Millimeter Wave Technology.
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Lecture-19.
Antennas at MM-Wave Frequencies (Contd.)

Okay so we will come back. We are continuing with on chip antennas. Next topic is loop antennas, loop antennas has very interesting characteristics if we consider1 one lambda loop which is resonating loop. In that case maximum radiation it comes in the broad side direction but for a small loop radiation is in the plane of loop maximum radiation.

When we are going to use loop antenna on chip obviously it will be a resonating loop antenna and we are expecting radiation in the broad side direction. So let us say this example.

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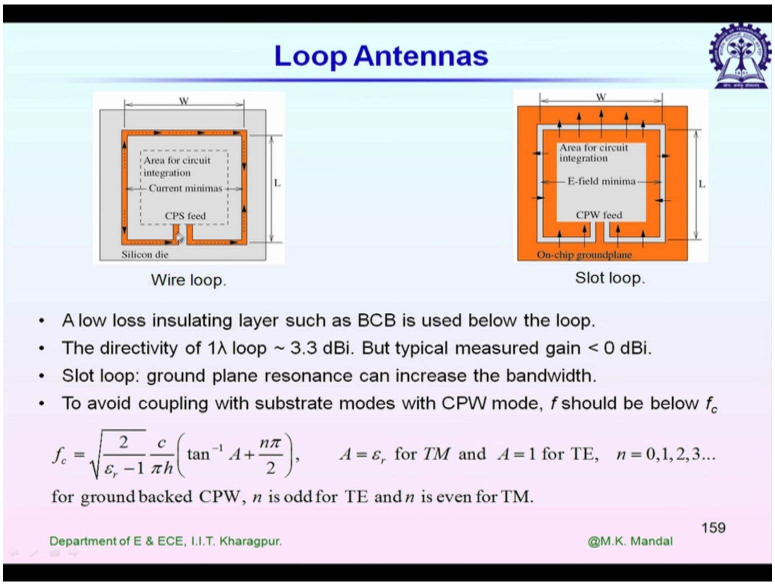

We are having 1 wire loop antenna and its length is 1 lambda at the operating frequency and typical gain we get from 1 lambda loop is more than 3 DBI but when we fabricate it on silicon because of those increased losses realised in always less than 0 DB we will be having some negative value. In this particular example this loop is being fabricated on DCB material which is placed on that silicon.

It will to some extend it will improve the gain or antenna efficiency we may have also complementary structure so here in left example its a wire loop. Its being feed by coplanar strip line CPS line. And its dual structure right hand side its a slot loop having almost similar characteristics. So look at the feed lines here we can use simply CPW feed lines. In the right hand side figure we have one advantage the advantage is that the outside ground plane it is really narrow and it can be used as a second radiator.

So that means as if we are having 2 coupled resonating structure and which increases the bandwidth of this antenna. This type of technique is very common for bandwidth improvement of any antenna. And now we have a thumb rule again here to avoid surface wave mode generation F should be operating frequency should be smaller than this cut off frequency FC.

Which is given here square root of 2 by epsilon R minus 1 and its a function of H thickness of the substrate and also A A is given as epsilon R if we have TM type surface wave mode otherwise A is equal to 1 if we have TE type surface wave mode and N is an integer. And not only that for a ground backed CPW N is odd for TE and N is even for TM mode.

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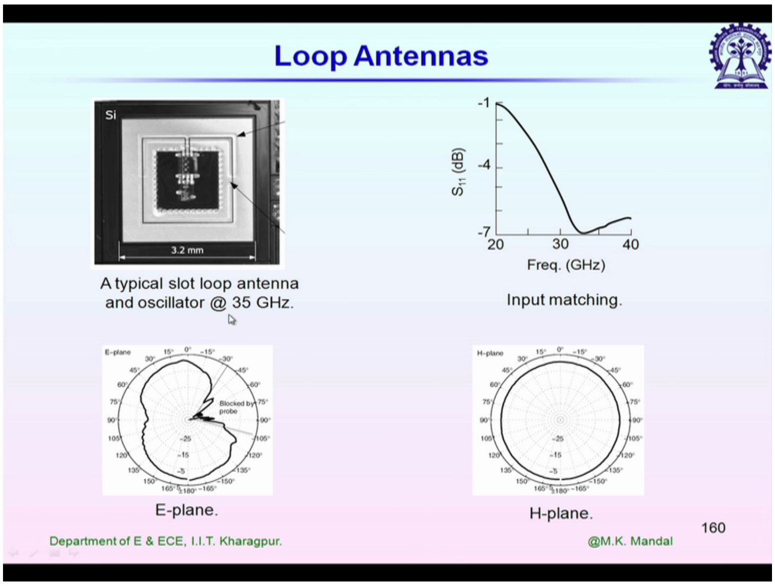

