Millimeter Wave Technology

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Module 6
Lecture No 25
Passive Components (Contd)

Well so we learned about different types of traffic components like filter, couplers, power dividers, T-junction, now a special case mesh termination. So for example, let us say you are using a branch line coupler, you are utilising 3 ports; Port P1, Port P2 and Port P3, but isolated port you are not using some, so should you keep it as it is? If you keep it open circuited then there will be reflection and the properties of branch line coupler will change, so Port 4 isolated port should be mesh terminated or we should connect 50 ohms load to Port P4. Similarly, mesh termination we use in many other situations also, now at millimetre wave frequencies realisation of mesh termination is really challenging because of the reactive contribution of different guiding stem means bends or discontinuities.

So whenever we are using let us say a 50 ohms register you can use for example 1 SMD resistor, so 1 end you have to be you have to solder it to your transmission line, what about the other end? It should be grounded, so the 2^{nd} end when you are grounding obviously you will be using some metallic wire and metallic wire it is one sort of discontinuity, it will give you some inductance. So you want to realise a 50 ohm, you have a 50 ohm SMD, but when you connect it to circuit it is not just 50 ohms it is 50 ohm with some additional reactant, then how to obtain this mesh termination at millimetre wave frequency? At lower microwave frequencies this inductance value is so small, usually you neglect it, but at millimetre wave frequencies we cannot, so let me give you one example and how we can compensate this inductive effect.

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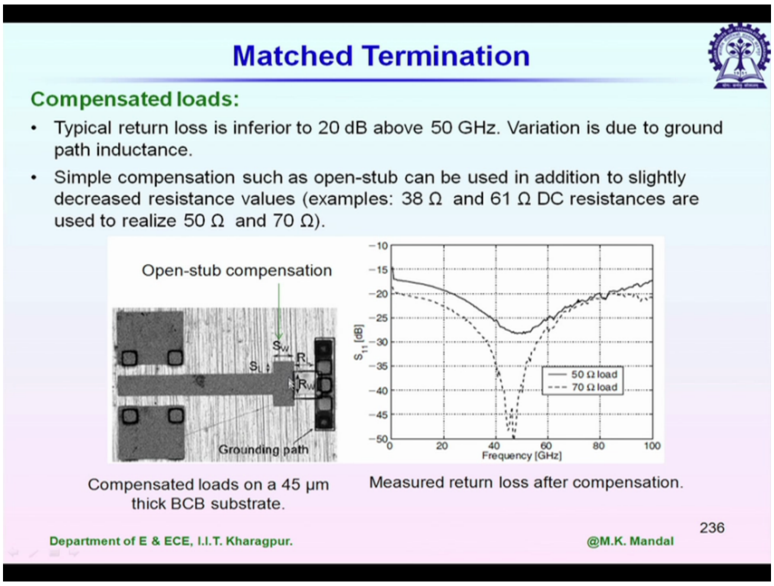

So in this example it is realised in BCB in 45 micrometres thick BCB substrate, you can see the top line metal, we have CPW line and basically and but this black rectangle it shows rectangular metallic wire that connects the top line metal with bottom plane metal and you can identify the central conductor. Now, for this BCB or in silicon or gallium arsenide technology, how we how would we design resistor, we cannot use SMD. We use nickel chromium alloy, usually the lab they will give you a standard thickness for the nickel chromium and standard resistance per centimetre, then you have to choose a proper dimensions so you know that resistance it depends on length and the width so accordingly you have to select your length and width to realise a given resistance value.

So in this picture this RW and R L, they show the length and width of that nickel chromium section we call it thin film resistor and right hand side you can see one long black line and on that we have 3 wires, instead of one wire they are using 3 wires to reduce the inductive effect. Now, if I simply take the R L and R W so that its equivalent DC resistance is 50 ohms, then if we measure it input impedance it becomes different because of the inductive wires. So for example, typical return loss is inferior to 20 dB above 50 gigahertz and this variation is due to ground part inductance due to the wires, so what is the compensation technique then? So for this shunt inductance we can use shunt capacitance to compensate or nullify by their effect, how to realise then the shunt capacitance?

from open stub from transmission line theory we know that if we have place one open stub with microstrip line, it will give some shunt capacitance, the same technique is used they are also now the thing is that you have to calculate what is the equivalent inductance given by the grounded wire, then you have to calculate what is the equivalent capacitance you need and for that what is the equivalent length of the open stub. But instead of this calculation step practically what we do, we simply use a full wave simulator, full wave later will give you the S parameter and then you choose the width of your open stub and simply tune the length just one parameter and if you simulation step you will get the desired result.

