Basic Building Blocks of Microwave Engineering

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Lecture – 11
Port Microwave Power Divider/Combiner Part – 1

Welcome to the 11th lecture of the course on basic building blocks of microwave engineering in first 5 lectures we have seen the mathematical model for microwave transmission. In next 5 lectures we have seen the various transmissions structure through which electromagnetic signal or microwave signals propagates.

Today will see the circuits various passive circuits that there used to play with the signals. Suppose we want to divide the signal into 2 parts. Or 2 signals are there we want to combine them. So, what are the devises by which we can do that? Similarly suppose we have a signal, we want to reduce the signal level. We want to attenuate the signal. So, how to do that microwave frequency or you know the basic building blocks of any electronic circuit it is an LC circuit a resonator.

So, at microwave frequency how to create that resonator, there can be various types of resonating circuit's series resonator, parallel resonator, or RLC circuit, second order complete second order circuit. Because those of the basic circuit by which we can produce any new frequency signals. Or you would amplify your sustain that new frequency signal, just from noise we can pickup that signals. So, that is called a resonating circuit. So, how to create a resonator? These will be discussed in this module that passive circuit components, there will see this. So, in the next 5 lectures you will see that these lecture; we start with microwave power divider. How to divide or how to combine?

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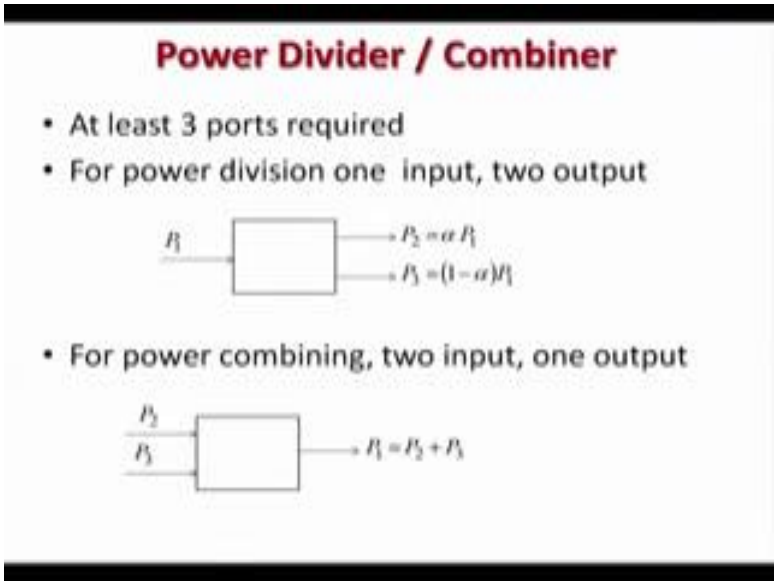

So, you see that if we have 1 to divide power at least we require 1 input, and 2 outputs may be more, but at least this is the minimum. So, at least 3 ports are required for a power divider. So, p1 is the power that is input as the arrow shows.

And then I need to give it. Let us say alpha faction I give one to give this port two. And then remaining that is 1 minus alpha portion I want to give it here, this is a case of a loss less divider. So, 3 ports are required. Similarly if I want to combine suppose I have 2 signals p2 and p3. I want to combine that signal power. So, I want that at output I should have a sum of the input power. These called power combiner. So, in many times, you will be requiring that, as you know that signals they needs to be divided they needs to be combine etcetera.

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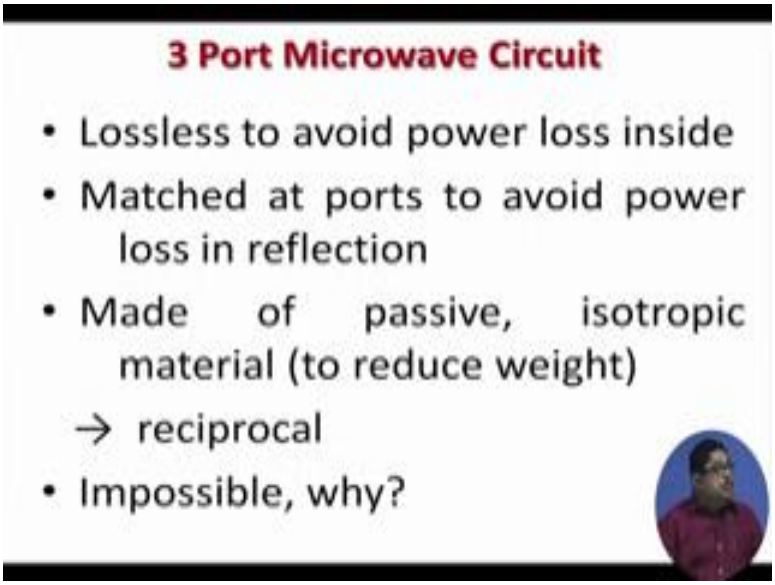