These are fabrication example from IBM. It is design for 35 gigahertz application and typical dimension it is shown left to right is 3.2 millimetre and you can identify the antenna structure we have a slot loop feed by the CPW line and also we have a ground plane and look at the S11 plot. Its bandwidth is quiet high the matching bandwidth.

Here you see we cannot even achieve minus 10 DB of input impedance but for handle device applications sometimes 3 DB bandwidth is enough here they are considering 3 DB bandwidth matching bandwidth and its quiet wide due to the ground plane resonance. Antenna radiation pattern so again in the E plane radiation pattern in this side we don't have any significannot radiation.

This is not because of antenna this is because of the measurements setup because this side radiation is blocked by the probe station. It is being measured in using a probe station. We don't have such problem in H plane radiation pattern.

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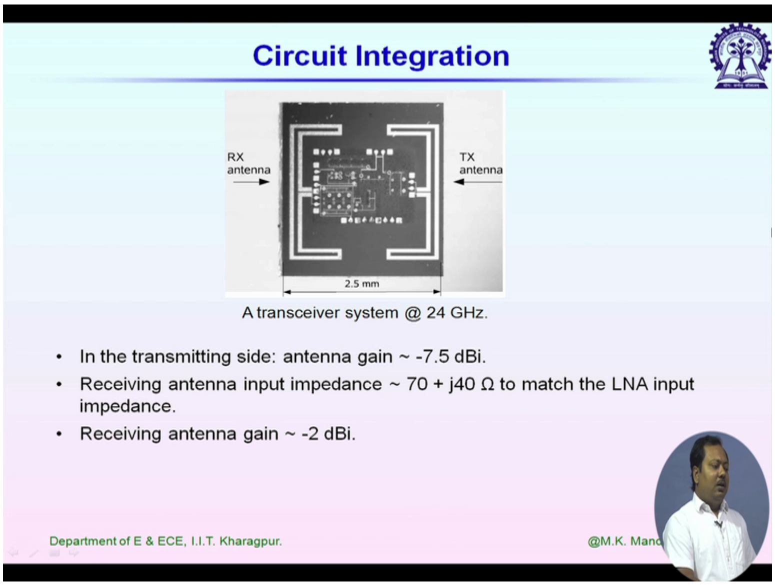

So now we know how to choose the type or radiator so next how to integrate them inside chip because in chip we also have circuit. So we if we use any metallisation for the circuit implementation obviously there will be coupling between that metallisation used in circuit and the radiator. Thats why radiator it should be placed as far as possible from the circuit board.

And when we implement circuit the metallisation for inductors it is having the widest area. So if there are any inductors on chip inductor in that case the inductors and antenna they should be placed on opposite side of the chip to avoid any coupling. Not only that we can use some sort of guard ring around the antenna structure to avoid the coupling between the circuit and the antenna radiator.

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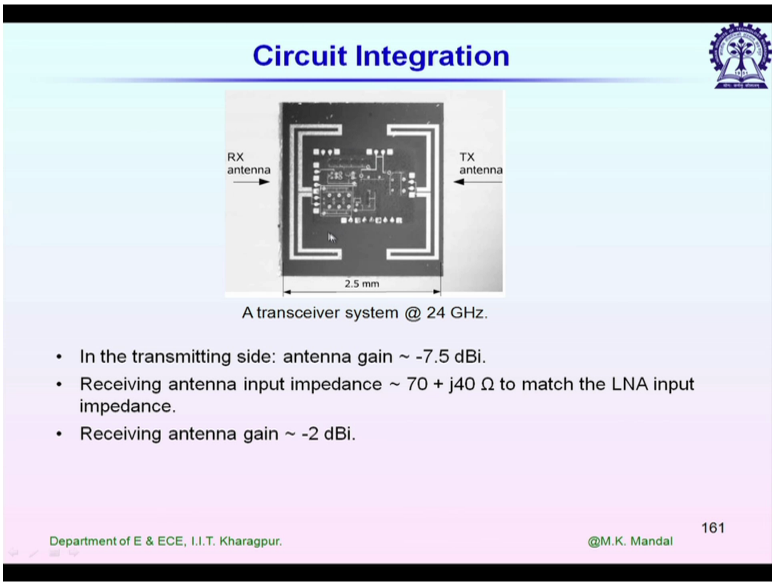