So in this picture you can see, they are using 2 open stubs with S w and length S L, they will give you the required shunt capacitance. So practically the resistance value it is chosen little lower than the required one for example, this particular example let us say the required value is 50 ohms, then they start it with 38 ohms this nickel chromium resistor and if they need let us say 70 ohms, then they start with 61 ohms and now you see the result. If you have inductive contribution S 11 will be very poor, now since they have compensated it at some given frequency let us say at 50 gigahertz, then for 50 ohms load it is showing this black line, S 11 is 27 dB. So in reflection loss, return loss is more than 27 dB so it is quite good and for 70 ohms design even it is better than 40dB at the design frequency, so it is quite good.

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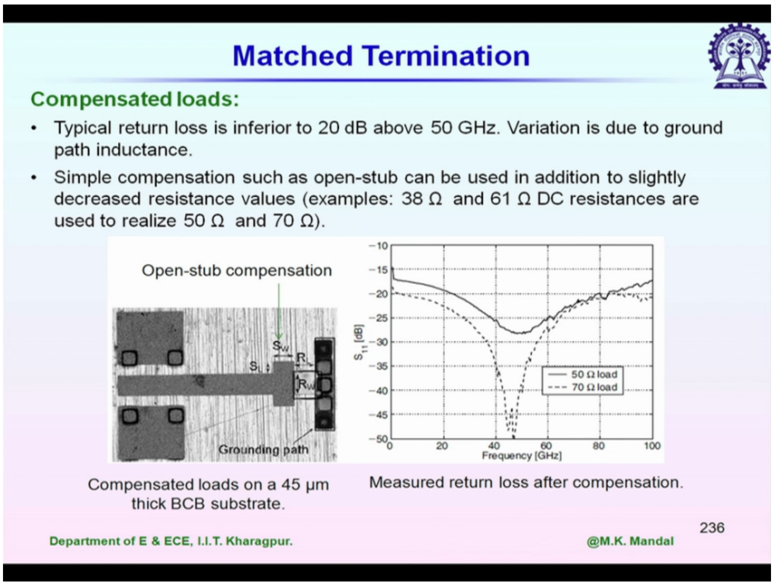

But without this compensation if you start with just 50 ohms, the loss value is below 10 dB it is quite high. So these are narrowband designs, now wideband designs is also possible there are several techniques to make it wideband I will show you an example, so in this particular example they use another shunt arm, how they realise it? So one single 50 ohms they are realising by using 2 shunt resistors nickel chromium thin-film resistors, so one is grounded by using chain of wires and the 2nd one it is connected to one open stub which will keep some shunt capacitance. So without the shunt arm the shunt additional arm of dimensions is given 250 micrometer by 60 micrometer which will give you equivalent resistance of 158 ohms, this is the DC resistance.

So without the shunt arm it shows 71 + J30 ohms and 100 + J53 ohms at 100 gigahertz and 160 gigahertz respectively. And now with this compensation so this is designed by using a full wave simulator, the required length, width of nickel chromium thin film resistor and the open stub of this given 59 ohms, then it becomes meshed over Y band width. You can see you here the simulated results over 0 to 160 gigahertz, so in this simulation also we are considering a fabrication tolerance of + - 10% dimensions, now you see the result. So left-hand side it is showing S 11, so actual S 11 value for this design given by the solid line always below - 20dB, so 25dB from 0 to almost 150 gigahertz. Now considering + - 10 percent fabrication tolerance, even then this dash line and dotted line, even then if you can say it is below 20dB over 0 to 160 gigahertz and now right-hand side, it is showing real and imaginary part of input impedance as seen by this microstrip line.

