Millimeter Wave Technology.
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Lecture-01.
Introduction to Millimeter-Wave Technology

Welcome to the lecture series of millimeter wave technology so roughly by millimeter wave we understand a section of electromagnetic spectrum of (())(0:37) of dimension 10 millimeter to approximately 1 millimeter so it translate to a frequency scale 300 gigahertz to 30 gigahertz. But we also have some practical applications which are starting at 26.5 gigahertz. We have a band and also we have some other applications at 24 gigahertz so for practical applications by millimeter wave we understand from 24 gigahertz to 300 gigahertz approximately. So now why do we need millimeter wave technology? So for wireless communication already we have some popular applications like Bluetooth, wifi, wireless LAN.

So for Bluetooth how much data rate it can support? So maximum in Kbps range in wifi or wireless LAN it can be increased to mega bit per second. Or (())(1:42) of mega bit per second but if we want gigabits per second. Let's say through output so in that case we have only option that we have to increased the carrier frequency to millimeter wave. So not only that high resolution radar, so high resolution imaging these are also possible by using millimeter wave frequency range.

So there are so many advantages at millimeter wave frequency range then why don't we use millimeter wave frequencies. Why it's not so popular? So obviously there are many problems and we have to solve this challenges some of them are already solved. So in this class we are going to learn all this challenges. How to solve them and umm slowly slowly we will see starting from the source to umm receive here receiver so what are the different component we use at millimeter wave frequencies.

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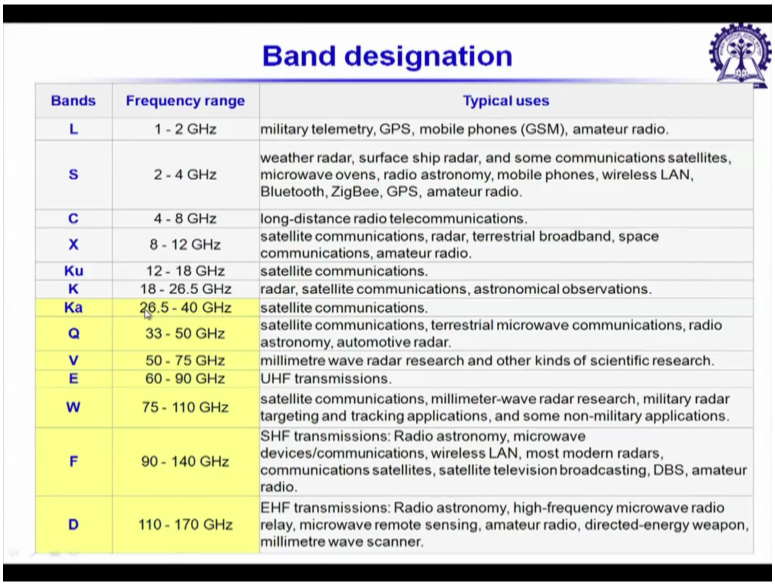

Bands	Frequency range	Typical uses
L	1 - 2 GHz	military telemetry, GPS, mobile phones (GSM), amateur radio.
S	2 - 4 GHz	weather radar, surface ship radar, and some communications satellites, microwave ovens, radio astronomy, mobile phones, wireless LAN, Bluetooth, ZigBee, GPS, amateur radio.
C	4 - 8 GHz	long-distance radio telecommunications.
X	8 - 12 GHz	satellite communications, radar, terrestrial broadband, space communications, amateur radio.
Ku	12 - 18 GHz	satellite communications.
K	18 - 26.5 GHz	radar, satellite communications, astronomical observations.
Ka	26.5 - 40 GHz	satellite communications.
Q	33 - 50 GHz	satellite communications, terrestrial microwave communications, radio astronomy, automotive radar.
V	50 - 75 GHz	millimetre wave radar research and other kinds of scientific research.
E	60 - 90 GHz	UHF transmissions.
W	75 - 110 GHz	satellite communications, millimeter-wave radar research, military radar targeting and tracking applications, and some non-military applications.
F	90 - 140 GHz	SHF transmissions: Radio astronomy, microwave devices/communications, wireless LAN, most modern radars, communications satellites, satellite television broadcasting, DBS, amateur radio.
D	110 - 170 GHz	EHF transmissions: Radio astronomy, high-frequency microwave radio relay, microwave remote sensing, amateur radio, directed-energy weapon, millimetre wave scanner.