Typical this is 1 example. We are using 2 folded loop. 1 for the receiving side another for transmitting side and you see 1 interesting thing the antenna gain for the transmitting side is just minus 7.5 DBI while for the receiving side it is minus 2 DBI. Why so? This is due to the coupling between the circuit plot and the antenna radiator here. They are not using any guard ring or any precaution.

Just they are placing the antenna radiator away from circuit part and now we put maximum importance on the receiving antenna since the received power is very small and we have to detect it. And for these type of antenna sometimes we don't care about the input impedance. If you may not be 50 ohm system it may not be 100 ohm system. What we do?

The antenna input impedance it should be just complex conjugated of the next stage that means the (())(7:13). For this typical application the receiving antenna input impedance is 70 plus J40 ohm. This is to match the LNA input impedance. Because LNA input impedance at the operating frequency its not 50 ohm something else. We have then we need a complex conjugate of that to transfer maximum power to antenna and from antenna to LNA.

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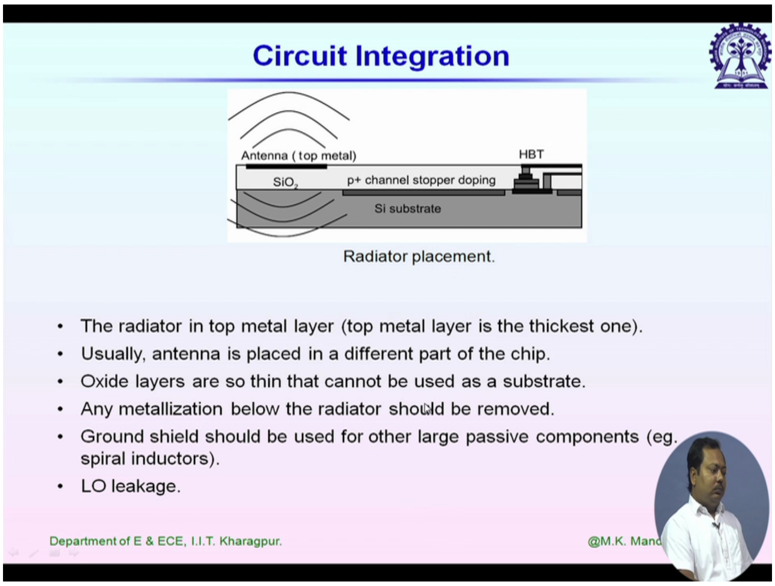

The some other issues when we go for circuit integration. Radiator it should be placed on top metal layer for gallium arsenide fabrication is used side space the circuit it grow side by side and for silicon fabrication it use vertical space so it goes top layer by layer then antenna its radiating structure it should be placed on the top layer always. The second point already we discussed that antenna is placed in a different part of the chip to avoid any coupling.

Then we have to use some separating layer between the radiator and the silicon substrate. Usually the silicon oxide layer is so thin that cannot be used as a substrate now if there is any metal below this radiator there will be obvious coupling between the radiator structure and the metal. So we cannot place any metallic structure below radiator we have to keep in mind this point when we are going for on chip antenna design.

Ground shield if its available it can be used as the reflector if the fab processes its supports and if there is any passive component for example inductor which you discuss it should be far away from the radiator we have to also avoid a low leakage. In silicon substrate we can we have the surface wave mode and we have leakage from local oxilator and it can damage the receiving side of the antenna.

