# Principles and Techniques of Modern Radar Systems

**Prof. Amitabha Bhattacharya**
**Department of E & EC**
**Indian Institute of Technology, Kharagpur**

## Lecture - 02
## Radar Bands and System Modeling

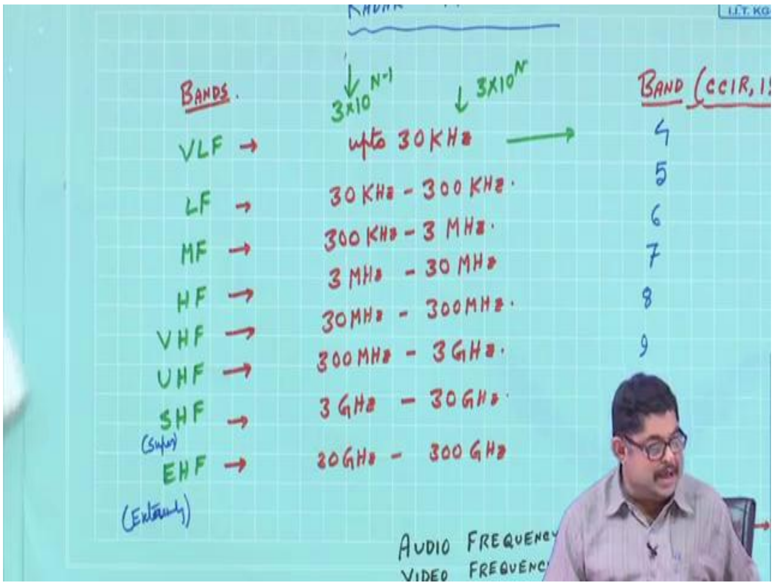
**Key Concepts:** Introduction to the Radar Frequency Bands, CCIR 1953 nomenclature of freqeuncy bands, Primary function of a radar, Introduction to basic model of radar

Welcome to the second lecture of this course on Principles and Techniques of Modern Radar Systems. Now the first lecture was an introduction, we have seen various history of radar development; then we have seen the applications. Now today we will see the technology the simple things. First Radar Bands; actually radars can operate in radio frequency bands.

So, there was actually as the historical development pointed out that it was invented due to first defence applications. So, initially there was some secrecy because it is very important to keep it secret from enemies what is the band of frequency in which the radar is operating, because if it is known to the enemy then enemy can fool the radar.

That is why there were some secret nomenclature, but after the World War in 1953; the scientific community they actually tried to make this radar band nomenclature scientific; so that first we will see.

(Refer Slide Time: 01:45)




So, you see that actually audio frequency; now what is audio frequency all electronics students know. That audio frequency is we can roughly say we know 20 Hertz to 20 kilo Hertz, but for radar actually you see that the velocity of light is 3 into 10 to the power 8. So, we will make instead of 2; everything in terms of 3. So, we can say audio frequency is 30 Hertz to 30 kilo Hertz. So, this is not radio frequency and what is video frequency? So, we know that if you want to communicate a video signal; then roughly you can say that up to 30 mega Hertz you can go.

Now, actually the radar bands they start just above this 30 kilo Hertz. So, generally radars they do not radars are a high power signal. So, if they are co located with other bands then there will be  problem; obviously, this audio frequencies when communicated they are communicated in some other frequency.

Obviously, in these bands you will see that there are lot of interference possible because these bands were mainly communication. And initial days radars they also were using those equipments later gradually they shifted to more higher frequencies giga Hertz frequencies and defence never operated in these lower frequencies though in World War 2; they operated in the communication frequencies, but gradually they after World War 2 they shifted to the real microwave frequencies.

