Millimeter Wave Technology.
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Lecture-02.
Introduction to Millimetre-Wave Technology (Contd.)

So now we are going to see some of the millimetre wave application which are already introduced.

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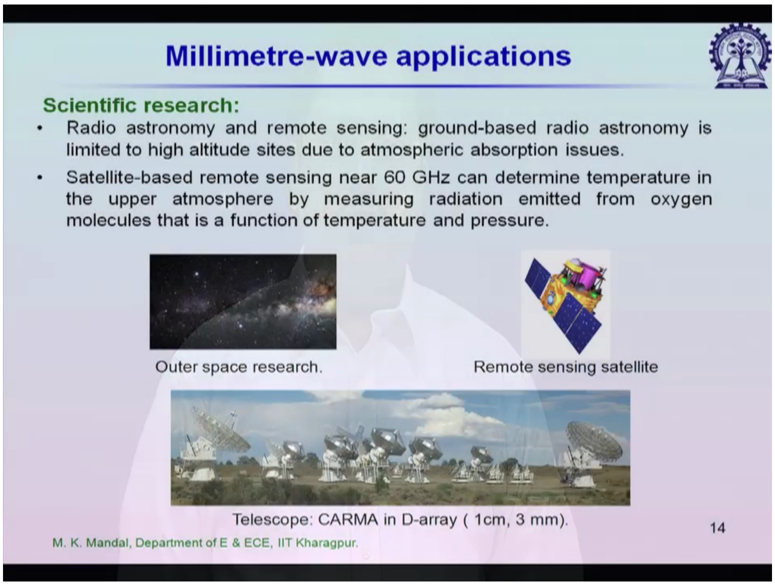

So the first one is in scientific research in space applications so we know that these galaxies stars they emits electromagnetic waves so starting from gamma rays, x rays, optical wave to even at millimetre wave frequencies so already we have imaging systems at optical wave frequencies at x rays frequencies so we can gather more information so if we have some imaging system at millimetre wave frequencies so that's why already different space based imager is there at millimetre wave frequency at sum millimetre wave frequencies even at tera hertz frequencies.

So which basically takes images of different galaxies and stars and we can extract information from this images more information which is which may not be available at optical frequencies so for example galactic dust it attenuates optical frequency x rays what the attenuation of millimetre wave frequencies compared to the optical frequencies is much smaller by this galactic dust so then if we formed any image at millimetre wave frequencies we can have more information about the galaxy.

So that's why imaging at millimetre wave frequency is very popular but one problem we faced when we go for millimetre wave imaging this is the atmospheric attenuation. So that's why ground best imaging which we called radio astronomy basically.

So its not very popular at millimetre wave frequencies we have to send these imaging or receiver in orbit and all these imaging systems are satellite based so in hubble space telescope in keplers keplers mission already they are being used not only at millimetre wave frequencies even at tera hertz frequencies.

So here one example so this photograph is taken at millimetre wave frequency. You can see the different stars here and not only that the galactic dust is also available here. So there was one millimetre wave array on earth its popularly known as CARMA D array. And typical frequency range it used 1 centimetre and 3 millimetres and it consist of 23 parabolic reflector antennas its quiet big it was a maintained by California institute of technology but right now its not in working condition.

So we put actual take image from ground based system by using this large aperture arrays and we could gather more many information by using this millimetre wave imaging systems so not only for radio astronomy we can also measure the upper atmospheric temperature at 60 gigahertz oxygen molecules they emits radiation and which is a function of temperature and pressure so by noting down the emission from this upper atmosphere we can determine the temperature.