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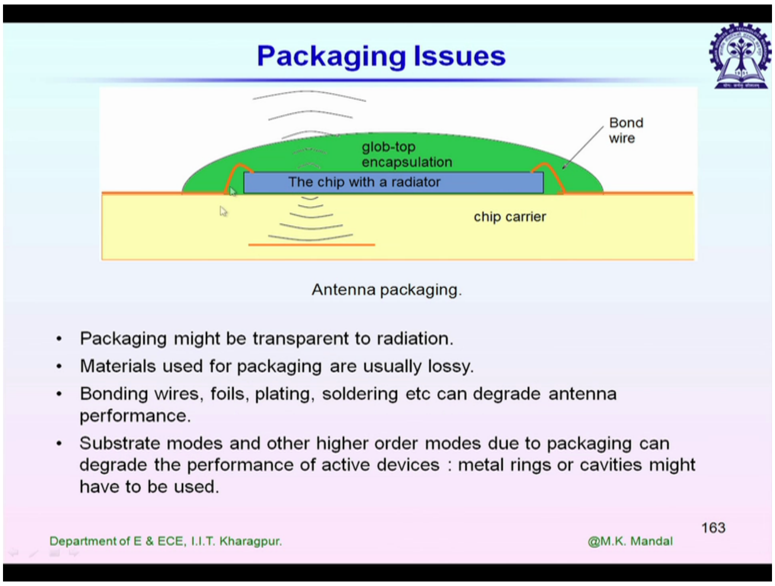

Next packaging issues, in practice always we will be using some sort of packaging material to protect the chip from different weather condition it showing a scenario like that a glob top encapsulation is being used as the packaging material. Then whatever material we use for packaging it is usually lossy material.

It will further (())(10:12) the antenna efficiency. Or you antenna gain will decrease so not only that the packaging material whenever we are going to use it should be transparent to radiation. Otherwise electromagnetic wave whatever being radiated by the radiator it will not come out we have to keep in mind also when we are selecting any material for the packaging.

This packaging layer itself it can support surface wave mode and again we may have coupling between the antenna structure and external circuit. That point also we have to keep in mind so typically people people use metal rings or cavities to isolate the radiating structure from rest of the structures.

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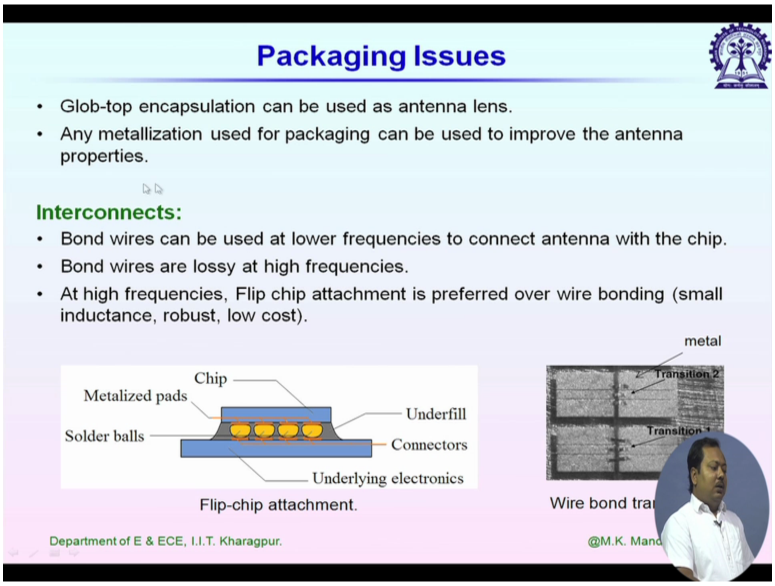

Now next is interconnect issue once we have the radiator we have to connect it to micro strip circuit so how to connect? We can use obviously micro strip line CPW line if possible or we can use wire bonding. That is the most popular method to connect the radiating structure with the micro strip with the millimetre wave circuit part. Now there are different types of connecting procedure popular one is the wire bonding.

And another one is the flip chip attachment. Flip chip attachment it will provide you lower inductance and it is less lossy but at the same time surface wave mode generation it can be more for flip chip attachment so depending on application depending on fab process then we can select the type of bonding it can be wire bonding or it can be flip chip attachment.