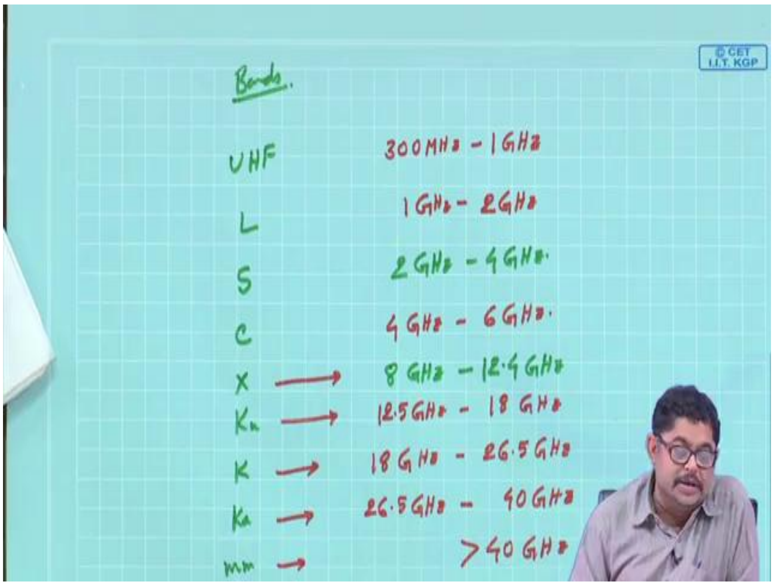
But while nomenclature coming this radar frequencies, they got divided into this starting from very low frequency. Now very low frequencies anything up to 30 kilo Hertz; then anything between 30 kilo Hertz to 300 kilo Hertz is called low frequency; these are bands. So, I can say that these are radar bands, then medium frequency 300 kilo Hertz to 3000 kilo Hertz or we can say 3 mega Hertz.

Then high frequencies 3 mega Hertz to 30 mega Hertz very high frequency V stands for very; so 30 mega Hertz to 300 mega Hertz. Then came ultra high frequency, so 300 mega Hertz to 3000 mega Hertz which can be called 3 giga Hertz. Then super this S stands for super high frequency; so, this is 3 giga Hertz to 30 giga Hertz and E is extremely high frequency; so, that is 30 giga Hertz to 300 giga Hertz; so you see it is always a change of decade.

Now accordingly actually this bands they were; while giving the name actually these were the communication peoples name. Radar people, scientifically they try to give this name. So, this was called band 4; so, first VLF band was band 4 band 5, band 6, 7, 8, 9 10, 11. How this numbers are coming? You see that lower end; lower end of the frequency band write that as 3 into 10 to the power N minus 1 in Hertz and this upper end make it as 3 into 10 to the power N.

So, 30 kilo Hertz means 3 into 10 to the power 4 that is why it is a band 4; so this N is giving you that band. So, this is what 3 into 10 to the power 5 that is why band 5. So, this was the scientific community decided that if someone says band 8; radar band 8 that will imply 30 mega Hertz to 300 mega Hertz. But unfortunately this nomenclature was never become followed in the industry and still the military bands which does not have any scientific basis they goes.

(Refer Slide Time: 07:49)




So, the radar people; they give this names UHF is UHF same from communication. But after that they give L actually all these are arbitrary, but everyone in the radar field they understand the meaning of these bands. So, we should know them that is why I am introducing them. So, these are the names of the band and frequency wise UHF means 300 mega Hertz to 1 giga Hertz.

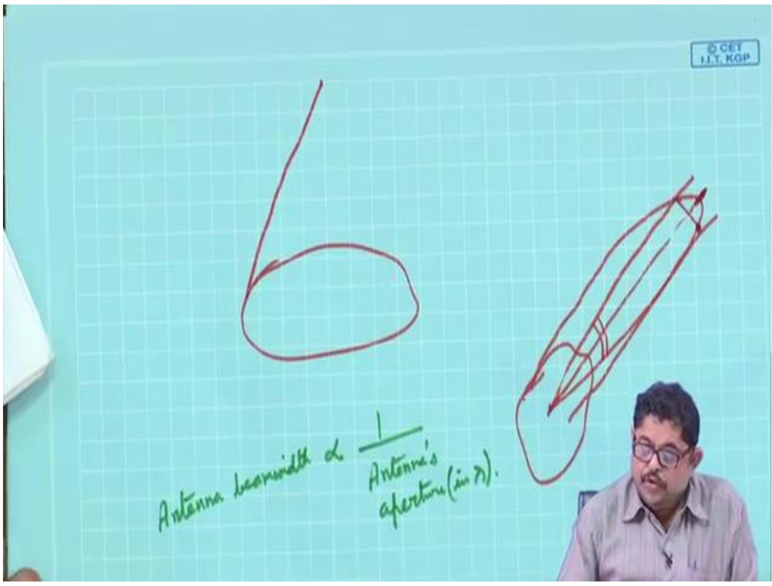
You see here that scientific thing is not followed it should have been 3 giga Hertz but it is up to 1 giga Hertz. Then L band which is a very popular band in satellite industry it is 1 giga Hertz to 2 giga Hertz. S band; which is a very popular band in various application, sometime satellite application sometimes even defence application; it is 2 to 4 giga Hertz, then C band it is a very good band for satellite people; so it is 4 giga Hertz to 6 giga Hertz. Then X band actually all military radars were earlier in this band; it is from 8 giga Hertz, exactly speaking it should have been 8.2 giga Hertz, but we can loosely say 8 to 12.4 giga Hertz.

