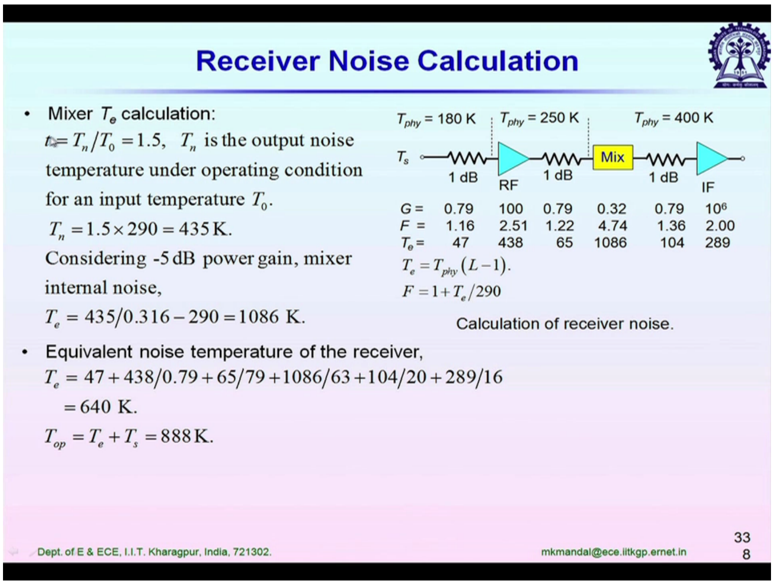
Millimeter Wave Technology
Professor Mrinal Kanti Mandal
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology Kharagpur
Module 8
Lecture No 39
Millimeter Wave Systems (Contd)

(Refer Slide Time: 0:32)

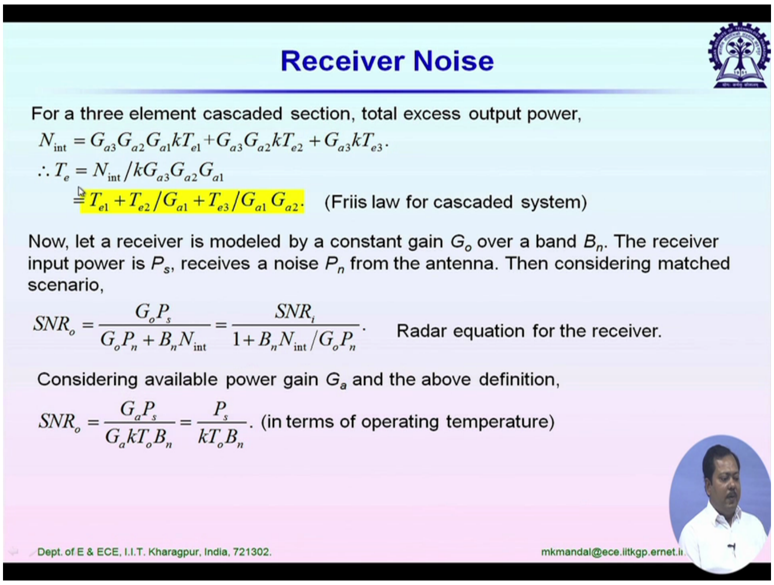


Okay, so we are continuing with the calculation now the second stage starting from the circulator. So main problem it comes from mixer, so for mixer T value is given that is the temperature ratio 1.5, so now then the temperature output noise temperature under operating condition for an input temperature T 0, it is given T n = 1.5 multiplied by 290, so it comes 435 Kelvin. Now with this 45 Kelvin we have to also consider the effect of conversion loss, conversion loss is given as -5 dB, so -5 dB let us take ratio so you have to divide it by 10 we are considering all power gain so -0.5 then you take 10 to the power, so T e then it becomes for 35 divided by this factor power gain 0.316 - the reference value 290 so it is equal to 1086.