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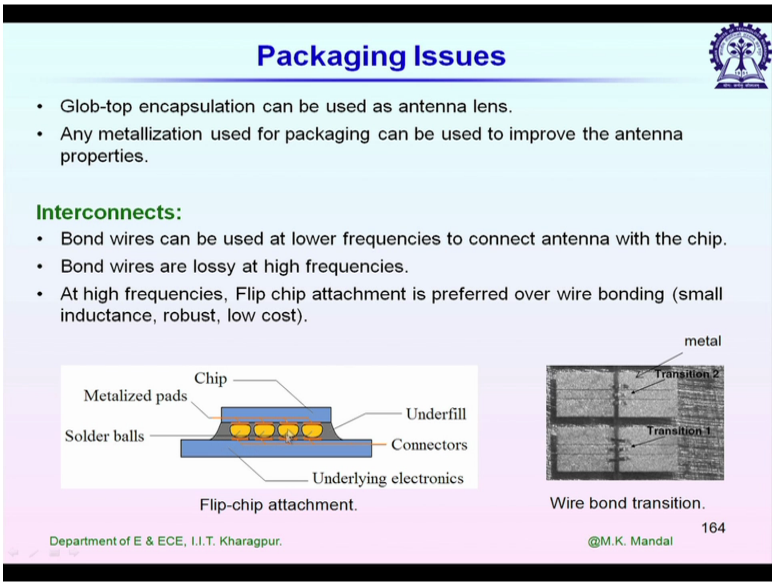

So here it showing a typical flip chip attachment in the right hand side left hand we have CPW line so left to right it is being connected by wire bonding. Any metallic wire if I we use some bend it is associated with inductance and wire bonding it is always forms a part of a loop.

It is always associated with some inductance which we cannot avoid. We have to properly model that wire bonding when we are going to use at millimetre wave frequency otherwise we will be facing input impedance matching problem.

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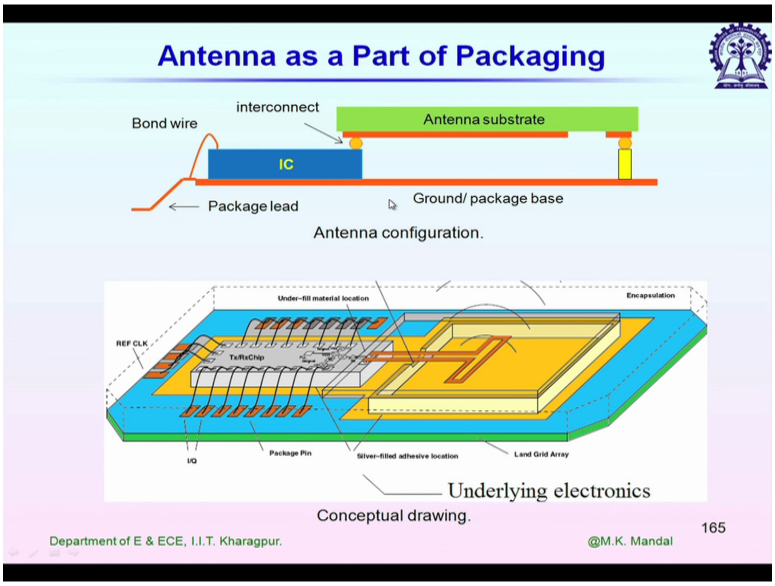

So finally how it looks when we for integration? This is a scheme suggested by IBM so let us say we have the integrated circuit here on silicon then antenna it is being fabricated in laminates so this is not on chip antenna but antenna as a part of packaging and the antenna radiator is connected to MMIC by using flip chip attachment in this particular example. And right hand side you can say we have a support for the substrate it cannot hang in air.

And below the radiator we have air cavity that will improve the efficiency of antenna. This below structure you can see we have a folded dipole antenna feed by coplanar strip line and we have 1 more guard ring here. That by metallisation metal ground it can forms it forms like 1 cavity we can call it a folded dipole backed by a cavity.

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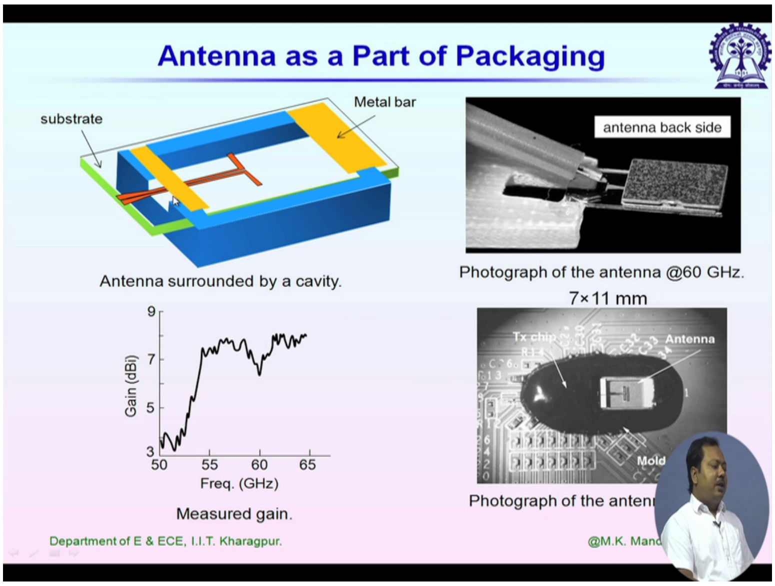