So imaginary part it is approximately 0, you can see this line you can follow this line, it is within + - 5j and the real part is very close to 50 it varies between 50 to 60, so overall S 11 is below 20dB. Now we have discussed about different passive components and in some of the designs we are using different types of wave guiding structures, so not only that when we go for any millimetre wave systems in the same system different components can be it can use different types of wave guiding structures. Some components can use microstrip line, components can use rectangular waveguide, some proponents can be designing in NRD, now all of this we have to integrate in one single system so obviously we need some adapters. One microstrip line component if I want to connect it with one rectangular waveguide system, we need one microstrip to rectangular waveguide transformer for transition we call.

Now, whenever we design transition we mainly face two problems; 1st one mode matching and the 2nd one is impedance matching. For example, microstrip to rectangular waveguide, in microstrip line it supports Quasi-TEM we know the electric field configuration, but inside rectangular waveguide we use TE 10 mode, it is transverse selective mode, which has different mode property. So we have to somehow transform this Quasi-TEM mode into TE mode and not only that, it should be matched from both microstrip feed point and also rectangular feed point, so let me give you some popular example of these different types of transition involving different types of guiding structures at millimetre wave frequencies.

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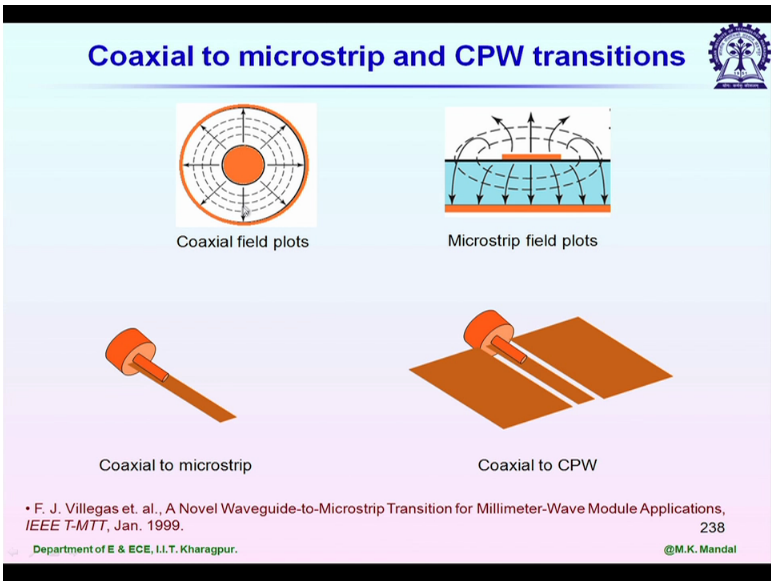

The 1st example is coaxial to microstrip line and co-axial to CPW transition, frequently be use for measurement purpose. So in coaxial cable if you recall that always we use TEM mode, we never use TE or TM mode, we want only mono mode propagation. So for TEM mode electric field, it is from the central conductor to outer conduct so they are perpendicular to magnetic field lines. Now we want to connect it to a microstrip line, so coaxial line it supports TEM mode, microstrip line it is also quasi TEM mode and it also has electric field component, which is particular to ground plane, so simply we can connect one coaxial line to microstrip line directly. Coaxial line let us say its impedance is given 50 ohms; microstrip line impedance is also 50 ohms, than directly it can be connected.

Only thing is that the central conductor should connect the strip of this microstrip and the outer conductor should be soldered to ground and we use only one hub of this so that it can excite the microstrip line because if I use both hubs of coaxial cable, then they will nullify the effect of microstrip line field configuration, so this is the structure showing the conducting parts only. Similarly, we can also excite CPW line so for CPW line you see electric field, it starts from signal line and terminates into ground so we can again use this TEM mode of coaxial line to excite Quasi-TEM mode of CPW line, let me draw the field diagram.

