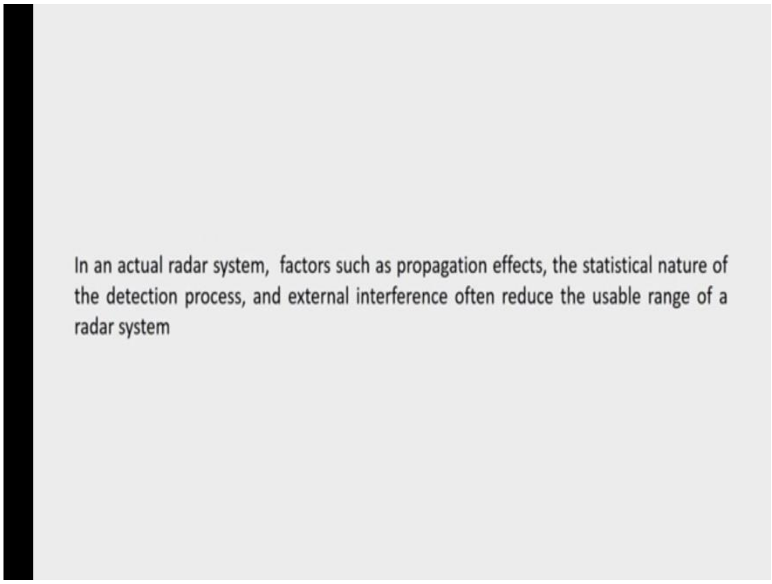

In an actual radar system, factors such as propagation effects, the statistical nature of the detection process, and external interference often reduce the usable range of a radar system

In the actual radar system, factors such as propagation effects, the statistical nature of the detection process, external interference often reduce the usable range of the radar system. So, we have discussed the basics of radar, we have discussed the radar configurations monostatic, bistatic configuration. We have discussed the radar cross-section of the target, and also, we have discussed the different frequency bands in which the radar operates and which frequency bands are suitable for what type of applications.

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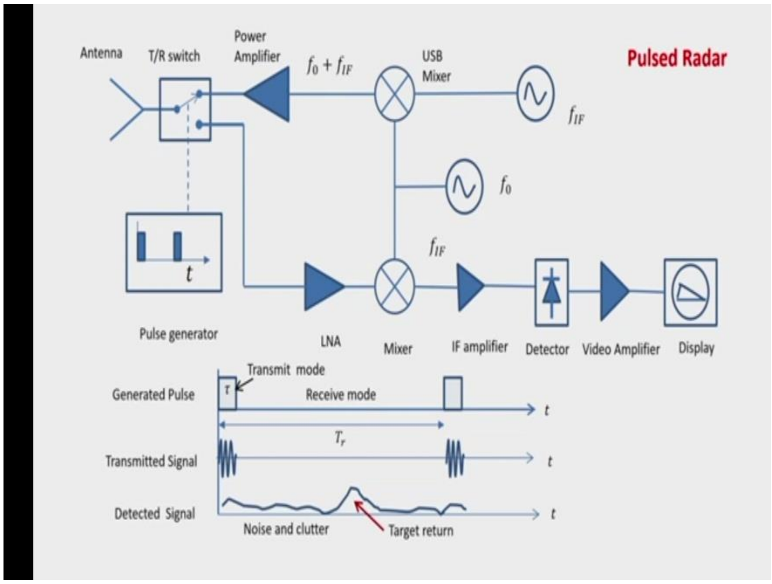

Let us now briefly discuss the two types of radars and their operation. First, we consider a pulse radar. Here, we show the schematic or the block diagram of pulse radar. So, we have an oscillator that produces intermediate frequency denoted by f_{IF}, and also, we have another oscillator that generates the main frequency f naught. Now, these two frequencies are mixed, and this is an upper segment mixer. So, after multiplying this f naught and $f_{IF,}$ this mixer filters out the sum of the two frequencies. So, we will have f naught plus f_{IF} this is filtered out and then a signal of this frequency f naught plus f_{IF}. It is given to the power amplifier, and output of the power amplifier is given to the antenna, which radiates this frequency.