This is the zoom in view of the structure of the fol um sorry these are dipole antenna with similar structure guard ring and right hand side it shows the photograph of the fabricated structure and look at the gain. Previously we are getting typical gain value below 0 DB. Now with all this precautions when we could avoid coupling between the radiator and the MMIC structure not only that power coupled to substrate.

We could also avoid in this we are using some air cavity for that. We can improve the gain to 6 to 7 DBI. So these are some techniques standard techniques used at millimetre wave frequencies to improve the gain of the antenna and the total size is 7 by 11 millimetre including the antenna structure itself.

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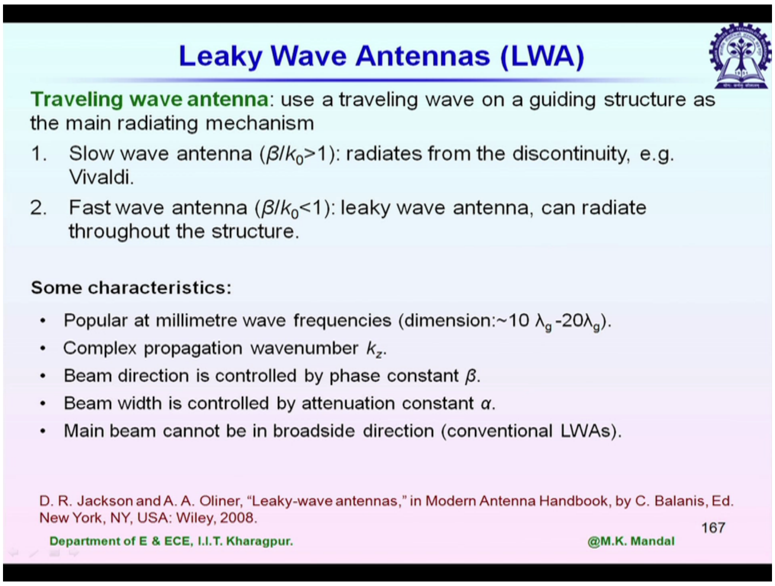

So thats all on on chip antennas, next topic we are going to start as leaky wave antenna. So till now whatever we have discussed we are using some sort of resonator structure and its length is typically lambda g by 2 or lambda g at the operating frequency now we will see some of the antenna another group of antennas where the antenna length is much more compare to lambda g.

And this antennas sometimes they radiates throughout structure sometimes they radiates from the from the dielectric air interface or metal dielectric interface and this group is known as travelling wave antennas. Now under travelling wave antennas again we have 2 different categories. If you remember beta by K nought value so if beta by K nought it is less than 1 for a guiding structure that means it is supporting fast wave and if beta by k nought is more than 1 it supporting slow wave.

Now under travelling wave antennas we have fast wave antennas and slow wave antennas. Slow wave antennas example is (())(16:40) antenna this antennas radiates from discontinuities and fast wave antenna it forms the group of leaky wave antenna they radiates throughout the structure. At millimetre wave frequencies they are popular. Why? Because of its dimension at low frequency.

If I want fabricate an antenna structure of typical dimension 10 times of lambda g it will be huge structure but at millimetre wave frequency we don't face any problem and we have advantages such as the design is very simple feeding structure is very simple and its less lossy also.

Since we are using increased volume so let us then concentrate on leaky wave antennas what are the characteristics of leaky wave antennas? How they radiate? What are the different structures possible at millimetre wave frequencies?