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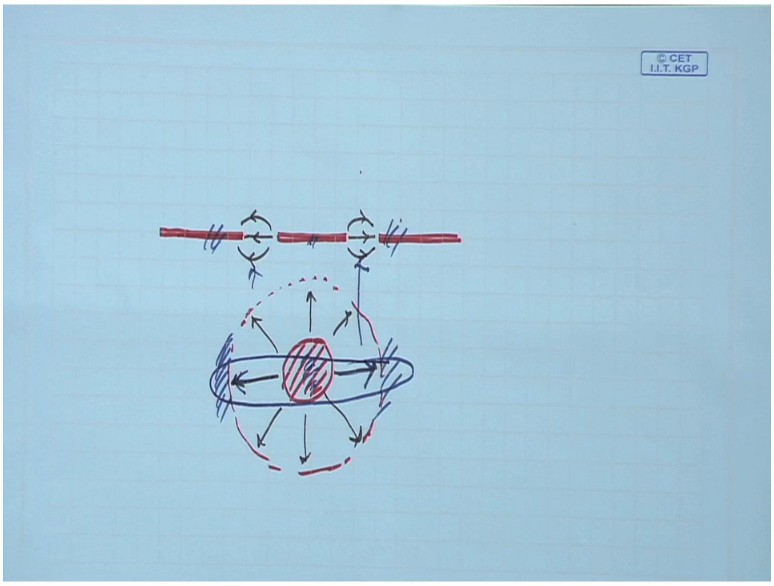

So for CPW line let us say this is the signal line and this is the ground plane. Now, we have electric feed lines from signal line to ground, now if I compare these feed lines with that of a coaxial cable, this is the central conductor of coaxial cable and let us say this is the outer conductor of coaxial cable and inside we have TEM field configuration, so you see then simply we can use this part of coaxial cable, we can connect this part of coaxial cable directly to CPW line, we will be soldering the central conductor to the signal line and this outer conductor this part to the ground plane and then this component of electric field it will excite this component and this right-hand side component, it will excite this component.

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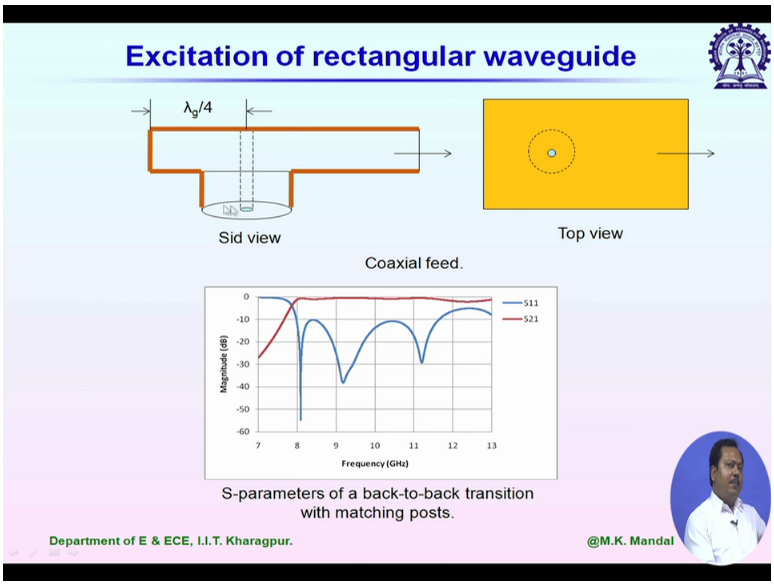

So we do not have any problem due to field matching and in both of these 2 different guiding systems, we have Quasi-TEM mode and if the characteristic impedance of both CPW line and coaxial cable is 50 ohms in that case we can directly connect it without using any impedance transformer. Next, coaxial cable to waveguide how we can excite it? Now, inside coaxial cable we have TEM mode and inside rectangular waveguide we have transverse electric mode. In this case we have to use a mode converter and this is done by using the flinching field of this coaxial line, so inner conductor you can see this is the cut-way view this is the side view, so wave inside rectangular waveguide is propagating from left to right and left hand side we are using a shorting plane, which lambda G by 4 away from the central conductor midpoint of central conductor.