So, let us see that how to do it in microwave region. So, we require a 3 port microwave circuit. Now obviously, this is our wish list. That we want that inside that circuit there should not be any power, because we trying to either divider combine power. So, unnecessarily we do not want to lose power. In microwave frequency is very closely to produce microwave power. Such high frequency power, we that is why we take at most care can not to lose it. Now lower frequency it is pretty easy to have it is resources at lower frequency. Nowadays that from with the advancement of electronics engineering, that is why they are it is not, important in the lab etcetera. We do not bother about lose less conditions.

Generally always it is vapor ed, but when you have something in abundance you do not pay. So, much in or you do not do. So, much engineering afford to have loss less. But a microwave region is very costly to produce when a 1 mili watt of power. That is why we take we microwave engineers are very careful about loss. So, we want that inside that device there should be any loss. That is called we want to make this 3 port power divider or combiner loss less 1.

Then also we know that when we suppose a signal is coming either from the source or we are giving it to the load, or it is passing to the transmission structure. We have

discussed all of them yesterday that wave guide, various types of wave guides, various planar circuit micro stream etcetera.

Now, to this power combiner or divider when we want to connect that we need ports electrical ports. Now in electrical ports, if the impedance is not properly matched there will be a reflection on the ports. And due to that mismatch there will be some power loss. Now that also we do not want. So, we want that all the ports all the input output ports should be impedance match, by the by that impedance matching was a concept we disused in an earlier NPTEL lecture basic tools of microwave engineering. 3 basic tools there we have seen one of that tools was this impedance matching. So, that you see that if the ports are not match, this power will be loss. Then also we want that these devices will light weight, because today you are saying that with the advancement of electronics engineering and IC technology. We have all the things suppose your mobile phone etcetera all in a card.

So, if we want to have that we want it to be having a very small weight things. That is why if it made of to reduce weight we required that it should be very light material and we also want. So, that is why it should be made of passive material. Because active material. Generally they are quite weight in microwave region the active material is or is non isotropic material that is generally fade, I to use which is magnetic material, any magnetic material generally bulky.

So, if we want to make it up passive isotropic material. Then you know that if we have any passive isotropic material, isotropic I think this term you have understood in case of a basically that in all detection it isepsilon mu etcetera is properties are same, then the whole circuit that should be reciprocal.

So, basically our wish list is our 3 port power divider power combiner. That should be loss less, that should be match that outputs and there should be also made of reciprocal or that should be reciprocal, so made of passive isotropic material.

Now, will prove from mathematics or from the basic microwave engineering, that you cannot have this; all this wish list cannot be satisfied.

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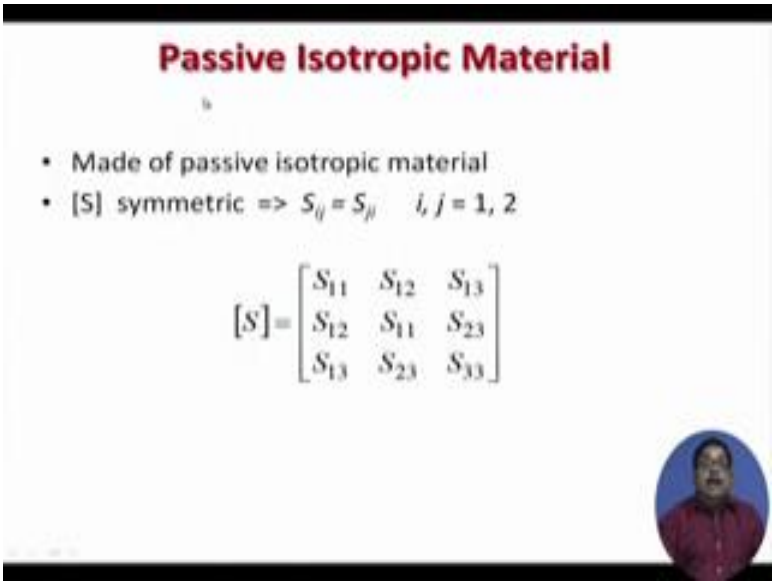

So, let us see that. So, there again will take the help of another basic tool fundamental tool of microwave engineering that is scattering parameter. In our earlier NPTEL lecture we have already talk about this scattering parameters. Is various properties referred to that because here you will be using those properties. So, if the any circuit is made of as a passive isotropic material. So, that it is it is reciprocal network, they need s matrix become symmetric. Symmetric becomes symmetric. Symmetric means for all i j combination s i j is equal to s j i.