Now, we can say that same antenna is used for transmission as well as the reception of the signal, and the antenna is connected to the rest of the radar system by a T R switch or a transmit received switch, and it is operated by a pulse generator. So, when this switch is connected here, the signal having frequency f naught plus f_{IF} is transmitted by the antenna, and then this switch is move to the other location, and the antenna goes in the receiving mode. So, during this period in the transmit mode, we essentially transmit an Rf pulse, which is having frequency f naught plus fIF, and it is active of duration tau. Now this Rf pulse when it hits the target and the signal is scattered back, and it is picked up by the antenna.

At this moment, this T R switch is connected to this location, and therefore the antenna is in the receiving mode. Now in the receiving mode, this signal is returned by the target and having frequency f naught plus fIF. Of course, it is a moving target then will have some frequency shift produced. It comes to the LNA, and then this low noise amplifier amplifies the received signal, and it is fed to the mixer.

Now, here we can see that this f naught is also fed to this mixer, and here again sum and reference frequency will be produced and this mixer will give f naught plus fIF minus f naught that means fIF intermediated frequency and then this goes to the intermediate frequency or IF amplifier. Then this IF signal is detected by a detector. Now, this detected signal is given to a video amplifier, and finally it is displayed in the display unit.

So, we can see that after transmitting the RF pulse the systems goes in the receiving mode. And the total time between the two pulses is represented by T_r. And 1 by T_r will be the pulse repetition frequency. Usually, it is of the order of 100 kilohertz. So, out of this time T_r only a small fraction of the time tau is used for transmission of the Rf signal and remaining time the system operates in receiving mode.

So, it picks up the noise, clutter as well as return from the target, and it is adjusted in such a way that the target return appears when the system is operating in the receiving mode, and then the next pulse is transmitted. This TR switch provides very good isolation because this switch after transmitting it is connected to the position corresponding to receive board. And since it is a switch the isolation between the transmit unit and receive unit is very high.

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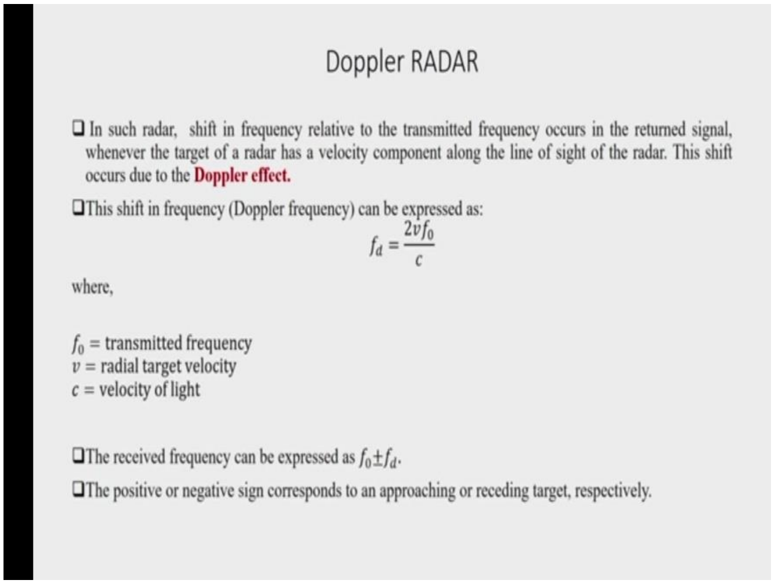
$$f_d = \frac{2vf_0}{c}$$



Doppler RADAR

- ❑ In such radar, shift in frequency relative to the transmitted frequency occurs in the returned signal, whenever the target of a radar has a velocity component along the line of sight of the radar. This shift occurs due to the **Doppler effect.**
- ❑This shift in frequency (Doppler frequency) can be expressed as:

$$f_d = \frac{2vf_0}{c}$$

where,

f_0 = transmitted frequency
v = radial target velocity
c = velocity of light

- ❑The received frequency can be expressed as $f_0 \pm f_d$.
- ❑The positive or negative sign corresponds to an approaching or receding target, respectively.