So you see I have calculated the gain of different components of this receiver chain for example, for the first component which is giving 1 dB insertion loss, gain value is 0.79, what we did simply 10 to the power 0.1. Next we have LNA for which in the first slide gain is given 20 dB, noise figure is given as 4 dB, so corresponding gain is 100 and noise factor to fraction if we convert it is 2.51. Again 1 dB it is 0.79 and 1.22, so how we are calculating F this is equal to 1 plus T w by 290. Next we have the mixer, for mixer also we calculated T e 1086 again we have the next resistor, so you see the 1 dB loss is providing different noise temperature why, because their physical temperatures are different. For the first one it is 180

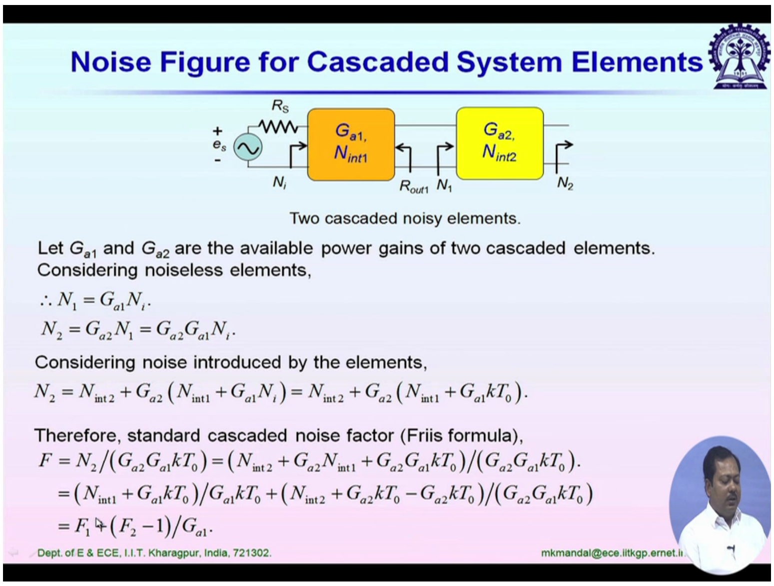
Kelvin, second one 250 Kelvin and the third one 400 Kelvin and simply we are using these 2 formulas, T e = T physical into L - 1 and noise factor F = 1 + T e by 290.

(Refer Slide Time: 3:53)



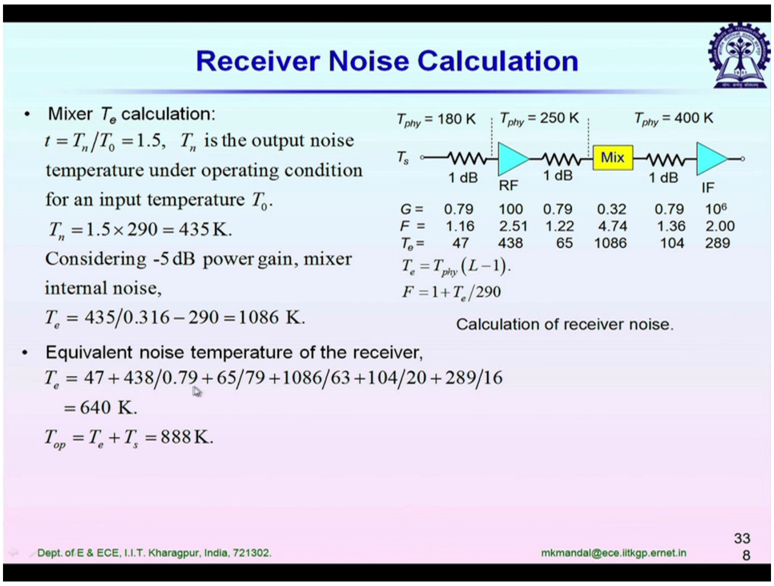
So that is how you can calculate these values for all these components, now once we have all these values then either one noise sector equation Friis equation or temperature T e anyone of them can be used. For example, in this calculation we are considering the Friis for noise equivalent noise temperature of the receiver, so if we go back so equivalent noise temperature T e this is equal to T e1 + T e2 by G a1 + T e3 by G a1 G a2 and it continues like this.