So, if the power divider combine is made of passive isotropic material, then that 3 port device it is matrix will look like that. You see s11 s12 s13. S21 due to this symmetric property will be s12. This, this is wrong this is a s22. This is not s11. This should be called as s22 will not this is a s22, s23. Then s13, s13 again because of these symmetric property s23 is thinking.

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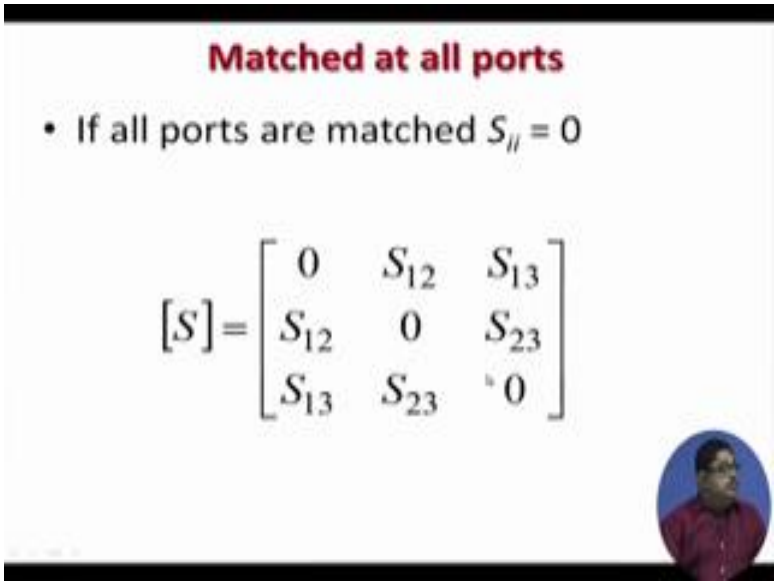

So, now then we enforce the second property that matched at all ports. If any port suppose the ith port of any microwave network if it is matched, match means the input impedance and the characteristics input impedance of the port there same. So, if it matched then we get Sii is equal to 0. So, port 1 match means s11 is equal to zero. Port 2, 2 match, port 2 match means s22 is equal to 0. Port 3 match means s33 is equal to 0.

So, apart from the previous that reciprocal condition, that is a s matrix symmetric will got hear this additionally, if it is match that all ports. So, out of our 3 list criteria, we have taken 2.

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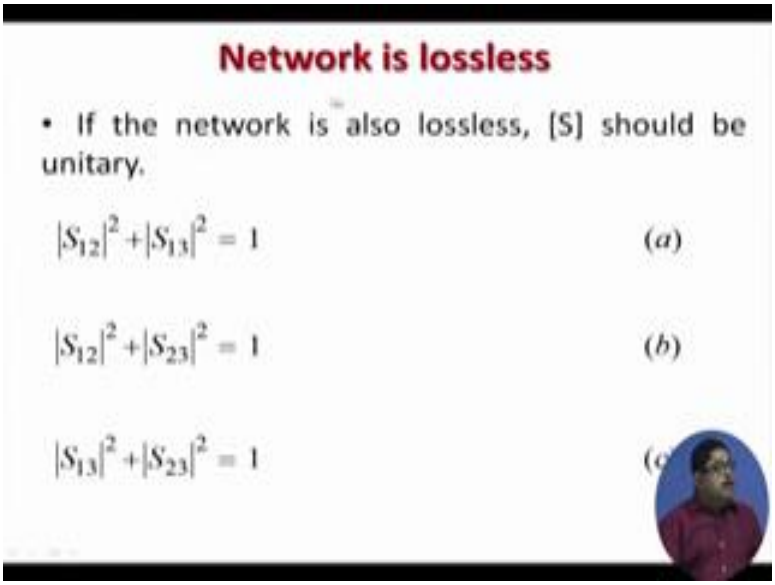

Let us put the third criteria. Which was in order it was pass that network is loss less. Now if a network is loss less, it is matrix is scattering matrix become unitary. So, unitary means, that the sum of all the column minimize their magnitude square that will be 1. And 1 column and any other column complex conjugate there product will be 0. So, this is called unitary property. Please refer to our earlier NPTEL lecture, basic tools of microwave engineering for that.