So let's start with the band designation. So at If you look at the different band designation mark by this yellow color. So the Ka band its starts from 26.5 gigahertz to 40 gigahertz. So the whole millimeter wave spectrum it is divided into several bands. So among these some popular bands are Ka band, then the V band which is from 50 to 75 gigahertz then the W band 75 to 110 gigahertz frequency range. And they are already in use for satellite application, for Radar applications and now people are trying to if use this band for wireless communications.

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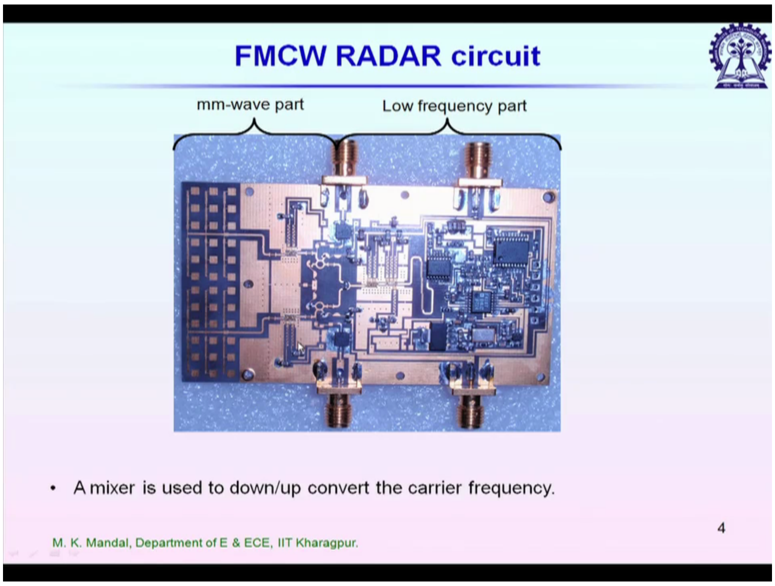

So if I, Let us just look at a circuit millimeter wave circuit. So this is a millimeter wave circuit which is fabricated on a printed circuit board. You can see the black color dielectric material and the shiny is the copper. So if I look at the left hand side it has actually two parts. One high frequency component parts which is millimeter wave frequency component parts and in the right hand side this is the low frequency component parts.

So it is a its frequency range in micro f frequency or in RF frequency range. Now for any wireless system we need antennas so this is an example of FMCW RADAR circuit so you can see these rectangular patches. These are actually the radiating antennas and at millimeter wave frequency the antenna dimension is very small. So a typically the resonating antennas its length is lambda g by 2. That means half wave length at the operating frequency. So at 60 gigahertz for example.

The wave length is already 5 millimeter in free space and then half of it so its 2.5 millimeter and not only that when we fabricate this antenna on some printed circuit board so its dimension further reduces by a factor of root f side on arc. Where f side on arc it is called the dielectric constant of the substrate. So at millimeter wave frequencies antenna dimension it becomes very small just a few millimeter.

So as you can see in the circuit. So this is actually an array of antennas 3 by 12 elements. So these antennas then it is followed by low noise amplifier then by mixer. So mixer it actually can down convert or UP convert the carrier frequency. We can use non-linearity of any active element like a PN junction diode or a transistor to UP convert and down convert frequency.

So once millimeter wave frequency down convert it to micro f frequency or RF frequencies then the conventional RF components or micro f components can be used. So this right hand side it consist of those micro f components.

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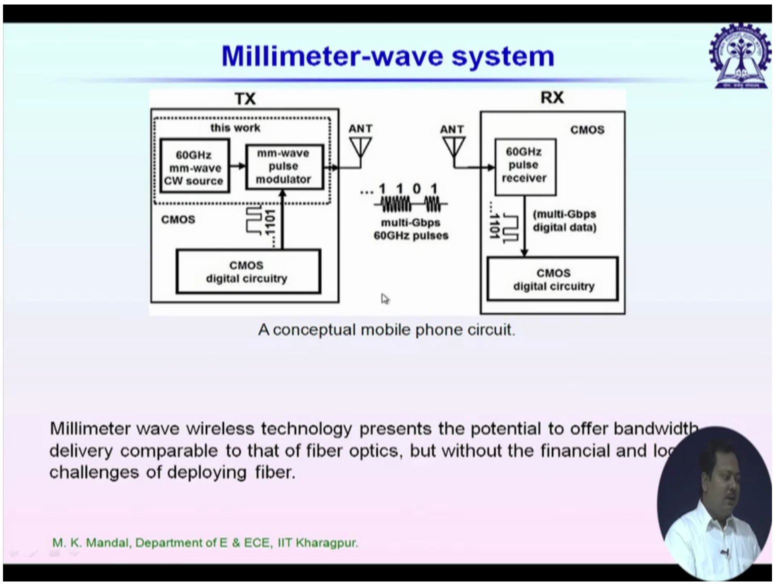

So this is a typical RF umm millimeter wave transmitter and receiver circuit there is conceptual diagram. So in the transmitter circuit you can see that we have a 60 gigahertz millimeter wave continuous source. So which is being modulated by the base band its coming from CMOS digital circuitry. So the cost of any millimeter wave system it depends on fabrication procedure.