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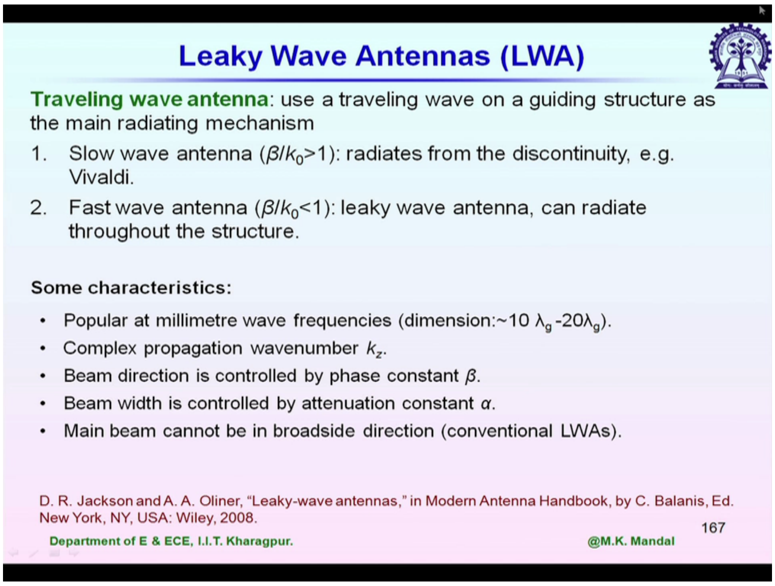

Some basic characteristics since these structure it leaks power throughout its length so we have to use the complex propagation wave no KZ. We have both alpha part and beta part it will be basically a wave guiding structure with some sort of semi open or open structure so that it can radiate or leak power throughout its length then the alpha part its non zero for the guiding structure. Beam direction is controlled by phase constant beta.

We will see that beam direction it depends on the beta value and beam width it depends on the attenuation constant alpha. Smaller the attenuation constant alpha smaller is the beam width of the antenna. Then main beam main beam cannot be in broadside direction for conventional leaky wave antennas.

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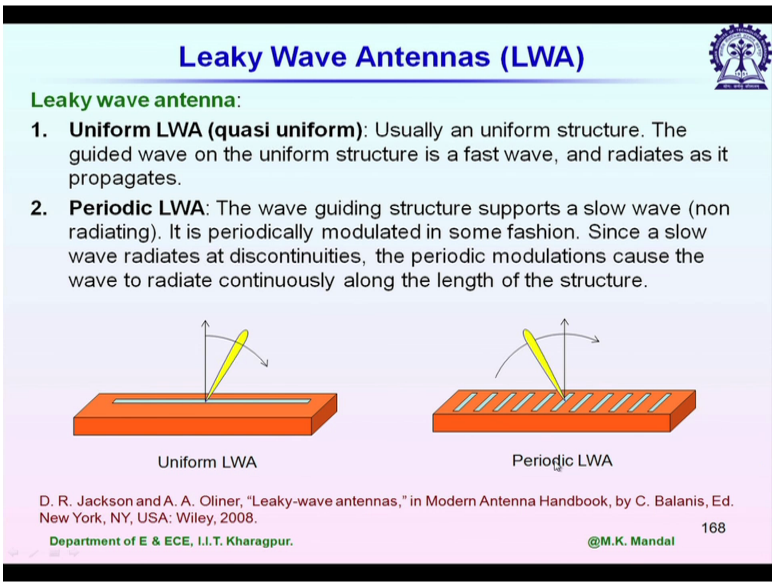

We will discuss now 1 by 1. Now under leaky wave antennas we have again 2 different categories we have we may have uniform leaky wave antenna and we have periodic leaky wave antennas. Here are the examples shown here. You can see a rectangular wave guide where 1 longitudinal slot is placed on top of the on the top wall and it is 1 example of uniform leaky wave antenna it usually radiates along the length.

So we have leakage along the length it comes out as radiation. And inside for fundamental mode operation we have TE 10 mode guided wave mode so for this guided wave mode then we have to consider both alpha due to the leakage loss and beta. Now you see wave guide itself it has some loss from the structure so whatever alpha will be calculating here it will be having the radiation loss and also the power lost inside the wave guiding structure itself so it has mainly 2 components.

The second example is periodic leaky wave antenna and for the periodic leaky wave antenna the guided mode usually slow wave mode. Even for the slow wave mode we can have power leakage and effective radiation but it can be shown that radiation for a periodic structure it is again coming only from the fast wave mode then from where this fast wave mode appears?

If we do if we analyse this structure any periodic structure it can be shown that any mode propagating along the structure it is the sation of infinite flow K modes. And at least 1 of this flow K mode it will be fast wave. And we will be having radiation only from that mode which is fast wave.