On central conductor on top point it is soldered on the broadside of this rectangular waveguide and then the flinching whale inside the coaxial cable, when it terminates it opens into rectangular waveguide, we have flinching field inside the rectangular waveguide and that flinching field, it excites the TE 10 mode inside rectangular waveguide. And because of this lambda G by 4 short termination, we do not have any wave propagation on left-hand side, you can say somewhat like if any wave propagates in left-hand side then it will be reflected from short plane and it will be out of phase and in the front side we do not have any reflecting surface, so simply it will propagate. So top view how it looks, you can see only the central conductor soldered on top plane and this dotted line it shows the slots in the bottom plane, so power is coupled to the slot in to rectangular waveguide.

We can also design coaxial cables to SIW transition, if you recall SIW is Substrate Integrated Waveguide, so for SIW inside we have dielectric and for coaxial again we have dielectric and otherwise all the principles are very similar. Usually it is a narrowband design physically, typical bandwidth 5 to 10 percent, we can improve the bandwidth by using some matching pin, so simply we use some metallic wire inside the rectangular waveguide for matching purpose to improve the input reflection coefficient and in that way we can cover a single band of 40 percent bandwidth.

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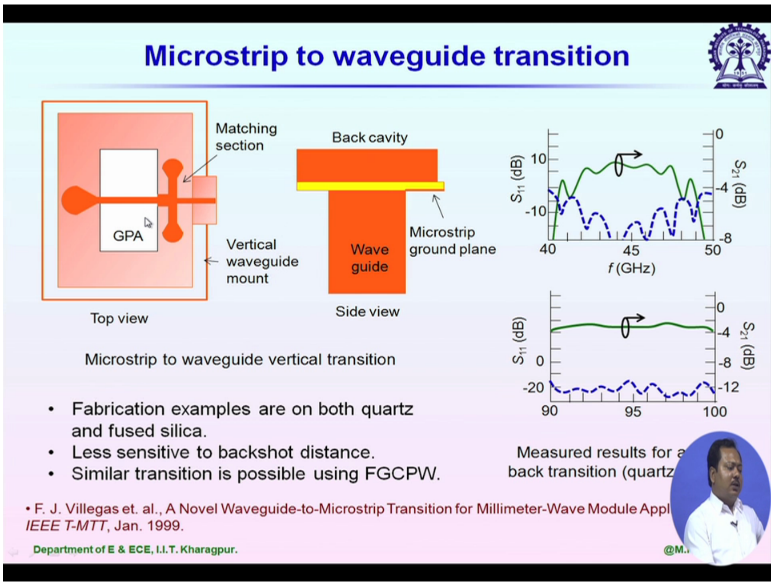

I am showing you another example, microstrip line to rectangular waveguide excitation at millimetre wave frequencies. So here what is done, the microstrip line geometry it is fabricated on a printed circuit board substrate, so this is showing the microstrip line geometry. Just below the microstrip line, in the ground plane of the microstrip line we have one aperture, we call it ground plane aperture, so power from microstrip line is coupled to waveguide through this ground plane approach so this shaded part orange colour part, it is showing the ground plane metal and this dark orange colour part, it is showing the top plane metallisation of printed circuit board.

So you can see the termination of this microstrip line, it is terminated into one open stub radials stub and before that just before ground plane aperture we have 2 matching stubs opens open circuited stubs, it is used for controlling the input impedance. Now, how it is placed inside rectangular waveguide, you can see this is showing right-hand side picture, it is showing the side view, so this ground plane aperture it opens inside the rectangular waveguide and above just above the strip we have a back cavity and the cavity hide it is lambda G by 4, but it is not very sensitive to this lambda G by 4 just like the previous one, it can be little less or more than lambda G by 4. Then right-hand side you can see the microstrip line, so from microstrip line power is now coupled into rectangular waveguide.

And here it shows measured performance of a back-to-back transition that means from microstrip line to rectangular waveguide, again from rectangular waveguide to microstrip line and this is the measured S parameter. The 1st example over 40 to 50 gigahertz band and you see, the S 21 is quite good for these 2 transitions including a section of rectangular waveguide, so its mid band loss is just 2 to 3 dB for 2 transitions. And the next measured example it is on quad substrate of the PCB, it is from 90 to 100 gigahertz and over this band, loss is below 4dB for these 2 transitions, so similar transitions are also possible using finite ground CPW line.