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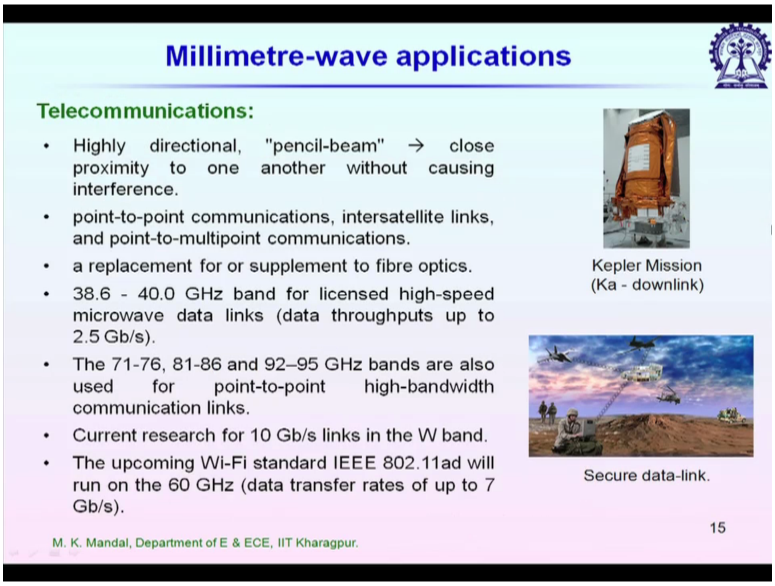

Some other application in telecommunication they are already being used by different satellite systems so at millimetre rate frequency we can generate pencil like beam so close proximity to one another without causing interference is possible. Point to point communications is possible so as a we have seen that millimetre wave we can use for line of sight communication.

So then from one satellite to another satellite link we can easily design at millimetre wave frequency so it can be a replacement or supplement to fibre optics. So for example 38.6 to 40 gigahertz band it is already being used for high speed microwave data link so as high as 25 GBPS. There are some more bands already in used for point to point and high bandwidth communication links. Like 71 to 76 gigahertz 81 to 86 gigahertz and 92 to 95 gigahertz.

So now scientist are now trying to increase the data (())(5:38) and as high as 10 GBPS and already some of the university groups they design this 10 GBPS link recently. So upcoming WI-FI standard for example IEEE 802.11ad will run on the 60 gigahertz typical data transfer rate up to 7BGPS so one advantage with this millimetre wave we see that secure data link is easily possible so that’s why its also popular in defence application.

So how the secure data link is possible because we can easily generate pencil like beam so we can send the electromagnetic signal to my desired direction and no other people will get the electromagnetic signal so we don’t need coding or anything so I will just send my pencil like beam to the desired receiver in desired direction so that’s how secure data link is possible using pencil beam.

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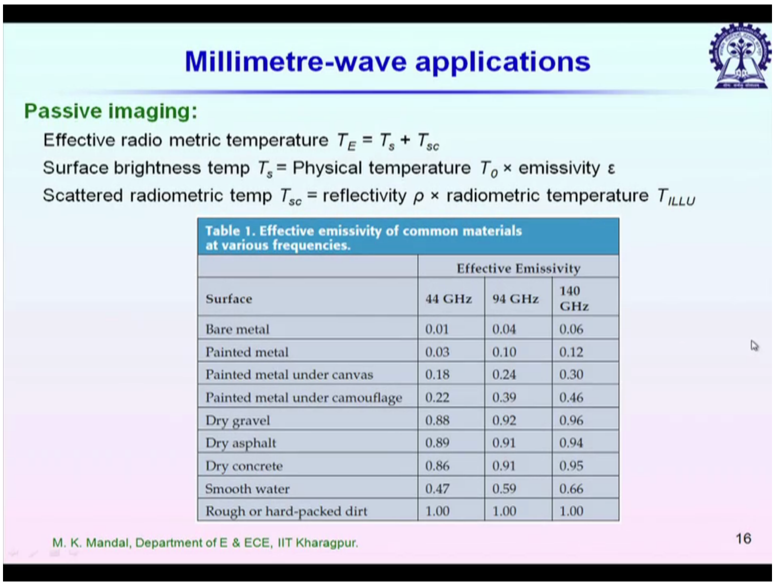

Some other application passive imaging so what is the define between passive imaging and passive imaging? In active imaging we use some sort of transmitter so for example in umm in remote sensing. So satellites they carry some transmitter which continuously generate microwave or millimetre wave pulses and these pulse illuminate the objects and then we can see this object by using umm receiver part of the radar.