(Refer Slide Time: 4:11)



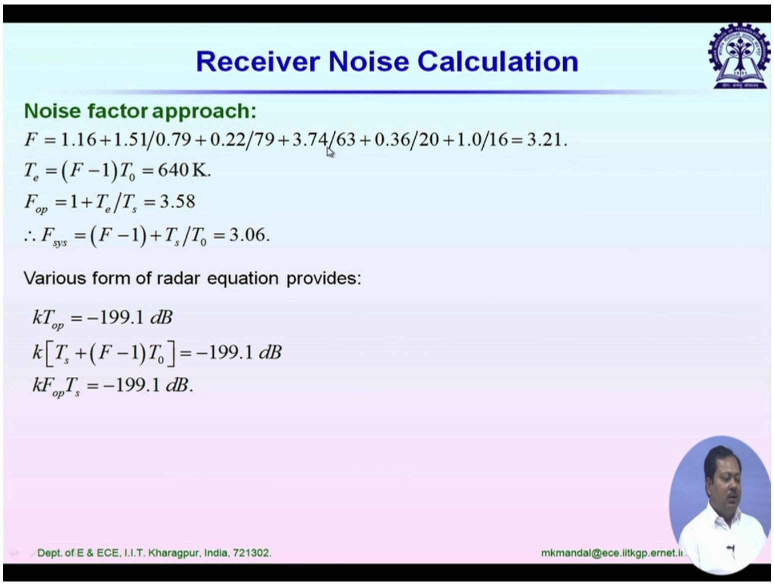
And if we use noise factor approach in that case F that is equal to this is equivalent F, F 1 + F 2 - 1 by G a1. For the next component it would be F t - 1 by G a1 into G a2 and it continues like that.

(Refer Slide Time: 4:32)



So using an equivalent noise temperature approach we just put the values, the first element is giving 47 + 438 divided by G a1, which is 0.79 and you continue, so equivalent noise temperature it comes 640 Kelvin. So T e is 640 Kelvin, then T operating this is T e + T s, T s already we calculated here source temperature this is 448 Kelvin, so simply add them up it comes 888 Kelvin, this is the equivalent operating temperature of the receiver. If you look at here, you see the main contribution it comes from the first component and the second noisy component is mixer.

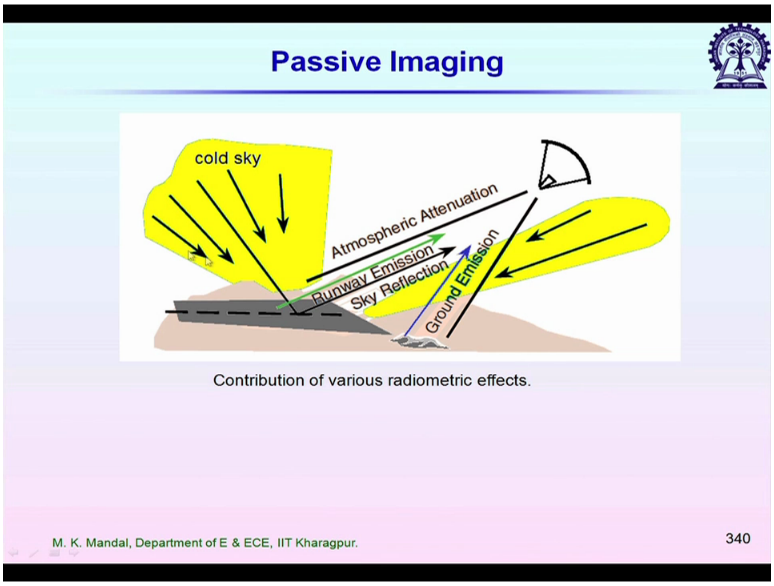
(Refer Slide Time: 5:32)



Next noise factor approach, so we have the values simply put the value in equation and then equivalent noise factor it comes 3.21. From this if I calculate T e using that previous formula, F - 1 into T 0 it is equal to 640 Kelvin so F operating = 1 + T e by T s so put T e = 640 and T s we calculated 248 so it comes 3.58. So F system for the given temperatures F - 1 + T s by T 0 it come 3.06. We have different forms of radar equations some of them already be derived, if we put the values noise contribution it comes k T operating - 199.1 dB, for the second formulas when it comes -199.1, for the third one also same. So all these equations you can verify individually by using their definition, in all the cases it is coming the same value it should be.