Then K u band you see that K band will come later, but K u come earlier; so it is 12.5 giga Hertz to 18 giga Hertz. Then came K band 18 giga Hertz to 26.5 giga Hertz; then there is a Ka band; actually there is a very good for propagation people this is an important band. Nowadays, even satellite people are also using this band heavily and then comes the millimetre band.

So, anything greater than 40 giga Hertz actually in last 10, 20 years there is another band came which is called terahertz band. Roughly you can see that millimetre wave is extending up to 300 giga Hertz; after that anything is loosely called tera Hertz.

So, early radars they as we have seen in the development they operated at HF band; high frequency band. So, according to this nomenclature high frequency 25 megahertz means that will be HF, but why that was used? Because that time high power sources radar always needs high power sources. So, high power sources were easier to develop at a HF band in those days because communication technology was there some simply modify that and give some high power things. So, that is why, but the drawback of that is if you were smaller in frequency there is a problem.

(Refer Slide Time: 11:41)

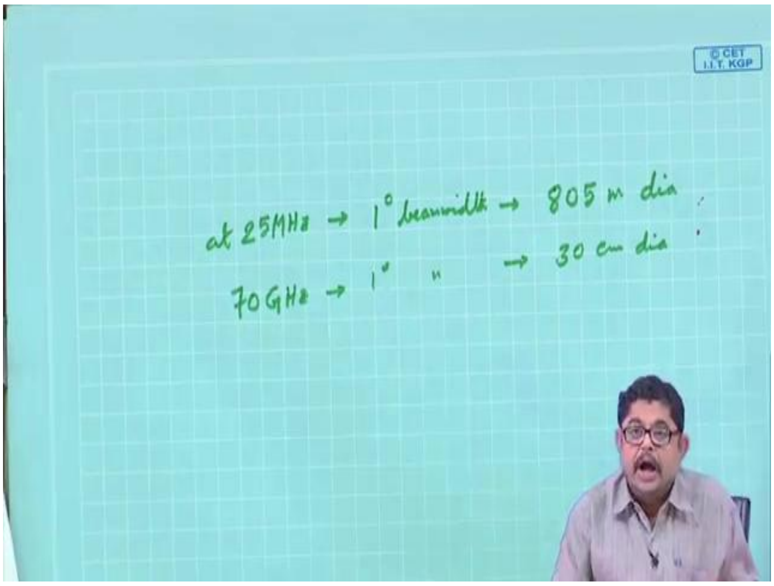



Actually, if you have any antenna the antenna's angular resolution; that means or I can say that antenna's beam width. You know any arbitrary antenna any arbitrary antenna; now this all this radio waves which are not in the frequency of light or even actually light also now anything when it radiates any antenna when it radiates; there is a beam it is not a straight line thing. But in case of light etcetera the beam width is so small that we almost say that it is a straight line thing.

Now, in case of this microwave things the antenna that has a beam width. Now beam width means the suppose the beam is like this; so we say that this is the peak direction and from some reference. And then generally we come that took a compare to this radiation if it is a power radiation then 3 dB down locate two points.

So, then from that reference you get this two; this angle is called the antenna 3 dB beam width. Now you see in our antenna courses we defined all these things band width. Now unfortunately this antenna’s beam width; antenna’s beam width is we can say inversely proportional to the antenna’s dimension or antenna’s aperture in wavelength.