So standard technologies in use are germanium, silicon and gallium arsenide material so in a group three group five like gallium arsenide material the circuit performance is better but it is very expensive procedure. So unless we can minimize the cost it will not be applicable to consumer market.

So in CMOS or BICMOS procedure this cost is quiet low but unfortunately CMOS or BICMOS process it cannot be umm used for millimeter wave circuit design. So in this particular example then we can use that gallium arsenide or silicon, germanium for 620 gigahertz or millimeter wave generation and for the basement part we can use the CMAS CMOS digital circuitry so then after modulation umm an amplification it can be transmitted by one antenna.

At the receiver side we have one receiving antenna then the receive signal it can be 60 gigahertz for example this one 60 gigahertz pulse receiver then it is demodulated by CMOS digital circuitry. So once it is demodulated and down converted then we can use conventional CMOS digital circuitry. So what is the advantage of this system?

The advantage is that these systems can support multi giga width communication. So that means we can we use we can umm these millimeter wave system for multi giga width communication without using any wiring. So fiber optics it can also support multi giga width communication but in that case we have to use wiring for fiber optics.

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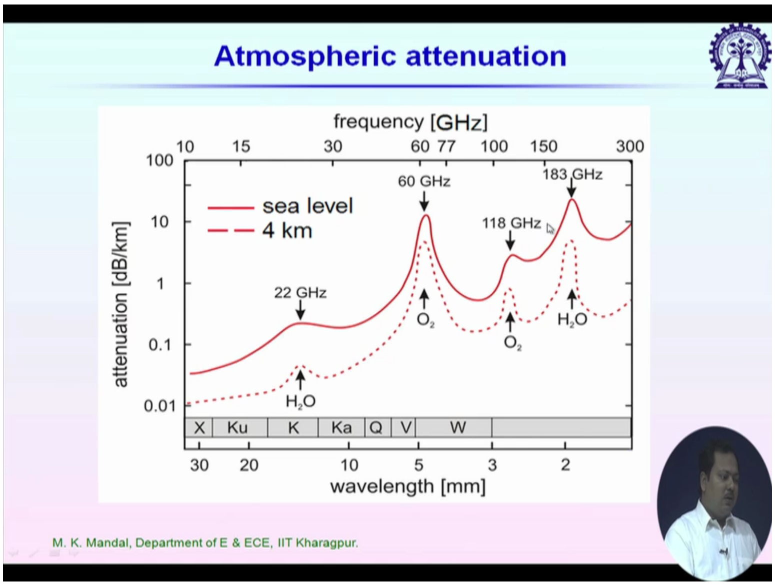

So but millimeter wave communication it has to face many challenges so one of them is atmospheric attenuation. So this figure typically it shows the attenuation in db per kilometer versus the wavelength. So if you look at the diagram we have a solid line and one dotted line so this dotted line it corresponds to the measured attenuation in db per kilometer at a 4 kilometer height from the sea surface sea level.

And the solid line it corresponds to attenuation at sea level so if we measure attenuation at sea level it higher than that at higher atmosphere now if I follow this curve so from left hand side to right hand side actual frequency increases so at 22 gigahertz we have some attenuation band.

This is due to the resonance of water molecule H2O again we have a 60 gigahertz peak here where attenuation is very high this is due to the absorption of oxygen umm so this is due to the resonance of oxygen molecule so again if I further increase the frequency we have one more absorption band at 118 gigahertz this is again due to the oxygen molecule and at 183 gigahertz.

We have one more attenuation band which is again due to water molecule so that means we have some propagation windows if we want to communicate over long distance we have to use these windows. So otherwise for example if we used 60 gigahertz band for long distance communication so signal will be highly attenuated. So this attenuation it depends on frequency as well as height from the sea level. So as we see from this graph that at higher atmosphere this attenuation is much smaller compare to sea level.