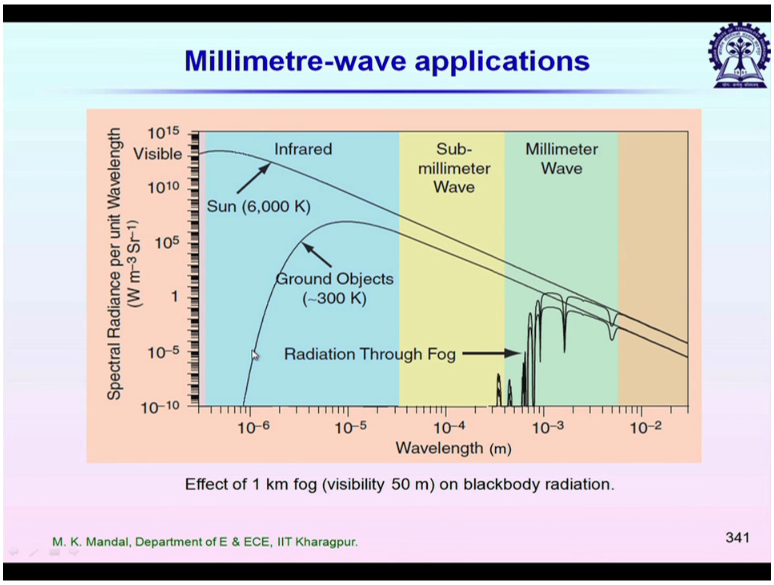
Now one application example passive imaging, so what is the difference between passive imaging and active imaging? For imaging application we have to use some source, so consider simply imaging at specific wavelength using any video camera, so daytime we have sunlight, it is illuminated by Sunray, but at night we have to use some source, right visible wavelength. Similarly, at millimetre wave frequencies also if I want to image capture image or may be video, we need to illuminate the object first. So if we use some transmitter some millimetre wave source and let us say after that one antenna, it is being used for illumination we call it active imaging, where we use some source. But noting down that we can also utilise the information due to brightness where we do not use any power source millimetre wave source, we use simply whatever radiation already available in nature, we call it passive imaging.

(Refer Slide Time: 8:36)



Then what are the different sources for illumination in this case? So let me show you this picture, we have dwelling radiation due to atmosphere because atmospheric particles they behave as secondary radiator and this radiation is coming from all the direction. Let us see we are going to image one runway without using any millimetre wave source, we are using whatever power already available in nature. So this dwelling radiation it will be reflected by the object here it is runway and some of this obviously this reflection it will be in all directions and some of this will be collected by the receiving antenna here after some attenuation because it is a getting through atmosphere. And how much power is being reflected by the subject, it depends on the reflectivity of the surface, which is given by Rho.

(Refer Slide Time: 10:07)

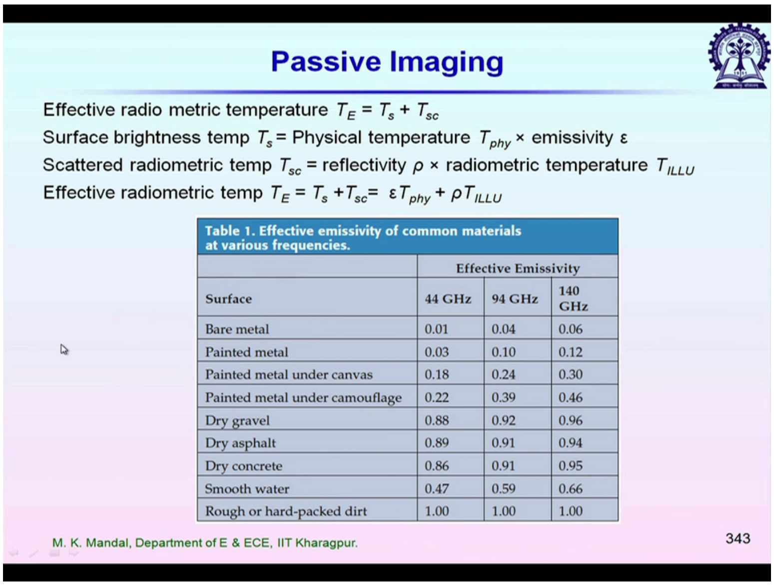


Now in addition to that, we have blackbody radiation so a blackbody radiation is due to its temperature profile, so if temperature increases, high-frequency component increases so for example, let me show you here. If we plot the spectral radiance per-unit wavelength versus wavelength for 2 different temperatures, one blackbody its temperature let us say 6000 Kelvin, then this is the curve. So it peaks in visible wavelength and the peak appears at yellow line, if we keep on increasing the frequency for this blackbody, radiation decreases. Now let us consider a second scenario, where the blackbody temperature is 300 Kelvin quite low. In this case peak it appears in infrared frequency range and if you look at millimetre wave frequency band, you see we still have some radiation.