So this is called the active imaging. In passive imaging we don't use any transmitter so due to black for the radiation all objects they radius some sort of power and the power spectrum is the function of the temperature of the particular object and emissivity of that particular object so we can utilize the emission by these objects without illuminating them so this is called passive imaging.

So the advantage of passive imaging you don't have to illuminate the object so you don't know the you don't know you are being imaging by some other person or not so this is then very use full for security application. So now when I deal with passive imaging we deal with several factors so two among these two word. So what is the emissivity of any object and what is the reflectivity of any object?

So when any other signal from any other source falls on anybody it will reflect that signal. It also happens at millimetre wave frequencies and reflection will be higher if the reflectivity of the object is higher. So for example metal its a good reflector so if anything falls on metal then it will reflect that power.

So why reflectivity is important at a for umm passive imaging because the outer atmosphere it is it has some finite temperature and it is also radiating electromagnetic signal. So these electromagnetic signal its constantly illuminating the umm objects in outdoor scenario and then we call it actually the dualing radiation and these dualing radiation is reflected by different types of objects.

So then for passive imaging we see that basically we have two different sources one is due to the reflected wave due to this dualing radiation and the second one is the black body radiation which depends on the emissivity of that particular object and the physical temperature of that particular object.

So now effective radiometric temperature of a any object TE it comprises of two component given as TS and TSC. So this TS we call it the surface brightness temperature it actually due to the black body radiation and it is equal to the physical temperature of the body lets say T not multiplied by emissivity of that object and the second term this is this scattered radiometric temperature.

So this is umm represents the reflection by object and this is equal to reflectivity (())(10:58) multiplied by radiometric temperature T illumination. Now if I go through different values for the effective emissivity of different material we see that emissivity it varies with material not only that emissivity its also a function of frequency for example bare metal it has an emissivity of point .01 at 44 gigahertz and it increases to .06 at 140 gigahertz and now if you go through the table then for the rough or hard packed dirt.

So its a very good emitter emissivity is 1 at 44 gigahertz at 94 gigahertz even at 140 gigahertz so if I consider that transmission through the medium is almost zero so in that case emissivity plus reflectivity that is equal to one so for bare metal then the emissivity is given as .01 then the corresponding reflectivity it will be point 99 similarly for the rough or hard packed dirt the effective emissivity is one.

So reflectivity will be zero so if any signal falls on bare metal it is going to reflect almost all of them but if it falls on hard packed dirt it will absorb all of them. so if we don't have a secondary source to illuminate this bare metal or hard packed dirt so in that case the due to the black body radiation we will expect more radiation from the dirt hot part hot packed dirt and less radiation from the metal.

So in case of we don't have lets say any secondary source and in that case if we do passive imaging so metal objects it appear as black colour and the since this dirt is emitting more power so it will appear as white in my picture.

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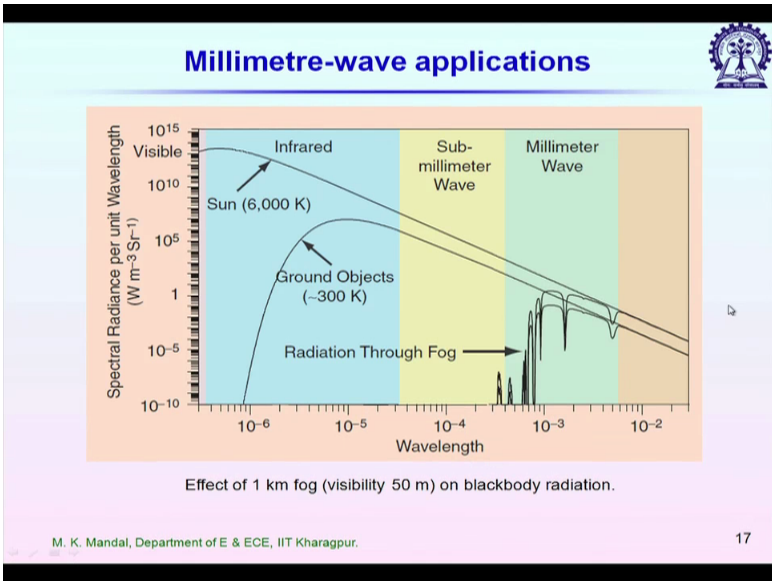