We next consider another type of radar which are called Doppler radar. So, in this type of radar, a shift in frequency relative to the transmitted frequency occurs in the returned signal. Whenever the target of radar has a velocity component along the line of sight of radar. And this shift occurs due to Doppler shift. We know that whenever we transmit signals from a source and it is reflected back by the target, and the target is a moving target. In that case, depending upon the direction of movement, it will produce a shift in the frequency of the returned signal. The frequency may increase or decrease depending upon whether the target is approaching the source or it is moving away from the source.

Now, this shift in frequency for radar can be expressed as f_d is equal to 2v f naught by c. So, we see that the Doppler shift produced depends on 2 parameters one is the velocity v of the target and also the operating frequency f naught. For a given operating frequency, higher velocity will produce a larger Doppler shift. Similarly, if we are operating for the same target velocity, if we are operating the radar at a higher frequency we will have higher Doppler shift. Now the received frequency can be, either f naught plus f_d or f naught minus f_d, depending upon the direction of movement of the target. Positive or negative sign corresponds to an approaching or receding target, respectively.

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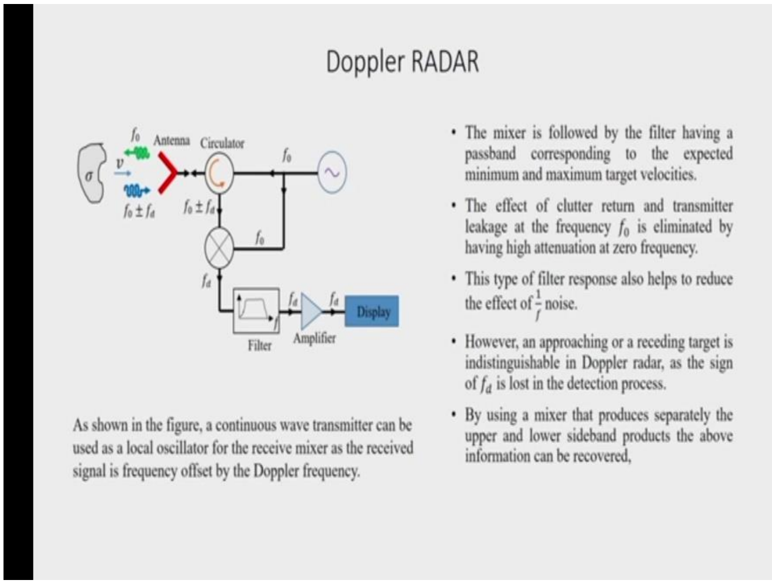

Doppler RADAR

- The mixer is followed by the filter having a passband corresponding to the expected minimum and maximum target velocities.
- The effect of clutter return and transmitter leakage at the frequency f_0 is eliminated by having high attenuation at zero frequency.
- This type of filter response also helps to reduce the effect of $\frac{1}{f}$ noise.
- However, an approaching or a receding target is indistinguishable in Doppler radar, as the sign of f_d is lost in the detection process.
- By using a mixer that produces separately the upper and lower sideband products the above information can be recovered,

As shown in the figure, a continuous wave transmitter can be used as a local oscillator for the receive mixer as the received signal is frequency offset by the Doppler frequency.

Here, we show the block diagram of a Doppler radar. We have a signal source that produces a frequency f naught. Now, this signal is given to a circulator. The circulator connects this signal to the antenna which is transmitted. And this is the transmitted signal. Here we have the target with radar cross-section sigma and suppose this target is moving with a velocity v and, therefore, in the returned signal will have a frequency shift. And it is denoted by f naught plus-minus f_d, here of course if you consider these to be the direction of velocity then it will be f naught plus $f_{d,}$ but in general it will be f naught plus-minus $f_{d.}$ Now, when this signal is incident in this port of the circulator by the property of the circulator, it will be transmitted to this port and not to the other port.

And this signal having frequency f naught plus-minus f_d in this mixer it is multiplied by the signal frequency f naught, and the difference of these two gives f_d at the output of the mixer. And then this is filtered out, now the range of the filter or the bandwidth of the filter is set according to the maximum velocity of the target that we are going to detect. Now, this signal f_d is then given to the amplifier, and finally, it is given to the display unit. We find that this velocity v this Doppler shift f_d is related to the velocity v of the target. So, a continuous wave transmitter can be used as a local oscillator for the receive mixer as the received signal is frequency offset by the Doppler frequency.