Even though if I compare the values may be it is 10 to the power 6 to 7 times lower than what available at infrared frequency. So here millimetre wave it starts from 30 gigahertz to 300 gigahertz, after that we are calling it sub millimetre or sometimes we can call terahertz frequency range. So at terahertz frequency we see the contribution is more for this uh temperature 300 Kelvin than compared to what available at millimetre wave frequencies. So now looking at this object which is runway and immediately surrounded by some other ground objects, so the emission it depends on temperature and as well as the dielectric constituents of this material, so it is the property of the material. So for example, if it is very close to blackbody, for blackbody emissivity is 1, but if we take something else which is not a pure blackbody, which is not a very good absorber as well as a very good emitter in that case the total emission will be much less.

In previous example, we considered emissivity 0.9 for example, then the effective temperature it becomes 0.9 multiplied by the physical temperature, so Lower is the emissivity, lower will be radiation from the object. So we have a chart actually, for metal emissivity is very small, whatever power falls on metal it simply reflects back so reflectivity is very high for metal, but emissivity is very small. Now, if we consider (())(12:46) or any gravel surface or let us say a muddy surface, for that emissivity is very high almost close to 1, it is not a very good reflector or almost it behaves like a blackbody, with emissivity nearly equal to 1.

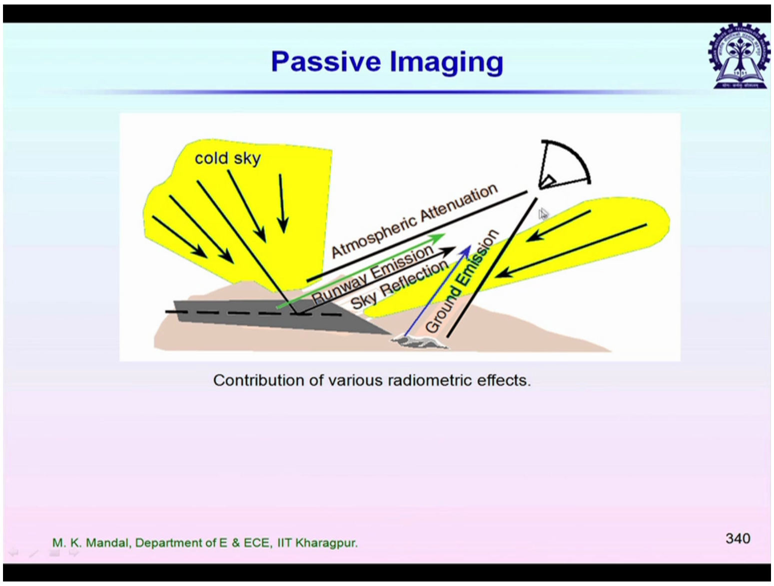
(Refer Slide Time: 13:10)



So we have a chart here I am showing, so you see for bare metal these are the measured effective emissivity, now again emissivity it not only depends on the type of material, it also depends on the surface roughness where you are placing the antenna if you and if you place your antenna immediately above that material, obviously it will receive maximum power. If you go to horizon, this power and emitted from this material it will decrease it depends on incident angle, so we are considering the maximum case when the antenna is receiving maximum power and it is just above that material in right polarisation. So this chart it shows the variation of effective emissivity at different frequency.

For bare metal at 44 gigahertz 0.01 so almost it behaves as a very good reflector it does not emit much energy. At 140 it increases to 0.06, even then it is quite low, now for painted metal it is little higher, we have also painted metal under cameras, painted metal under camouflage, dry gravel, dry asphalt , dry concrete, smooth water and rough or hard packed dirt. So you see hard packed dirt emissivity is one at all the frequencies, so it behaves almost like a perfect blackbody and if any power falls on it, we do not have any reflection, almost all of this power will be absorbed by it and it will reemit all this power, so now going back to the previous one.