So, this matrix sorry, so, this matrix now, we put the unitary condition. So, from the first condition that the square magnitude square will for each column is 1; that means, in the first column it will be s12 square when s12 magnitude square plus s13 magnitude square is equal to 1. For the second one, s12 square plus s23 square 1. Here s13 magnitude square plus s23 square is equal to 1.

So, you see that we have written that and name them is a b c this 3 equations and then the next property that complex conjugation. So, there we can see that if we do between these two, will have 1 condition that s13 start s23 is equal to 0.

Similarly, between these two, will have s12 star s13 is equal to 0. And between this one and this one, will have the s23 star is12 is equal to 0. So, those are another 3 equations. So, this we have written and name them d e f.

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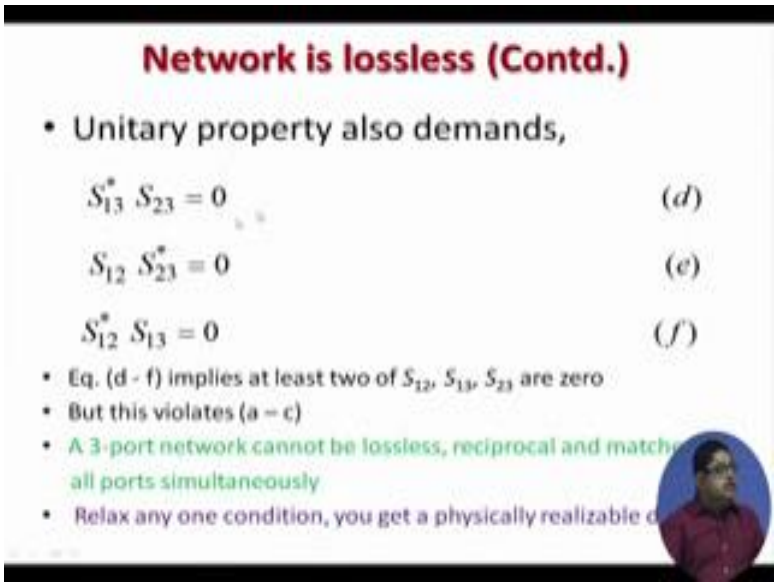

Now,. So, we have 6 equations from that will find the properties or various values for this s parameters. So, let us see how many unknowns we have. We have the s12 is unknown. S13 is an unknown. S23 is an unknown. So, you see that due to the first 2 properties that reciprocal and match. We have got a 9 element is matrix that as reduce to 3 element is matrix, we have 6 equations; defiantly will be able to have some more inside about the network.

So, let us observe these 3 equations, if we need to simultaneously satisfy these 3 equations. It is obvious that out of s12 s13 and s23; that means, 3 of those things which are unknown, 2 of the unknowns should go to 0. Here you see you can take this you do your by pen and paper. That suppose I think that s13 star is equal to zero; that means, s13 0. Now s23 non zero, s13 if it is 0, then here I can say s12 non zero and, but, so, here s12 is if it non-zero s23 is non zero, but these equation demands a. So, it is needed that at least two of them should go to 0.

Now, if that is true that any 2 of them is 0, now that condition we put on the previous one, but here you see that any 2 0, by that you cannot satisfy this equation. Because any 2 here you see any 2 there this square is 1. So, if any 2 are 0. Suppose s12 s13 zero, but this condition, but this condition cannot be satisfied. Or if you say no, no s13 and s23 they are 0. Then also you can not satisfy these. Or you say that s31 and s12 they are 0, then also you can not satisfy that. So, the thing is it is impossible to satisfy this equation. So, whatever assumption that all 3 can be simultaneously put in a 3 port network, that is not true. So, we can say that a 3 port network cannot be loss, less reciprocal, and matched that all ports simultaneously. Please remember which is a fundamental thing that a 3 port network any electronic network cannot be loss less reciprocal and matched that all ports simultaneously.