The mixture is followed by the filter having a passband corresponding to the expected minimum or maximum target velocities. The effect of clutter return and transmitter leakage at the frequency f naught is eliminated by having high attenuation at 0 frequency. So, if we have a since will have this mixture, we will subtract a f naught. So, any clutter return and transmitter leakage around f naught will translate near 0 frequency, and therefore we require very high attenuation near 0 frequency.

And this type of filter response also helps to reduce the effect of 1by f noise. But the approaching or receding target is indistinguishable in Doppler radar, as the sign of f_d is lost in the detection process. So, here we can see that we have returned here f naught plus-minus $f_{d,}$ but thereafter mixing operation it is only f_d . So, by using a mixture that produces separately the upper and lower sideband products the above information can be recovered.

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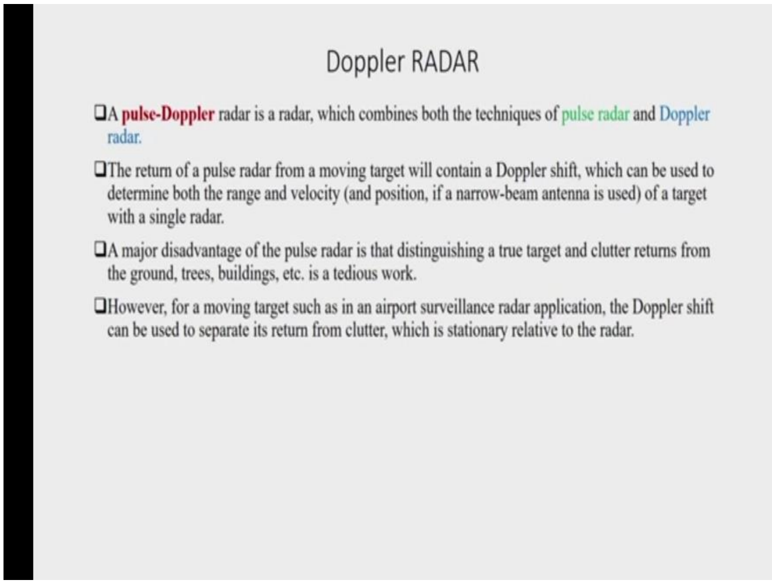

Doppler RADAR

- ❑A **pulse-Doppler** radar is a radar, which combines both the techniques of pulse radar and Doppler radar.
- ❑The return of a pulse radar from a moving target will contain a Doppler shift, which can be used to determine both the range and velocity (and position, if a narrow-beam antenna is used) of a target with a single radar.
- ❑A major disadvantage of the pulse radar is that distinguishing a true target and clutter returns from the ground, trees, buildings, etc. is a tedious work.
- ❑However, for a moving target such as in an airport surveillance radar application, the Doppler shift can be used to separate its return from clutter, which is stationary relative to the radar.

A pulse-Doppler radar is a form of radar, which combines both the techniques of pulse radar and Doppler radar. The return of a pulse radar from a moving target will contain a Doppler shift, which can be used to determine both the range and velocity. And also the angular position if a narrow beam antenna is used of a target with a single radar. So, by measurement of pulse delay, we can find out the range from the frequency shift produced in the signal, returned signal we can find out the velocity, and finally if we are using a very narrow beam for transmission. So, by observing the angle of the transmitted beam we have knowledge about the angular position of the target.

A major disadvantage of the pulse radar is that distinguishing a true target and the clutter returns from the ground, trees, building, etc is tedious work. So, if the targets are static it is very difficult to identify the true target, but for a moving target as in an airport surveillance radar application, the Doppler shift can be used to separate its return from clutter, which is stationary relative to the radar.

So, when we have the background, which is relatively stationary and the target which is moving at high speed it is easy to detect the target. So there are many other advanced form of radar, which have been developed over the year. In this lecture, we have only discussed the fundamental principles behind the operation of these radar system, and the radar systems they employ high power sources for transmitting signals covering a very long range and therefore some of these high power microwave sources that we have discussed particularly magnetron is very-very useful in the context of radar.