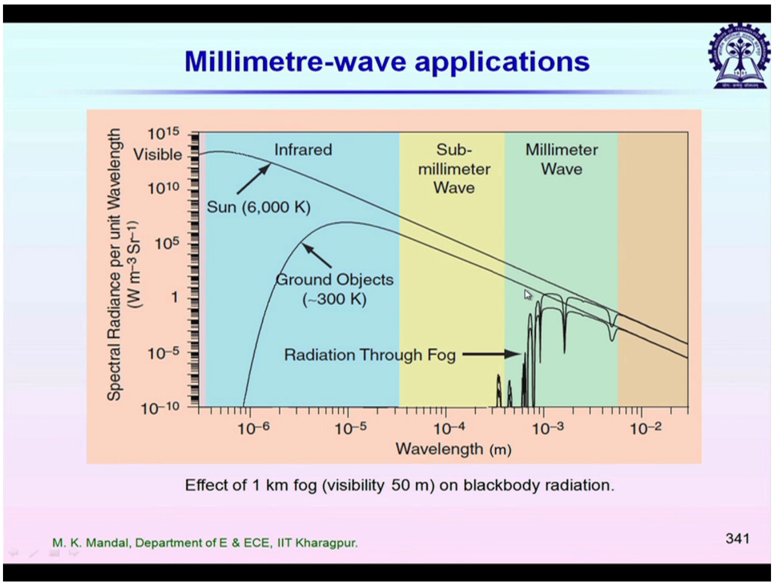
(Refer Slide Time: 15:11)



So whatever power is being collected by this antenna, it then depends on the physical temperature of the surface, emissivity of the surface and also to reflectivity because it is also reflecting some of this dwelling down radiation. Now practically in practice, this radiation due to this cold sky is very small so mainly contribution due to the emission or emissivity is higher. Now we can scan this object and thus we can form a two-dimensional image and since we are not using any source, so it is passive imaging, example of passive imaging.

Now why millimetre wave? Already millimetre wave components are very expensive, already we have this type of imaging system available at visible light even at infrared frequency then what is the need of millimetre wave imaging? So main thing, millimetre wave imaging it can be used even under heavy foggy condition, under sun storm, dust storm, even under heavy rain, this is the main advantage. So we can design all weather system even though resolution of millimetre wave image is much lower compared to infrared visible light image. So when visibility is very low and weather condition is bad, we cannot use any other system even then millimetre wave system will work, so that is why it became so popular.

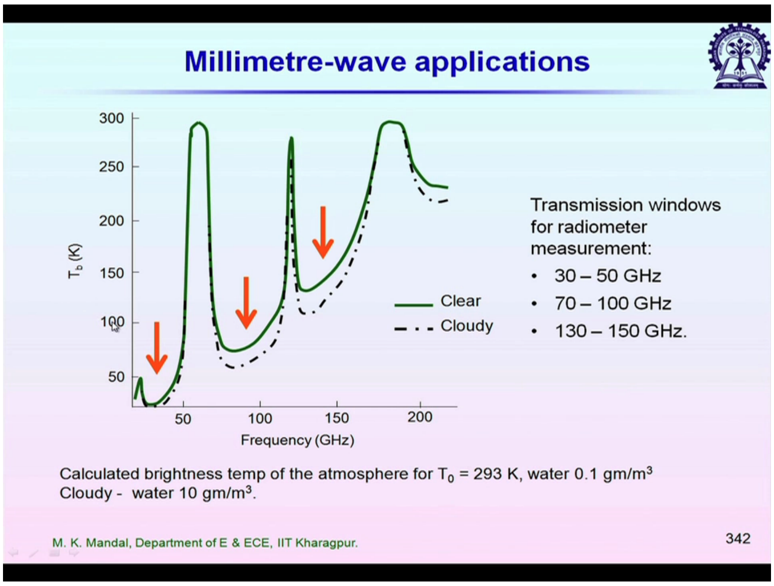
(Refer Slide Time: 16:55)



So now let me give one example, the significance of millimetre wave imaging again going back to that plot, you see this is the radiation coming from blackbody at 6000 Kelvin or 300 Kelvin this for these two different graphs, this is for this we did not consider any atmospheric attenuation. Now let us consider this radiation whatever receiving by antenna, it is obviously going through atmosphere we have some atmospheric loss, so we are considering the effect of 1 kilometre fog. Now visibility in foggy condition it varies with water content, so here we are considering a foggy condition where visibility is 50 meters, in naked eye you can see at least 50 meter distance, so this is an example of light fog not even dense fog.