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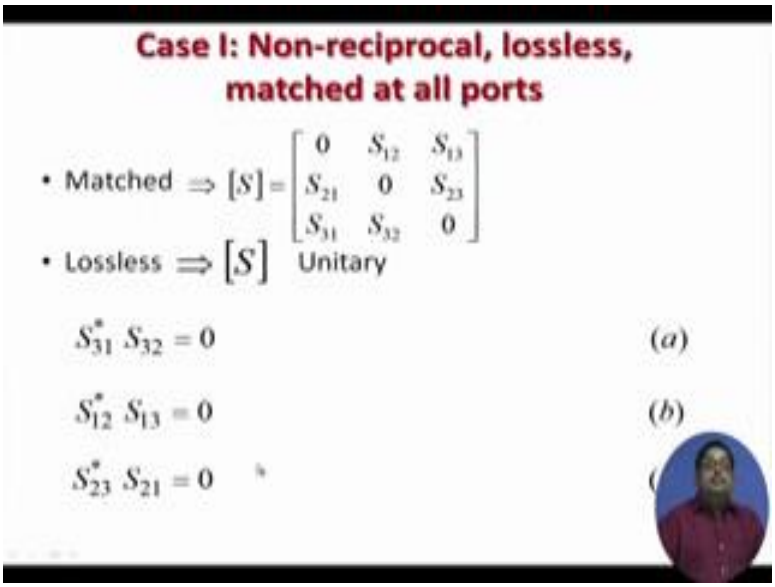

So, now if we want to have a 3 port device one of these criteria will have to relax. So, relax any one condition, and then we get a physically realizable 3 port device. So, let us one by one relax the conditions, any one condition. Keep the other 2 conditions intact. And let us see what happens from the properties of s parameter you see this one we saying that we are keeping that lossless matched at all ports, we are keeping only that reciprocal thing we are not making that; that means, it will be made of a bulky thing that or active devices that, will active material will have to have non reciprocal, material we

are ready to suffer that. Then you see from the again as same thing that matched at all ports means all these zero, but generally equation that s12 s21; obviously, it is not a symmetric circuit. So, s12 s21 and different s13 s31 different s23, s23 are different. So, match means it will put this. Then we are also saying that it is a lossless.

So, again the properties we have written that s31 star s32 is equal to 0. Then, this, this and these 2, if we do that gives as a last equation that s23 star s21 that is 0.

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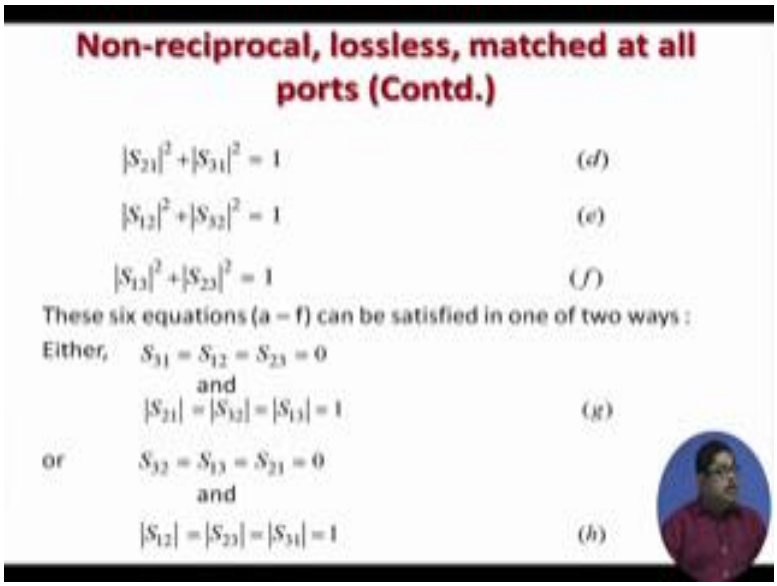

So, this is a b c condition we have boil down to an. For other 3 unitary properties we can write column wise this or d e s.

Now, this 6 equation can be satisfied, in one of 2 ways you see it. Either you can have this or you can have this. So, that we are now simplifying and saying this means this and this. So, g; that means, one solution that, that, is that we are taking if s 1 s12 s23 all are 0 and the s21 s32 s13 is 1 then. So, these 2 solutions we are calling 2 different equations g is the solution, 1 solution h is 1 solution. So, these 6 equations we can have 2 such different solutions.