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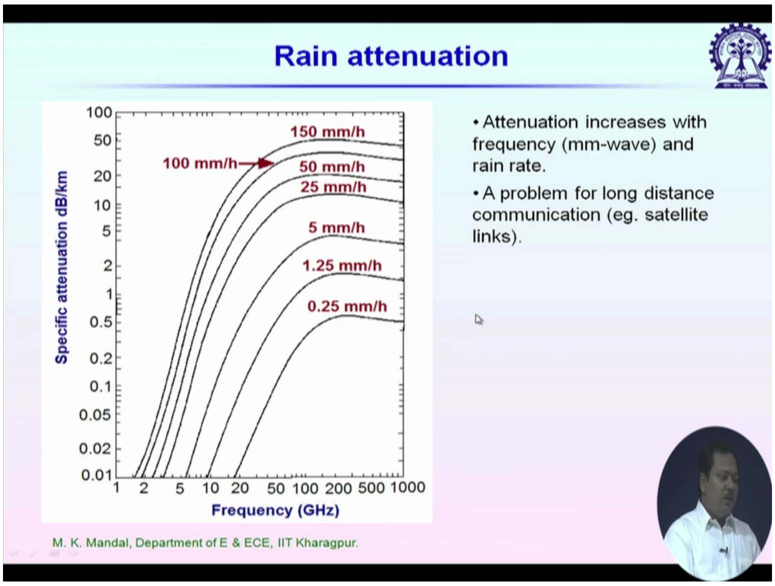

So not only that fog, rain and sand storm, dust storm so all of these weather condition also affect millimeter wave propagation. So this is a typical attenuation plot umm with rain rate with difference frequency range so if you follow any one curve so lower rain rate for example .25 millimeter per hour to 1.25 millimeter per hour.

So for this range the attenuation is typically at millimeter wave frequencies 1 to 2 db or kilometer but for moderate rain for example 5 to 25 millimeter per hour it increases to 10 db per kilometer and for a cloud burst typically 150 millimeter to 250 millimeter per hour this attenuation can increases to as high as 100 db per kilometer.

So why this attenuation happened because the droplet rain droplet it scattered millimeter wave frequencies and because it's the size of the rain droplet is comparable to millimeter wave wavelength so that's why this effect is more prominent at millimeter wave frequency compared to the lower frequencies. For example umm if I follow any curve let us say for moderate rain rate 25 millimeter per hour.

So below X band the attenuation its showing 2 db per kilometer but in millimeter wave frequency range typically its increasing to 10 db per kilometer so this is a problem for long distance communication. For example for a satellite link. So for satellite it has to communicate between ground based system to satellite which is umm which can be umm as high as 36 thousand kilometer above the earth surface. So we have to keep in mind when we are going to design any millimeter wave system rain rate it can affect the channel performance.

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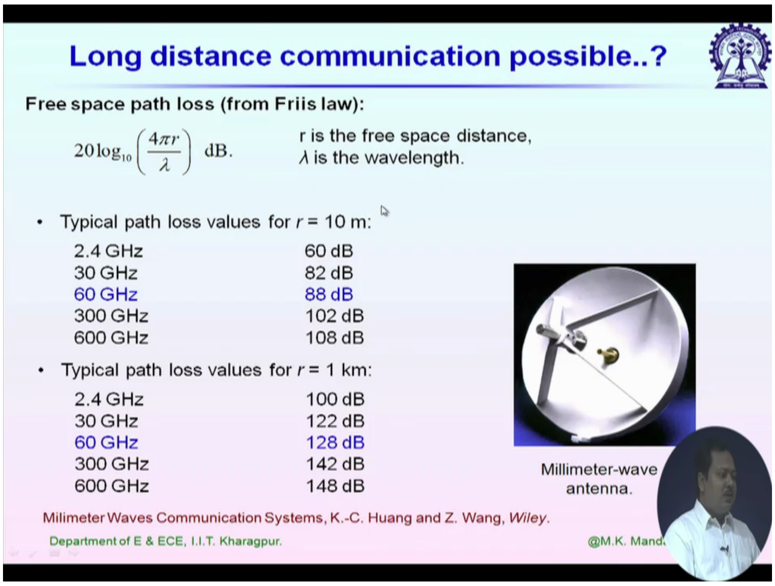

So now long distance communication really possible at millimeter wave frequencies? So we have actually one formula we call it Friis law by which we can calculate the free space path loss at different frequency range. So free space path loss it can be given by 20 log bas 10 4 pie r by lambda in decibel. So where r is the free space distance lambda is the wavelength. So in this expression we are not considering any atmospheric effect this is just due to the increasing distance between transmitter and receiver.

So why if umm this loss increases with distance you can consider one transmitter let us say it is placed at the origin of a polar co-ordinate system and it is transmitting in all the direction now I have an receiving antenna so the received power by receiving antenna depends on the effective aperture of this receiving antenna. So we can consider is fea is spherical surface and the receiving antenna is placed on that surface.