(Refer Slide Time: 13:42)




So, the fall out of these is that suppose at 25 mega Hertz; at 25 mega Hertz, to get a 1 degree beam width because why I need smaller beam width? Because beam width means in that portion my maximum power is concentrated. So, suppose if I want to detect something, if I can localise the power then I am making efficient use of the power.

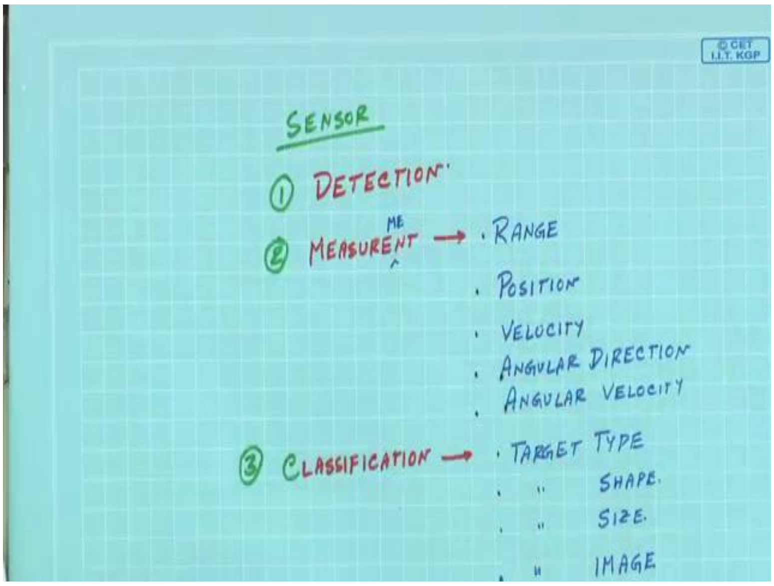
But if I spread the beam, then lot of portions are getting illuminated which are not wanted; my information will not come from there that is why it is always good to have smaller beam width. And later we will see that on this here resolution in the angle etcetera angular resolution depends.

So, if you do the calculations; antenna people can do the calculation that to get a 1 degree beam width at 25 mega Hertz; if I have the best possible antenna, suppose a parabolic dish reflector antenna I require 105 metre dia antenna 805 metre dia. You see in our home we see 1 meter dia dishes; 1 metre, 1.3 meter etcetera. Think of 805 metre dia; so it is a not a practical system at 25 mega Hertz.

But the same thing suppose I scale up; that at 60 giga Hertz; I require the same beamwidth I can show that it will require only 30 centimetre dia. So, see the advantage that if I go to the giga Hertz range; the thing become practicable, so that is the need of microwave technique. But then at the microwave technique at the high frequency it is a giga Hertz range; there the lumped circuit model does not work; so I will have to see go to the distributed circuit model.

And if I go further up 70 giga Hertz it is actually a millimetre wave religion; there not even the distributed model there I will have to find the optical techniques etcetera required; so that is the things. Now let us start first with a; so before that I can say that radar we should remember that radar is a very good sensor; obviously, when it is detecting; that means it is a sensor.

(Refer Slide Time: 16:21)




Now what are the primary functions of radar? First thing is as the name suggests that if the primary function of this is detection. There is no doubt about it that I will have to detect whether there is an object or not.

Now that does not mean that I am doing any measurement, but radar also; nowadays radars they not only say that there is something they also make some measurement. So, what type of measurement a typical radar makes? So, measurement; it measures first thing is range that we see that every radar should measure range. Also it can measure the position of a target; it can also be used to measure velocity because from mechanics; if I know that if I know the position and if I knowing this position as a function of time easily I can find velocity that is the principles of mechanics.

So, velocity can be done; also if I know velocity correctly I can find out also the other accelerations etcetera. But those are not generally a thing up to velocity generally a radar measures. Also you see that to specify a particular object; if I know the range of the object then actually I am in a coordinate system three dimension I am using only one dimension.