So next lets see what advantage we have umm at millimetre wave frequencies particularly for this passive imaging so this is showing the black body radiation which is a function of frequency and temperature so you can see left hand side we have spectral radiance per unit wavelength and along X axis we are plotting the frequency. So some it has surface temperature of six thousand Kelvin.

So the highest spectral density is at umm it corresponds to the yellow line of optical wavelength and if I increase the frequency for some it left hand side so it decreases and right hand side if I decrease the frequency it also decreases and the peak value where it will appear it depends on the temperature now if I consider any ground based objects lets say the temperature is 300 kelvin.

So in that case the peak value as you see it appears approximately in infrared frequency range so now if I go to right hand side at lower frequency first sub millimetre wave then the millimetre wave frequency range the efficienc the umm emission it decreases so if I compare typical values umm at infrared and at millimetre wave frequency umm at millimetre wave frequency this is approximately 10 to the power 7 times less than that at infrared frequency.

So that means if we design any passive imager we have to keep in mind that we are going to have a spectrum density which is much smaller so as high as 10 to the power 7 compared to what available at infrared frequency range but we have some other advantages at millimetre wave frequency.

So first of all millimetre wave receiver is much sensitive compared to infrared receiver. How sensitive approximately 10 to the power 5 times and not only that you can increase the received power by simply increasing your aperture area receiving aperture.

So you will you can use arrays and antenna arrays or you can use a wing size parabolic reflector to receive more power so then umm at the end of the day you have a comparable system umm at millimetre wave frequency but millimetre wave frequency some special advantage which we don't have at infrared. What is that advantage? Lets see

So even though we have seen that millimetre wave frequency it is attenuated by atmosphere or weather typical weather conditions like fog, dust storm, and rain but if I compared that attenuation with what we have at infrared frequency it is much less at millimetre wave frequency.

Let us take one example lets say we are measuring the same quantity under foggy condition typical visibility is 50 meter and in that case you can see this right hand side plot radiation through fog so for the infrared in clear con umm sky condition it was approximately 10 to the power 7 times and now even at 10 to the power minus 10 we don't have anything but at millimetre wave frequency it of course it decreases attenuation.

We have some finite attenuation due to fog but still may be umm just 10 DB per kilometre so if I can design any imaging system at millimetre wave frequency we can call it all weather imaging system so its very popular for defence application so you can take imaging even under heavy rain even under heavy fog, dust storm and even in sand storm condition. So all weather imaging is possible at millimetre wave frequency.

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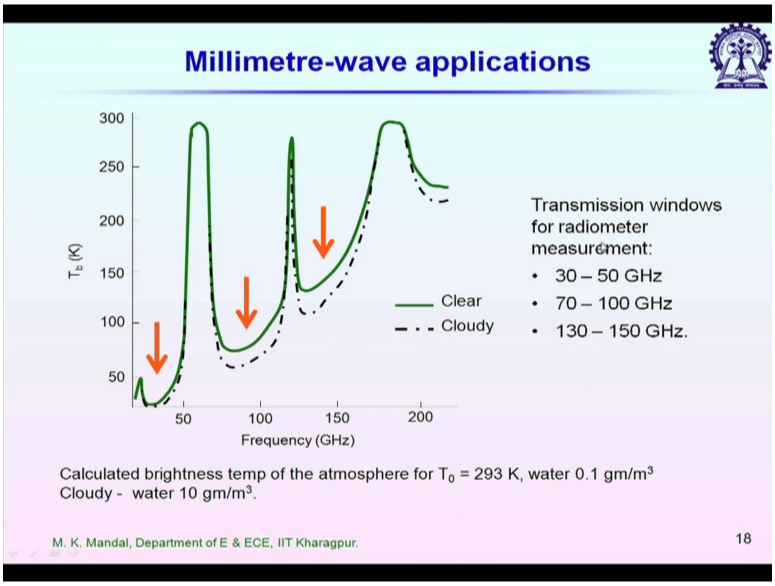