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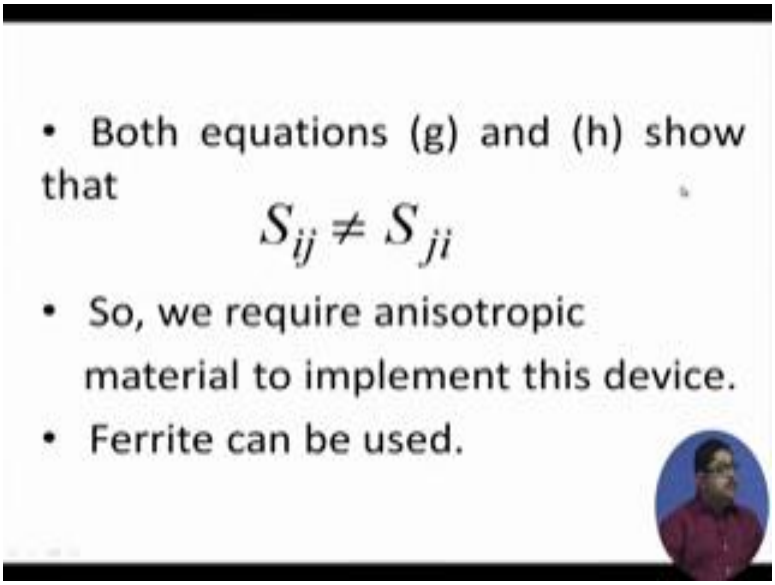

Both equation g and h, show that it is not a reciprocal device. You see that s31, the solution says s31 zero, but s13 is 1; that means, defiantly they are not equal.

Similarly, s12 is 0, s1 magnitude is 1. So, they are not equal and s23 is 0. S32 magnitude that is 1, definitely this is not a reciprocal device. Similarly also if you do see this solution h, it is not a reciprocal device by definition we started with that that it is a not reciprocal device. So, to implement these we require, non isotropic that is called anisotropic, material to implement this device. The very popular anisotropic device is ferrite, but this will be bulky. So, this is one thing.

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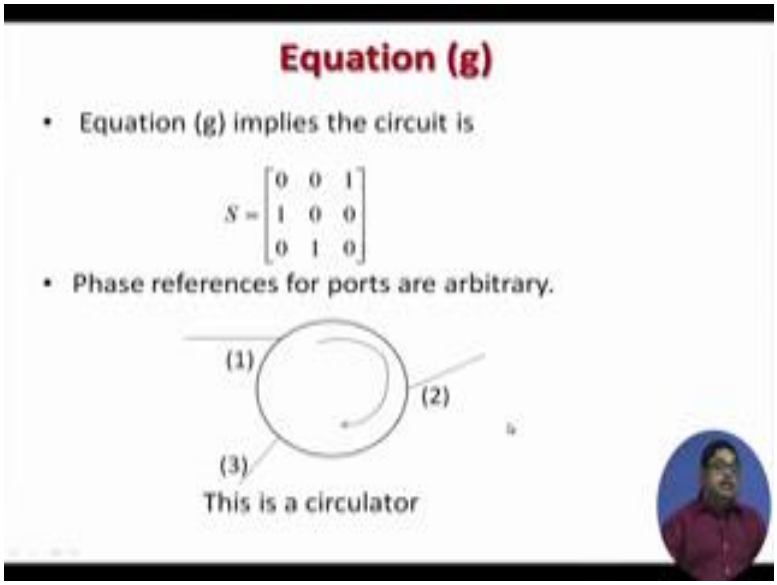

So, this a 3 port device made of a anisotropic material. So, equation g, let us if we take the solution of equation g that is s21. So, we put those values 0 and these magnitudes 1. So, that s matrix become like this. Where taken a particular face thing reference and equation g implies that, that is s matrix can be written something like this.

Now, what does this say by just looking at this s matrix, we say we have 3 ports12 3. Now we are giving power to one the first column in an s matrix says that if we give power to port 1, what happens. So, you see that if we give power to port 1; obviously, port 1 match. So, there is no reflection no power comes out of port 1, the whole power goes to 1. Remember s matrix is a, it is a ratio of the voltage webs. So, power means will have to square to get the power, but 1 square is 1, basically the, if you power to port 1. The whole power is going to port 2 and nothing is going to port 3. So; that means, we can say that it is as if, we are giving the power to port 1 whole power will be going to port 2. And no power is coming in this sight that is way this arrow shows that from here whole power is coming to 2 and so, then let us take the second port if I give power to port 2 you see the whole power is going to port 3 to no aerials; that means, if I now give power here, the whole power will come to port 3 that is why this arrow is correct, and then if we give power to port 3, from outside. Then you see the whole power is going to port 1.