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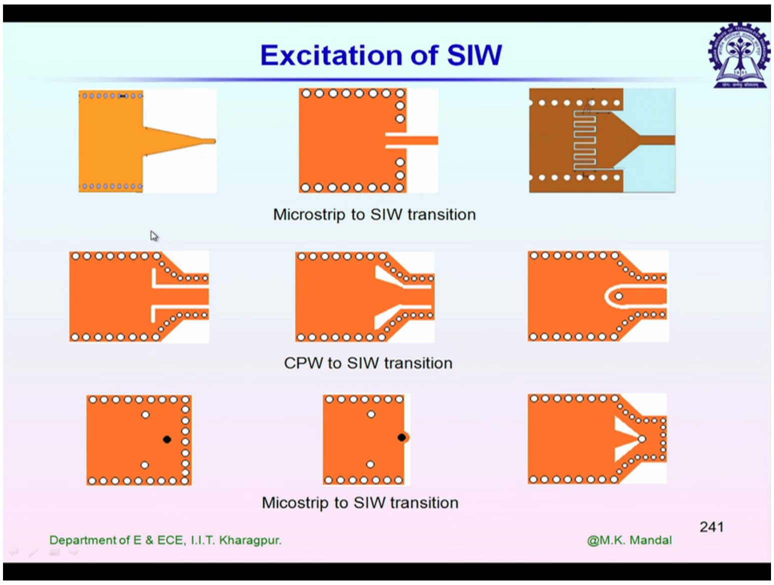

Now, excitation of substrate integrated waveguide from microstrip line, from CPW line and from coaxial cables, there are different techniques reported in literature for millimetre wave applications, so for all of these 9 designs so the very basic thing two points; one point, we have to convert the mode and the 2nd point is impedance matching. For an example, for this 1st design you can identify, left side we have one substrate integrated waveguide structure, which supports TE 10 mode and right side we have 50 ohms microstrip line. So rightmost it starts with 50 ohms and they are designed in one single substrate, so that means single PCB is used for the same design and now 50 ohms microstrip line is terminated into TE 10 for field configuration field matching or more matching.

For microstrip line we have the perpendicular field components, inside rectangular waveguide again we have perpendicular field components, so we do not have any problem due to freely matching however, we have problem due to impedance matching so that is why we lead one impedance transformers, so how it is done here, you see you can see a linear tapering used here, usually the length of this linear tapering is lambda G by 4 at the centre midpoint mid band of frequency and by using a full wave stimulator simply you can tune the terminating width to obtain a better S 11 and S 21 usually this design is wideband having more than 40 percent bandwidth. So similar design is possible and right-hand side instead of open circuit, they start with a short-circuiting valve, it somewhat looks like how we feed rectangular patch antenna, it is using some infant feeding.

And the rightmost one, instead of just simply inset it is actually capacitively coupled; we are using one thinker type capacitive coupling. Next, CPW to SIW transition, so in all these examples you can see we are not using conventional CPW usually we avoid it at millimetre wave frequencies because a simple CPW line it sits on dielectric substrate it will excite surface wave mode, rather we prefer boxed CPW or Brownback CPW line. So right hand side you can see the wires of the ground back CPW line and left hand side we have the SIW structure. Now, in SIW we have perpendicular electric field components and right-hand side for the CPW we have both microstrip line mode and CPW mode. For CPW mode you remember that it is inside the slot and it will be then parallel to top plane and for the microstrip line mode it is perpendicular so in the same direction as of TE 10 mode.

So again, we have good field matching, the only thing is that we have to obtain good impedance matching and that is being done here by using short-circuited slot termination of different shape. In the next row this is example of coaxial to SIW transition, this 1st example actually we discussed for an angular waveguide, you can see the coaxial central conductor shown by this black dot, which is lambda G by 4 away from the shorting valve and 2 matching pins they are used to improve the input impedance matching. And instead of a shorting valve we can also use one open circuited valve. In this case you can say that the central conductor is directly soldered to one open circuited end, so we do not need any extension but again we are using similar matching wires here and right-hand side again a shorting valve, but with different geometry for impedance matching.