But when we go for imaging we have to keep in mind that we can use only some windows because we have some attenuation band so this is typical plot of temperature of atmosphere versus frequency so since at 60 gigahertz oxygen molecule it absorb power due to resonances so at 60 gigahertz atmospheric temperature will be very high.

So similarly at 118 gigahertz we have one more attenuation band again due to the oxygen molecule and near 180 gigahertz we have one more due to H2O molecule so for passive imaging only some windows are available we have to utilize those windows so here for example 30 to 50 gigahertz or 70 to 100 gigahertz or 130 to 150 gigahertz we can use these windows for any radiometric measurement or for passive imaging.

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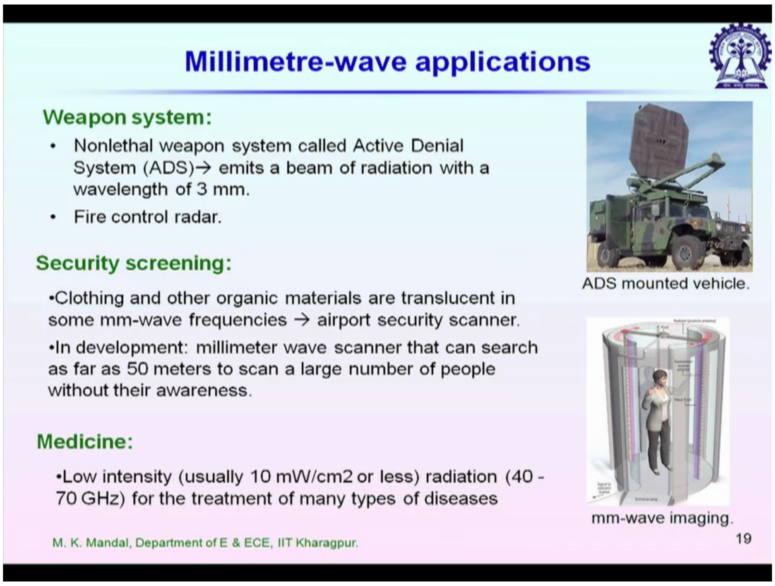

Some more applications weapon system. So its a nonlethal weapon system called active denial system or ADS you can see its mounted on a truck military truck. So what it does? It basically generates high intensity millimetre wave signal and umm typically it uses a frequency for which the wavelength is 3 millimetre.

And when it falls on any person they will have a burning sensation but due to the size of the system it did not become popular some other popular applications security screening. So millimetre wave it can pass through clothing and other organic materials so thats why but it does not pass through our skin and muscle so thats why we can use active millimetre wave imaging to find out if anybody is carrying any weapons or any other things and it is already in use in airport.

So for example this is you can see this photograph so what it does so they will ask you to enter one chamber as shown in this figure and we have arrays of millimetre wave antennas as can be seen here so it generates mil millimetre wave signal and we have another arrays of antennas which actually receives that millimetre wave signal and it can turns to perform the complete image.

And since millimetre wave it can pass through cloth but not through skin so it can shows picture and it can show if there is any hidden weapons is there or not. So at present scientist are trying for long distance millimetre wave imaging so once it possible most probably you don’t have to enter this chamber in airport.