So; that means, there are lot of places where that target maybe if I specify the range. Because suppose if I say that some object is there at a distance of 10 kilometre, basically I can say that on a spherical surface anywhere it can reside; at a distance of a 10 kilometre; that means, at a radial distance of 10 kilometre.

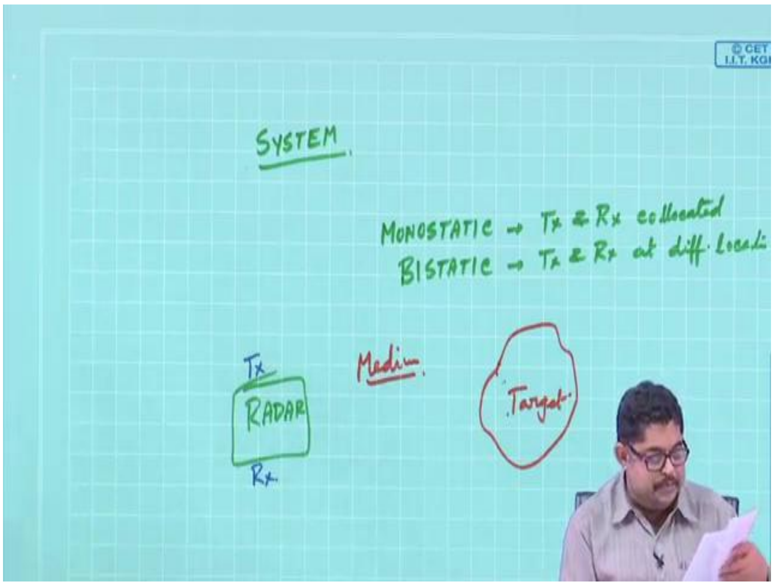
So, to exactly specify the thing I need to have two more informations; you see in a global scale these are sometimes called azimuth, elevation etcetera and so; that means, two more angular informations are necessary. So, radar also measures angular directions; angular directions. So, the moment I know angular direction and if I know it as a function of time; I can measure also the angular velocity. All these are vector quantities 3 D quantities; so these are generally measured. So, sensor the radar sensor detects the radar measurement m e n t; measurement.

And nowadays with the advance of radar technology; another job of radar is coming that is called classification. So, after measurement you also give more information that what is the class of the target? So, here one thing is can you say what is the target type; what type of target it is? Is it a bar? Is it a plane? Is it a missile? Then what is the shape of the target? What is the size of the target? And finally, this is leading to can you give me an image of the target?

Now, image means a description may be in two dimension, maybe in three dimension of very small dots or pixels per unit area. Can you give that? Now actually the radar is going here the image it is giving that image may not be comparable to the optical camera image, but it is going into this direction. So, a radar technique student; he should be aware that the radar sensor it can be used for all this things, this three major thing. It can detect, it can be used as a measurement tool, it can be used as a classification tool.

Now let us come to a very basic design of the, or very basic model of the radar because it is a complete system that system consists of certain things.

(Refer Slide Time: 21:52)




Obviously, it is a, you see that this system there will be radar as a system we are saying. So, what does that mean? System means it can be called whether it is an active system or a passive system. Now the meaning means that if I, actually radar works on radio waves.

Now, radio waves are always present; you see that everywhere the radio wave is present, even in the outer space also there are radio stars; so they are creating a background radio noise. So, now from that; so every object is absorbing that and scattering that, so some radars they detect that; that means, they do not give their own source of power, but from the background the every target that is radiating some radio waves and it is detecting that the radar those are called the passive radars.

But it is not very good technology. So, people in radar things they generally go for active radars, where they themselves pump some power, radio waves, known signal etcetera known power. And then find out what is the eco and from that they try to do all those sensing functions of detection measurement classification; those are called active radars.

Also radar has a transmitter. So, an active radar has a transmitter and all radars have whether passive or active; they have a receiver.