Now the intensity on that spherical surface it obviously depends on a distance arc. So if I increase the distance from origin then the power it decreases with r square. So this law we call the path loss and its given by this expression so it so its function of r as well as lambda the wavelength. So here are some calculated values of free space path loss for example this first table showing the path loss value at r equal to 10 meter so at 2.4 gigahertz this typical path loss value is 60 db now if I increase the frequency to 60 gigahertz where free space wavelength is 5 millimeter so this path loss increase to 88 db.

So not only that if I keep on increasing the frequency let us say 300 gigahertz (())(15:39) millimeter wave frequency range so it further increases to 102 db so now if I recalculate this values at r equal to 1 Km so at 2.4 gigahertz we can see the previous path loss was 60 db now it increased to 100 db and at 60 gigahertz from 88 db it now increases to 128 db.

So if you send one watt of power at 60 gigahertz it will be attenuated by 128 db at 1 kilometer so this calculation does not consider the attenuation due to atmosphere. This is just the free space path loss. So this picture is showing a typical millimeter wave antenna a parabolic reflector and this is the feeder horn.

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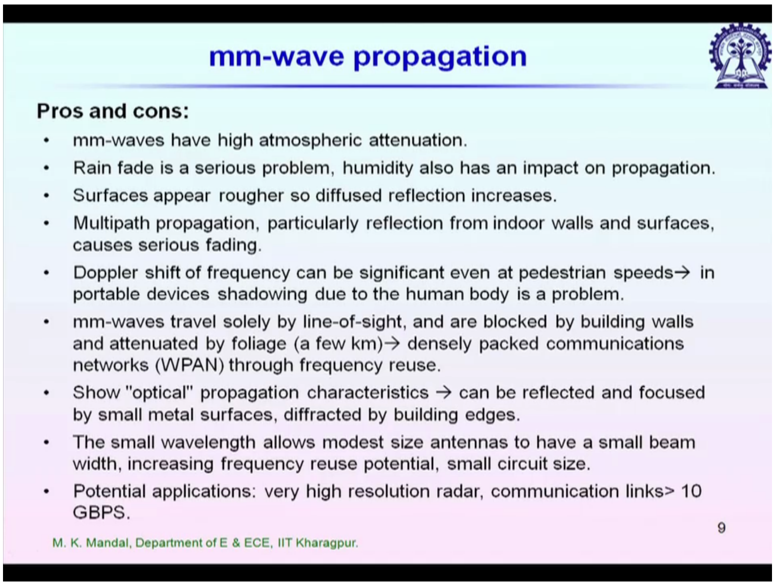

So now what are the advantages and disadvantages of millimeter wave communication? So already we have seen that millimeter wave have high atmospheric attenuation so if we increase frequency so attenuation will increase. And not only that at millimeter wave frequency we have some transmitting window so for any wireless link so we have to use those windows to get minimum attenuation.

Rain feed that is another problem and we have seen that attenuation it increases with rain rate so similarly it is also attenuated by fog, it is attenuated by sand storm, dust storm. So weather condition it affects millimeter wave propagation. Humidity that also has an degrading effect on millimeter wave propagation.

So at 60 gigahertz we have seen that attenuation due to oxygen its quiet high it can be 10 to 50 db per kilometer but if I go to that window let us say 70 to 80 gigahertz frequency band so in that band the attenuation due to oxygen is very small let us say .2 to .3 db per kilometer but in humid condition let us say humidity is almost 100 percent this attenuation can increase to 3 to 4 db per kilometer just due to humidity.

Then next is surface appear rougher so diffused reflection increases. So multipath propagation that cause another problem so particularly from reflection from indoor walls and surfaces, causes serious fading. So this fading problem you might have experienced even at lower frequencies for example FM radio. So it might have notice that the radio when I place at one corner of the room its working but if I place it at other corner of the room it's not working so this is due to fading.

So we have actually reflection of the signal from walls from doors from furniture and this reflective signal from the various sources the umm they provide they produces in constructive and distracting intervance so which is will be a function of space so at some points then you will get some signal at some points of the in the same room you may not get any signal so this is called fading effect.

And it's very prominent at millimeter wave frequency so even just umm if you displace your comp receiver by a few centimeter you your signal level it will degrade. So Doppler shift another problem. So doppler shift as we know that it depends on the frequency as well as it increases with the velocity. So but at the millimeter wave frequency the frequency is so high that even at pedestrian speed this shift can be significant. So whenever we are going to use any portable device we have to be very careful about this Doppler shift. So it should be consider in our design and another problem is shadowing problem.