So it can umm the target is 50 meter so it will be able to scan a large people without asking them to enter that chamber and without their knowledge it will be able to scan any hidden weapons. And least popular application in Russia it is used for medical application treat some diseases

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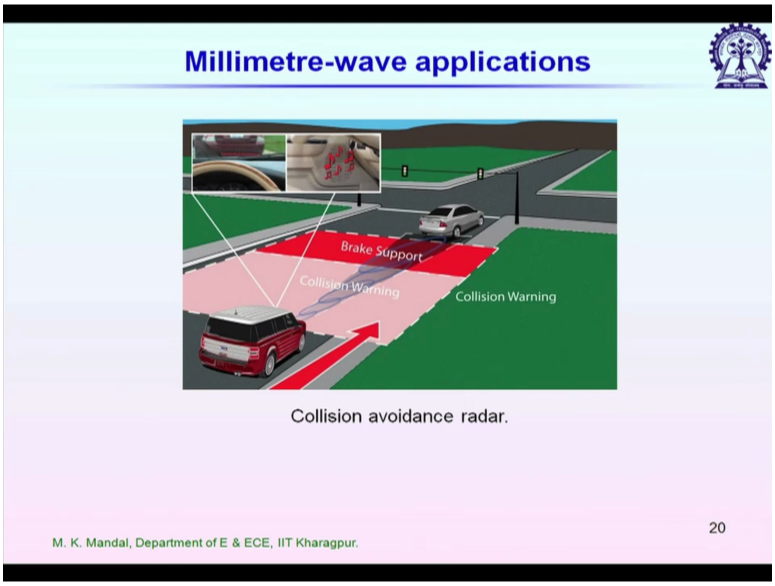

Another popular application collision avoidance radar it is already there so typically it uses 77 gigahertz spectrum so we have a one FMCW radar installed inside the car which constantly monitored the traffic in front of this and just beside it and when it is within a distance we call it collision warning distance then it will warn you by giving you some beep sound.

So we have seen that already we have different applications and to give you some ideas about the frequency range and the power already being used for different satellite based applications here is a chart.

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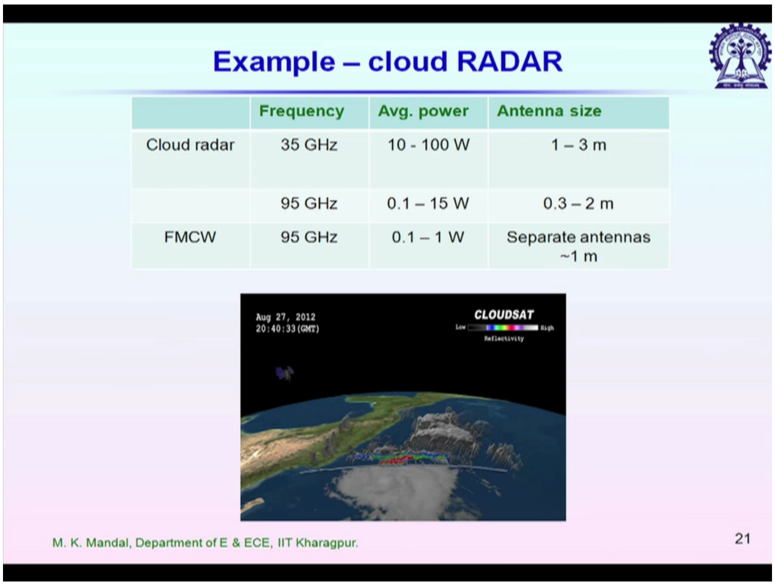

So for example for cloud RADAR its already in use typical frequency its operate at 45 gigahertz.And the average power 10 to 100 watt and antenna size it use 1 to 3 meter FMCW RADAR umm frequency 95 gigahertz in one type of system its working its transmitting power is point 1 to 15 watt and antenna size point 3 to 2 meter and in second category its point 1 to 1 watt and umm the antenna typical diameter is 1 meter.

So we have seen that already there are many millimetre wave systems its being used and now scientists are trying different other applications at millimetre wave frequencies typically for wireless systems but till now it is popular mainly in defence application. Why? Because of its cost so to minimize cost.

Or to reduce it we have to go for some new technology typically silicon germanium or CMOS by CMOS technology because whatever millimetre systems umm you are showing till now they are based on gallium arsenide or other group three group five material which are very expensive only military can afford this price.