So in that case if I look at this spectrum, you see it has been redrawn under foggy condition. So millimetre wave part it is attenuated how much? Maybe 10 to 20 times, but if I look at sub-millimetre wave or infrared range we have nothing even till 10 to the power - 10, so infrared or sub millimetre wave we can say that it is attenuated more than 10 to the power 10 times whereas, at millimetre wave frequencies almost it is unaffected that is true also at microwave frequencies, but at microwave frequencies already the radiation value is smaller. So this shows the significance of millimetre wave imaging so that is why we call it all-weather imaging system.

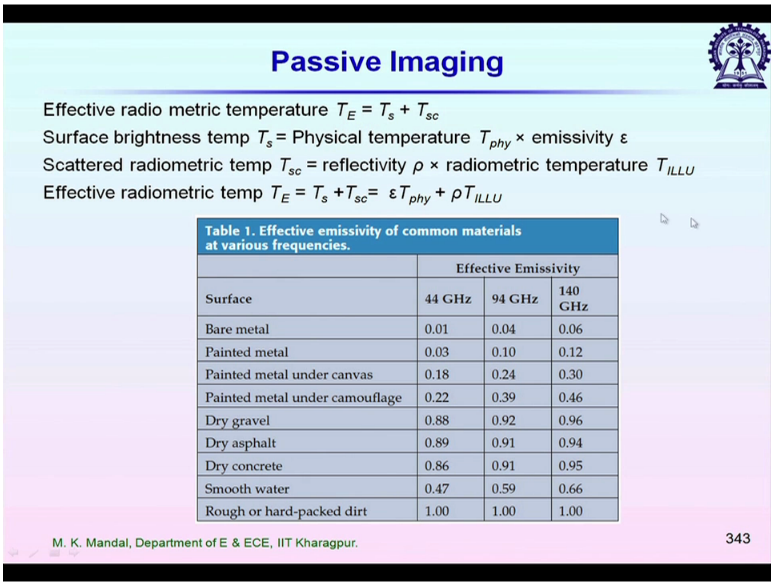
(Refer Slide Time: 19:32)



So now when we go for actual design, we cannot use any arbitrary frequency range, we have some atmospheric windows we have to use those frequency bands only. So why, let us say 60 gigahertz band, so oxygen molecules it resonates at 60 gigahertz band and it will reradiate or the brightness is already very high, so we will not have good contrast, for imaging we need also good contrast. So we have a effective brightness variation versus frequency, so this curve it shows the calculated brightness temperature of the atmosphere for T 0 = 293 Kelvin and when water content in atmosphere 0.1 grams per meter cube, so one curve for clear condition and the second curve of black dotted cloudy condition, for cloud is defined as 10 gram per cubic meter.

So you see the brightness the effective brightness temperature is quite high at 60 gigahertz due to oxygen resonance and left-hand side we have a small attenuation band due to 22 gigahertz similarly, again 118, so we have in between some windows are available where we can use this radiometer for imaging purpose or passive imaging, so these windows are 30 to 50 gigahertz band, 70 to 100 gigahertz band and 130 to 150 gigahertz.

(Refer Slide Time: 20:49)