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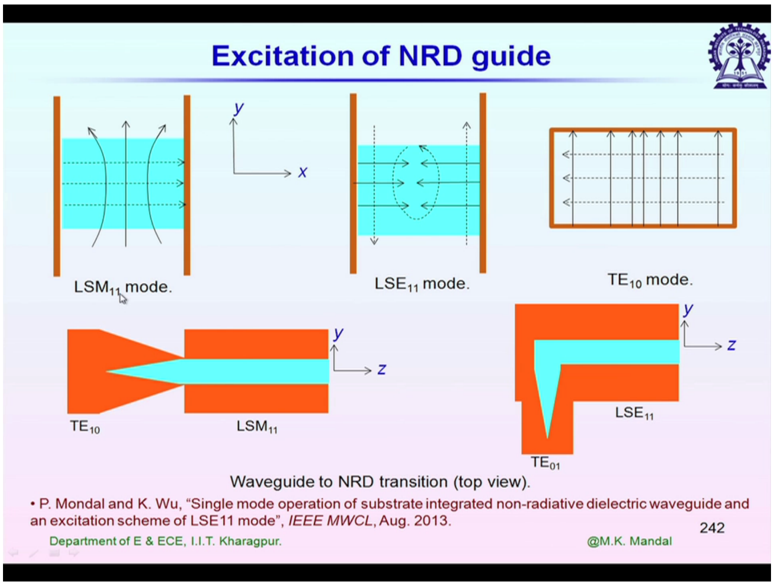

Next is NRD, NRD it can support both longitudinal section magnetic and longitudinal section Electric. In longitudinal section magnetic mode in the propagation direction mainly we have the magnetic field components. So for LSM 11, if I concentrate on electric fields, electric fields they are maximum on the central plane and they are parallel to the ground plane. If you recall we are using a dielectric slab in between 2 ground planes, so now if I want to excite this LSM 11 mode by using a rectangular waveguide, so right hand side it shows a TE 10 field configuration of rectangular waveguide. We have electric field perpendicular to broadside, so simply then we can place a rectangular waveguide on top of this so that electric they are in same direction, so then it shows the top view actually I am chewing a cut-way view.

So you see LSM 11 mode, it will have parallel electric field components parallel to ground inside this and then you have to turn this rectangular waveguide to have the electric field of the TE 10 mode in the same direction, we do not have any problem due to field matching. Next problem is impedance matching because left-hand side we have transverse electric mode, right-hand side we have longitudinal section magnetic mode. So how it is done, rectangle waveguide it is air filled, so you see its dimensions we are using a tapering slowly (())(29:01) and right-hand side we have the dielectric slab, it is now extended into rectangular waveguide and again we are using a tapering. And by controlling the tapering length we can tune the input impedance, now hard to excite LSE 11 mode?

For longitudinal section electric, if I look at electric field configuration you see it is coming from left-hand ground plane, than going into propagation direction. From right-hand side is coming then from on mid place it is in propagation direction, so we cannot simply place a rectangular waveguide on top of it because we have both left-hand side and right-hand side components and they will cancel each other away. So we have to use a different scheme, rather than electric field we can excite this LSE 11 mode from an any aperture from the ground plane and using let us say magnetic field coupling. Here this is the geometry, so instead of TE 10 we are again turning into have the TE 01 mode and left-hand, side it is terminated with a short plane similar to go coaxial to rectangular waveguide, it is lambda G by 4 away from this midpoint.

And you can see this rectangular waveguide section, and right-hand side we have the NRD section, now we have coupling through magnetic field from the rectangular waveguide to LSE mode of this NRD guide. Again we can change; we can tune the tapering length for proper impedance matching. So we have discussed about the different types of passive components, mesh termination and also transitions frequently used at millimetre wave frequencies. Next we will start some active devices and then its applications typically electronic switch because electronic switches very popular for controlling the performance of wireless systems and then some examples of millimetre wave systems, so for today let us stop here, thank you.