So at lower frequencies for example 1.8 gigahertz to 2.4 gigahertz wireless LAN application so electromagnetic signal actually it can bend around our body this is due to the effect of distraction but at millimeter wave frequencies the wave length is so small that it can bend around our body so what we see what we observed at optical wavelength shadow effect so similar effect we experience at millimeter wave frequency so if I have a transmitter sitting just at back of me so in front of me you can't get any signal so it's called the shadowing effect.

Millimeter wave it travels solely by line of sight and are blocked by building walls and attenuated by foliage. So long distance communication its in question so only line of sight communication may be possible so but it also has one advantage that we can design impact communication networks which is called WPAN system through frequency reuse.

Os for example let us say we are designing a wireless LAN like system in one building which is using let us say 77 gigahertz frequency range and we know that it will be highly attenuated outside the building so just in the next building we may not get any signal from that building so in that building then we can in the second building we can use the same frequency spectrum to design another wireless wireless LAN like system. So this is called frequency reuse and highly dense network is feasible due to it.

So millimeter wave it shows optical propagation characteristics so that's means it can be easily reflected or focused by small medium surfaces. So even a few square feet of antenna is sufficient to generate (())(22:27) like beam and it is diffracted by building edges. So the wavelength at millimeter wave as we have discussed that its 10 millimeter to 1 millimeter and for resonating antennas which length is typically half wavelength so it is then 5 millimeter to point 5millimeter.

So that means the antenna size it decreases. So we can design arrays of antenna at millimeter wave frequency easily because antenna size is small so a an array of antenna we can easily fit over let us say a square feet area. So potential application very high resolution radar, communication links typically more than 10 gigabit per second.

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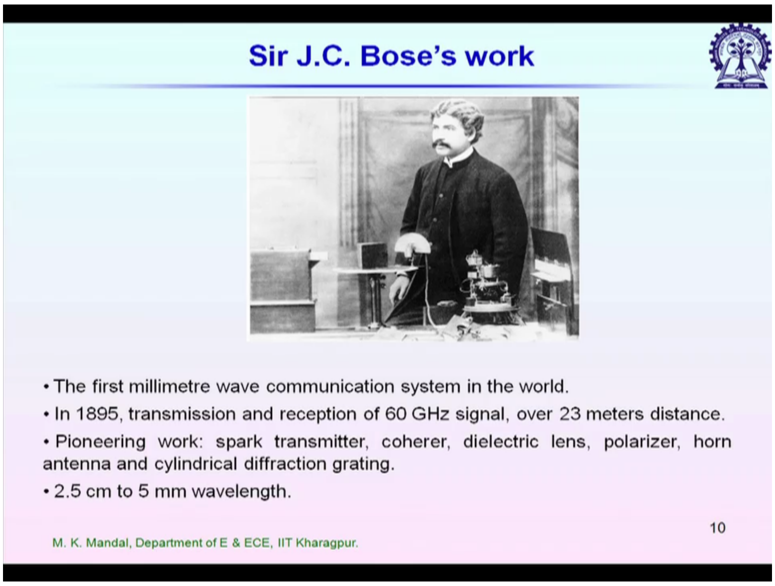

So before starting the next part let me discuss about a Sir J C Bose's work. So you will be surprised to know that the first millimeter wave system were build by professor J C Bose in Kolkata in West Bengal. So in 1895 actually umm he demonstrated a millimeter wave system and its typically working at 60 gigahertz frequency band and he communicated over a distance of 23 meters.

So at that time umm these different sources of millimeter wave frequencies how to transmit it? How to receive it? How to design different components? It so all of these were not known at that time so he has to design all of these components starting from the transmitter. How to receive it?

And then he had shown the refraction property refract refraction property and the polarization of millimeter wave and also he has shown that millimeter wave its nothing but another form of electromagnetic wave which follows more or less optical properties. So in his experiment typical wave length he used starting from 2.5 centimeter to 5 millimeter so roughly it correspond to 12 gigahertz to as high as 60 gigahertz.