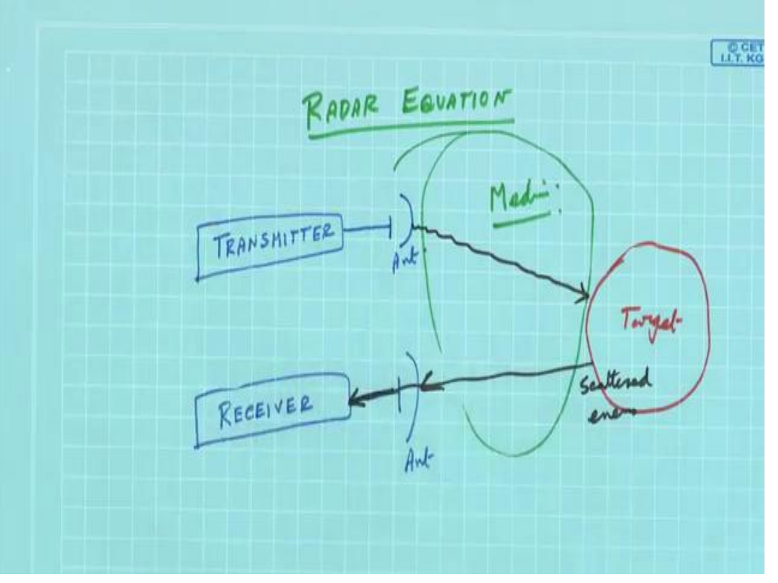
Now, if this transmitter and receiver they are co located then it is called a monostatic radar; mono static; that means, transmitter and receiver co located in the same place. If not if they are separated they are called bistatic radar, at different location. Then what is the medium between the; so I can say that I can see this is a radar now this is a target. Now in this radar block there can be; if it is a monostatic radar, there is a transmitter, there is a receiver.

If it is not a monostatic radar then there will be a transmitter block; there is separately there will be a receiver block, but all of them will have a target. Now there is a medium in between, so this is the intervening medium. Now what is this medium based on that there may be a; so it may be a, in the outer space, there will be some type of medium. In the atmosphere there will be some type of medium, in the lower atmosphere and upper atmosphere the medium is different etcetera; so, medium also needs to be known.

Then and when we say transmitter question will come what is the power; what is the power, what is the frequency, what is the antenna used, what is the wave form of the radar signal? Similarly in case of receiver the question will come how much; how much small signal it can detect; that means, what is the sensitivity of this receiver, what is the noise sensitivity of the receiver, what is the signal processing done in the receiver etcetera? So, based on this we will have to change the models etcetera.

So, the first thing that we will see is what is the basic model, because you see we engineers we always try to give a complex problem radar is a complex problem a complete system. Now unless and until mathematically we use modelling, we cannot play with it. So, all engineering studies are basically modelling mathematical modelling the actual system. So, we will also approach these radar study; this whole course we will start with a very simple model which we will be calling radar equation.

(Refer Slide Time: 27:00)




Though the name is equation it would have been more appropriate had it in called a radar model or something. So, this is called radar equation or radar range equation etcetera; now we will see in the next class, but we will start from here that what is the model.

We will take a general case that there is a transmitter; there is a receiver. Now here deliberately we have shown them separately; if it is a mono static radar that will be co located this two blocks and this transmitter is connected to a transmitting antenna. Now from there, there is a target here; now from here electromagnetic wave will go here.

The target will be illuminated by that. Then target will take that energy and scatter back the energy. Remember scattering is different from reflection that it is not plane reflection because depending on the body it will scatter how much power that depends on the body. So, a metal will reflect the whole thing; that means, the whole energy it will reflect. A non metal will reflect some portion, will scatter some portion of the thing.

Now depending on the shape, depending on the size, depending on the material of this target, how much energy will be scattered that will depend? Also in which direction how much power will go; that means, angular distribution of the scattered power; that also depend on the target etcetera. So, we will say always that is why scattered energy; that means, it is a secondary phenomenon.

Initially, the target is getting some illumination from the transmitter then it is re radiating that; that means, it is scattering and a portion of that will come to the. Sorry, this receiver also will be connected to an antenna this is an antenna, this is also another antenna. So, the scattered energy; this is the scattered energy that is coming and falling here.

The receiver through the antenna it is taking that and then it will do some processing and do those functions, detection, measurement, classification. So, this is our problem the whole thing in between; this is a medium. Now this problem, we will have to convert to a mathematical model that is radar equation that we will see in the next lecture.

Thank you.