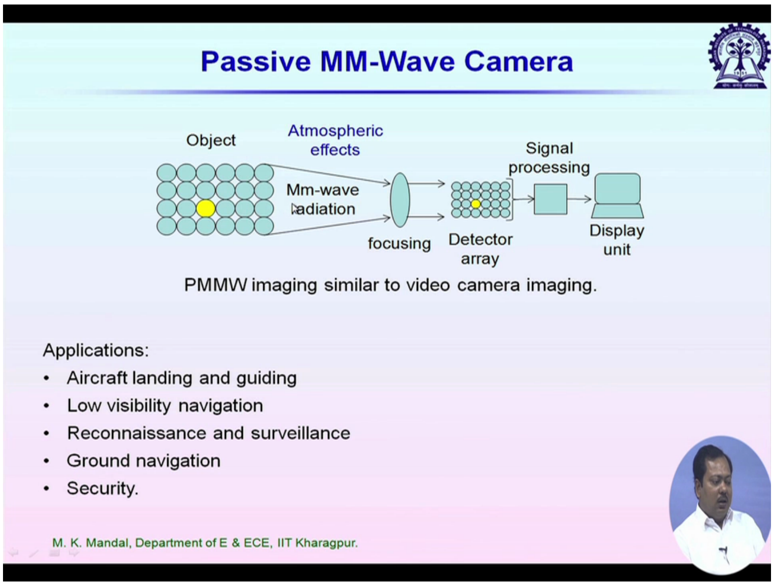


	Effective Emissivity		
Surface	44 GHz	94 GHz	140 GHz
Bare metal	0.01	0.04	0.06
Painted metal	0.03	0.10	0.12
Painted metal under canvas	0.18	0.24	0.30
Painted metal under camouflage	0.22	0.39	0.46
Dry gravel	0.88	0.92	0.96
Dry asphalt	0.89	0.91	0.94
Dry concrete	0.86	0.91	0.95
Smooth water	0.47	0.59	0.66
Rough or hard-packed dirt	1.00	1.00	1.00

Now effective radiometric temperature, so when we are forming any image then the received the power it is expressed in terms of some effective noise temperature T. Now, if the effective received power it varies, accordingly effective noise temperature will vary so you can form a two-dimensional image and for good contrast that temperature sensitivity is also very important. So when we calculated radiometric temperature T e, we have two contributions in that same, one that is due to reflection and the second one that is due to emission. So T s + T sc, so where T s this is we call due to the surface brightness temperature that is equal to physical temperature multiplied by emissivity epsilon so it represents due to emission. And this scattered radiometric temperature T sc this is due to reflection that is equal to reflectivity Rho multiplied by radiometric temperature T illuminator.

So this T eliminator it depends on whether condition under T r open sky T illuminator will be something, but cloudy under cloudy condition T illuminator will be something else. Then the effective radiometric temperature T e that is equal to if we put the value it comes Epsilon T physical + Rho T illumination. So it depends on the physical temperature, emissivity of that object, reflectivity of the object and T illumination. So if I compare the contribution, left-hand side the first component, Epsilon T physical contribution is much more compared to the second one, but in practical system actually we need to calibrate the system first then only we go for imaging.

(Refer Slide Time: 23:04)



So this is one imaging skin, left-hand side it shows object, it simply follows the principle whatever we use for video camera at optical frequency range. So we have to use some focusing arrangement so this object is radiating millimetre wave radiation all the directions, so we are collecting some of them by using a focusing lens, it can be one dielectric lens antenna or simply a parabolic reflector antenna so the whole parabola it will collect the power. And then at the parabolic reflector at the feed point, feeder on point we have to place one detector array. It can be one array antenna and each antenna let us say connected to diode detector, or we can use also single antenna element so in that case we have to introduce some sort of scanning, so in this example we are considering detector array, it can be an MMIC, it can it can be actually fabricated and already people are using it millimetre wave integrated chip, where antenna it is followed immediately followed by detector.

So each and every antenna it will give you 1 pixel. If you want to improve resolution you have to improve pixel density or number of antennas in the array, so next is followed by signal processing and then the display unit. So this is a very simplified diagram of a PMMW imaging system and here we did not consider SNR, so what is the minimum power we need to sense so there will be many calculations and signal processing part is little complicated. So what are the applications, some of them already are in use for example, in aircraft landing in guiding system and we can use them at low visibility conditions, for low visibility navigation both in let us say harbour or for ground navigation as well, for uh reconnaissance and surveillance applications, for security applications.

For security applications how we can use it, so you see millimetre wave signal it can easily penetrate through clothes, thin clothes or even sweater, jacket, but it will be reflected by skin. Now skin it appears to be one warm object that means its emissivity is high, now if we place a metal on skin that will block that radiation from skin and metals usually appears as a cold surface. If any if we do not have any external source, which is illuminating that metal then metal it appears to be a cold surface because its emissivity is very low. Now, if we use a millimetre wave source in addition to these, in that case it becomes just opposite, so metal it looks like a one object. Now depending on you are using active or passive imaging obviously the image it looks completely different, but the good thing is that millimetre wave signal since it can penetrate through, you can see concealed weapons, you can so for security applications it can be used. So next we will take a break, after that we will discuss on transceiver architecture.