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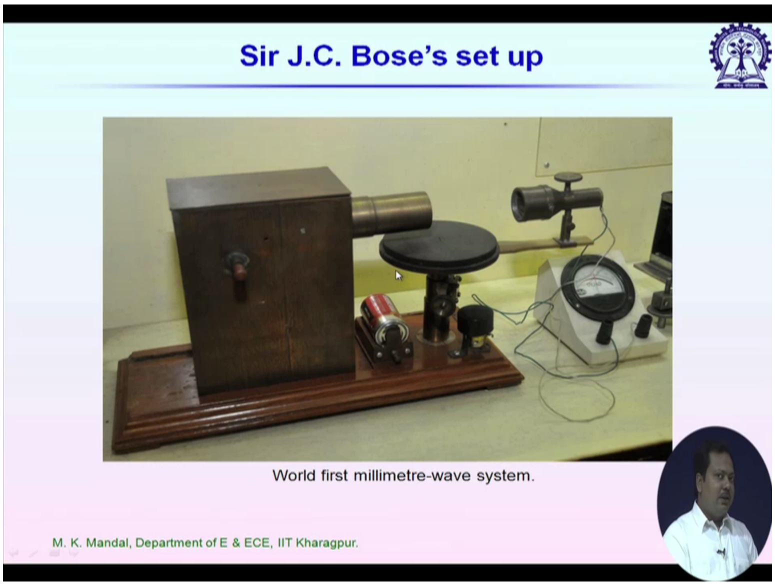

So this an replica of the original system design by Professor JC Bose in Kolkata. So you can see this a box so inside this box we have millimeter source which is nothing but a spark gap and then he used a tube metallic hollow tube as the transmitter now we know that it behaves as an antenna and we have a (())(25:33) table here.

So where he can use a umm prism and other structure to show the refrect refraction and reflection property and on the right side we have a receiver so this receiver receives millimeter wave signal then how to sense this millimeter wave signal so he designed one detector which is a metal semi conductor junction. I am going to show the picture in next slide so when millimeter wave signal falls on this detector it provides DC current simply DC voltage so we can then detect this DC voltage by using a galvanometer.

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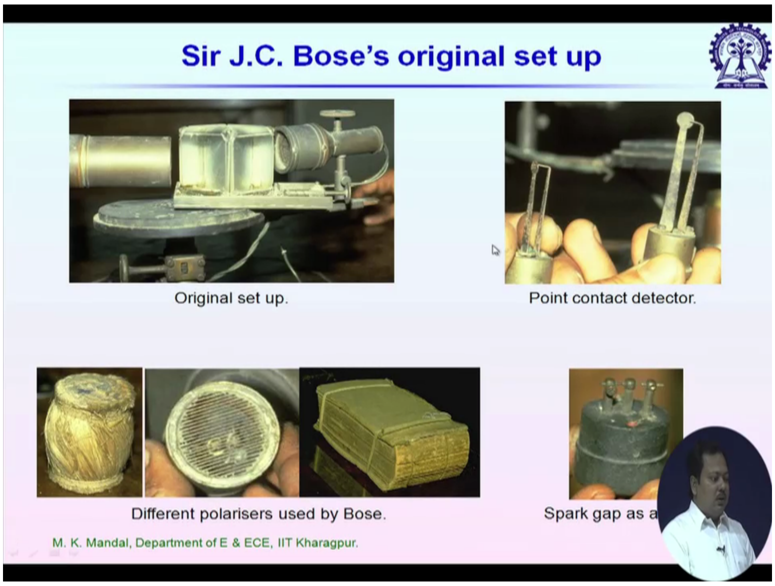

So in this slide you can see the different component used by Professor JC Bose this bottom right corner it shows this spark gap so we have two gaps between this two pin. High voltage is applied between these two pins which generate sparks so sparks it content a white electromagnetic spectrum starting from optical wave to RF.

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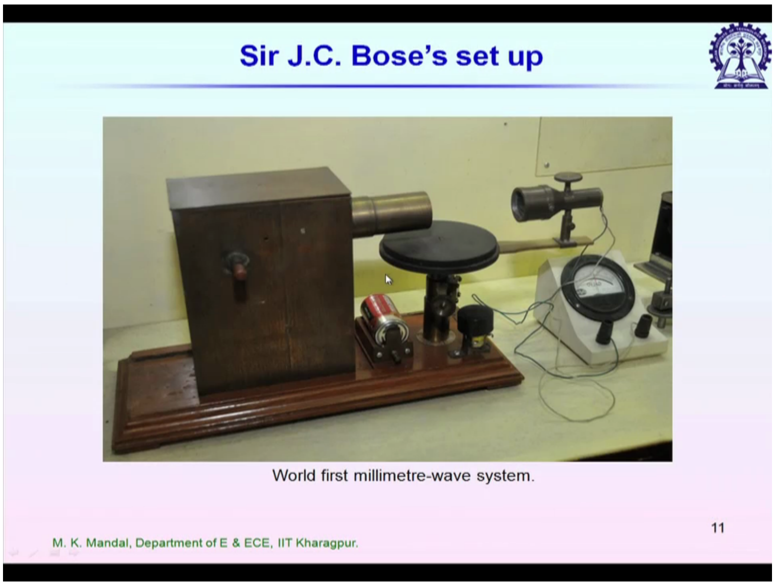

He used the millimeter wave frequency range so he placed this spark gap inside this box.