So if you if we really want for consumer application so we have to first find out a solution so that it can be fabricated by using a cheaper process like CMOS and BICMOS and I will show you some of the examples so already scientist umm they fabricated some of these devices and in CMO in silicon and germanium technology and its already there in market.

So in near future we can expect that in consumer application so we will be using millimetre wave components millimetre wave systems. So next lets discuss some other things.

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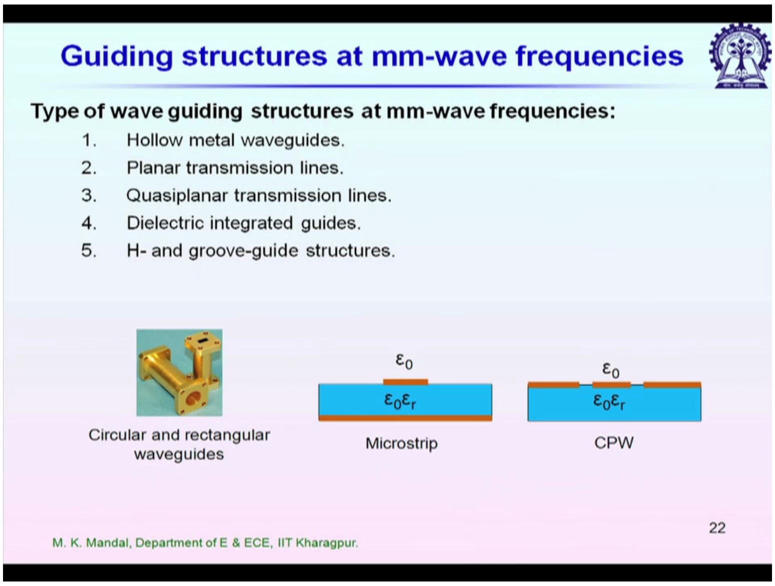

So different guiding structures so for this wireless medium we send millimetre wave signal from transmitter to receiver umm without using any wire or any guiding medium but when we design the millimetre wave system lets say a transmitting system medium or a receiving system so inside we have many components for example for the transmitter we have the source then we will be having filters, couplers and low noise amplifier, power amplifier.

So different components in a single system so we have to connect them so for these connection we need some wave guiding structures so then what are the popular wave guiding structures those we use at millimetre wave frequency. So we learnt these popular wave guiding structures in this class so some of them are listed here.

So hollow metal waveguide its very popular and its bulky but the main advantage is that its attenuation is minimum among all available solutions. And also it has highest power handling capability so thats why even though its bulky and expensive it is in use for millimetre wave umm for millimetre wave applications.

Then the planer transmission lines so at microwave frequencies we use micro strip line CPW line at millimetre wave frequencies they are (())(27:10) but for chip to chip communication we can still use it when umm its typical distances not more than a few millimetre we also have some quasiplanar transmission lines like fin line then we have dielectric integrated guides like non radiating dialectic guide we call it NRD image guide insular image guide.

So different forms of dielectric integrated guides and then H and groove guide structures. So H and groove guide structures now a days we people don’t use it because it has some other problems so here we can say some typical guiding structures the first one is circular and rectangular wave guides. So it looks like hollow metallic pipe you can see inside we have gear and this is a micro strip line this is actually showing cross section of this transmission line system.

So this umm orange colour its showing the metallic part and this blue colour its one type of insulator we call it dielectric its showing its dielectric constant is epsilon r and we will see later that at millimetre wave frequencies we cant use metal for power transmission at 50 hertz we use twisted wire for power transmission at mega hertz frequencies we use two way parallel parallel to a system at gigahertz or microwave frequencies.

You might have seen rectangular waveguides in your lab or coaxial cables but at millimetre wave frequencies coaxial cables and these two way system or twisted wire we cant use it. It becomes very (())(29:03) so we use typical a dielectric material which actually supports this energy propagation and metals will be using just to guide this electromagnetic wave so that this electromagnetic signal is confined inside the dielectric material.

So before starting the next section we will first learnt some terms because we frequently using those terms so we will take again a short break then we will first learn those terms. Thank you!