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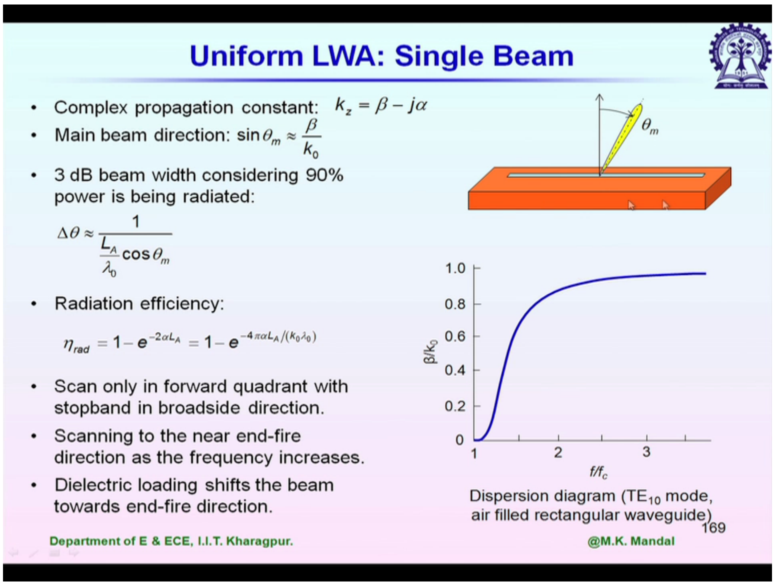

Let us continue with the uniform leaky wave antenna. This is a typical example here it shown for rectangular wave guide we are measuring the beam direction from broad side direction its given by theta M as we discussed the propagation constant its complex here. It can be written as beta minus J alpha then main beam direction it is being determine by beta.

So sin theta M approximately that is equal to beta by K nought now 1 interesting thing already we know the beta by K nought variation for typical rectangular wave guide it shown here its for TE 10 mode its supports fast wave and always beta by K nought is less than 1 now we frequency beta is changing.

Beta by K nought is changing so what we expect then if I change the frequency theta M will change and at cut off frequency beta is 0 in that case beta by K nought is 0 in that case we have radiation in broad side direction. But since its a cut off input impedance sin is infinite we don't have any wave propagation inside though we don't have any wave propagation inside. We don't have any radiation in the broad side direction.

Radiation will start with some positive value of theta M may be 5 to 10 degree and then as we increase beta as we increase frequency operating frequency then beta by K nought increases. So theta M will increase and the highest possible value where beta by K nought convergence to 1 and it is approximately 90 degree.

So for this type of antenna scanning is possible by frequency sweep if we change frequency accordingly beta by K nought will change and theta M will change so by frequency sweep we can scan 1 quadrant but what we see from this relationship the scanning beam is always in 1 quadrant and we cannot achieve any radiation in the theta M equal to 0 degree direction and theta M equal to 90 degree direction.

So typical values we have 10 to 20 degree theta M 2 70 to 80 degree and now if I use some dielectric inside the rectangular wave guide. So if you remember for dielectric loaded wave guide this beta by K nought its starts from 0 then it crosses beta by K nought equal to 1 point. That means this whole radiation pattern it is shifted to theta M equal to 90 degree or we can go very near to (())(24:22) direction.

Theta M equal to 90 degree so this is the dependence of theta M on beta next the antenna characteristics how it depends on alpha leakage rate? So how we can control leakage rate for this rectangular wave guide just like the resonant antenna as we have seen? If we place this slot near central axis then we don't have any radiation from this slot. Because we cannot excite this slot in that case.

So we have to use some sort of offset if I increase offset in that case radiation will increase or leakage from the slot will increase. Leakage also can be controlled by changing the width of the slot if I increase the width it will have higher leakage from the slot structure and now the beam width of this radiation pattern it depends on the leakage rate.

Considering let us say 90 percent power is being radiated then half power beam width delta theta this is approximately 1 by LA by lambda nought into Cos theta M. Where LA represents the total loss over this length. Radiation efficiency eta rad this is given by 1 minus E to the power minus twice alpha LA sorry LA is the total length of this slot from left to right. So for smaller alpha we have to use longer length LA to radiate at least 90 percent power.

And to have narrow beam width some other properties already we discussed some of them scan only in forward quadrant this type of antenna and it can have near end fire radiation pattern when beta by K nought approaches 1 and if we use some dielectric material inside then this radiation pattern shifts to end fire direction. So we will take a break then we will continue with this antenna.