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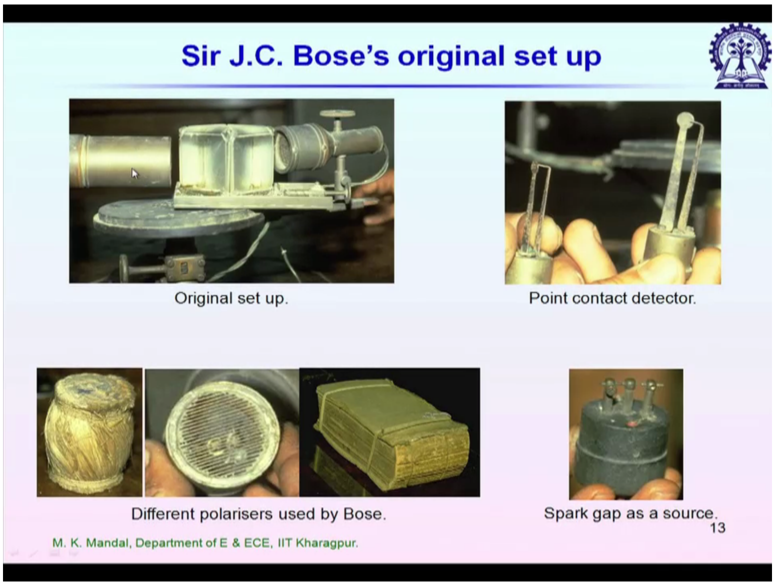

And then you can see the transmitting part here so inside we have the spark gap so from which electromagnetic wave is being transmitted by this pipe now we call it horn antenna. So this is a prism made of dielectric material so to show the refraction property of electromagnetic signal and this is the reviver side. So at the receiver you can see top right figure so we have a point contact detector so this is it.

It is made up a metal needle and bottom side it's a semi conductor material its galena lead sulphite so it has non linear characteristics so almost similar to a P N junction and when electromagnetic signal falls on this it provides DC voltage so then by measuring this DC voltage we can detect electromagnetic signal so he invented this type of detector so it's a long time back in 1895 these are some polarisers.

So this umm this middle part you can see some parallel metallic wire so when electromagnetic signal falls on it so if the electric field is a perpendicular to this metallic wire it can pass through this wire mesh but if the electric field is parallel to this wire then dif diffraction of the component incident electromagnetic wave it will pass through this wire mesh so similarly so he designed some other polarisers so its nothing but your book.

He used several metallic plates inside the books so this plates are parallel to each other then any electromagnetic wave which whose electric field is parallel to this metal it can pass through this book. He also designed another polarizer this is made of jute and inside he used different wires.

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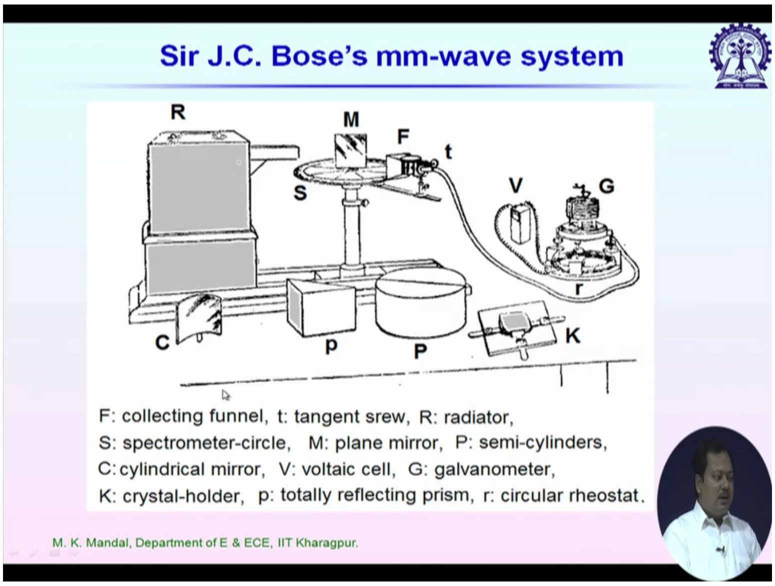

So we see that even at in the 1895 long time back J C Bose in Kolkata. He designed the world's first millimeter wave systems so after professor J C Bose's work almost 50-60 year there was no work at millimeter wave frequency. So again its started at during Second World War 1940 so now we will take a short break then again we will start.