So, all these things we can write in this diagram, physical diagram. That, there is a clock wise power; if you give here it will come here. It if you give here it will come here and if you give here it will go here. So, this is called a this type of device were your giving power, the whole power is going to other; obviously, this is also a lossless device, because inside there is no loss ideally.

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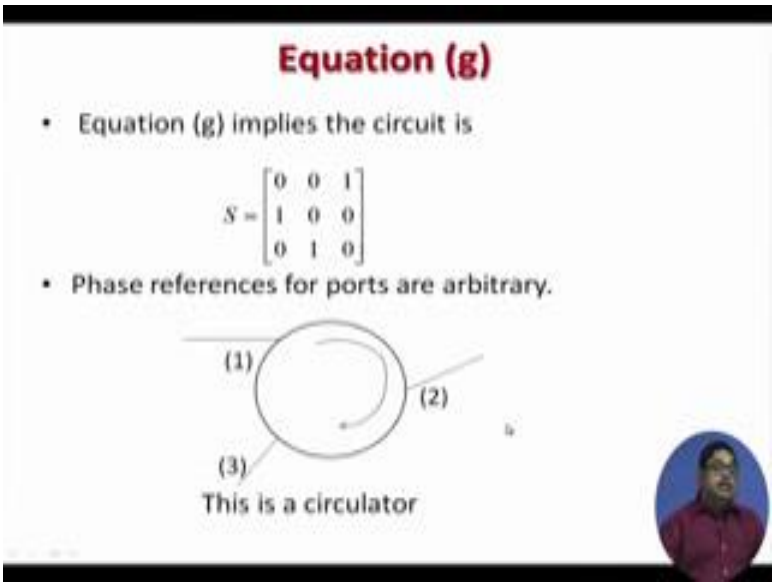

Now, this is example of a circulator. Similarly you do on your own I am just giving the concept that we can have a solution of equation h also that will implies this. Here also you see your giving power to port 1. It will directly go to port 3. So, 1, 2, 3, it will go like this 1, 2, 3; if I gave power to port 2. It is going to port 1. So, 2 I am giving it is going to port 1; that means, this is arrow and 3 I am giving it is going to port two. So, 3 I am giving it is port two. So, anti clock wise is the direction, but this is also a circulator.

So, both of the solution; that means, when we say that no we will not have a reciprocal device when wee relax that condition; that means, it will be a multi device circulator are all bulky. All of you know that is why generally it is a very heavy thing. In application were people use is, were you cannot avoid having this type of thing, but; that means, a 3 port non bulky isocirculator, and is not possible. Circulator means you will have to have an isotropic material inside that.

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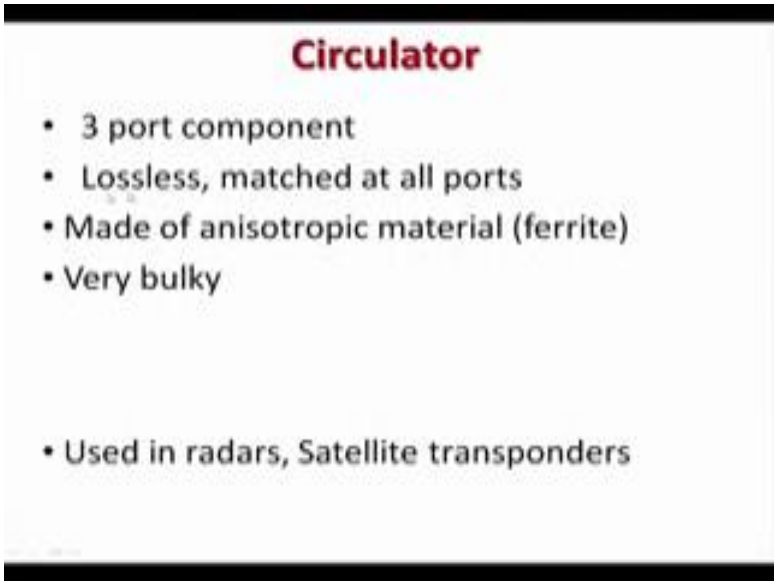

So, circulator is a 3 port component loss less matched at all ports you have seen. Made of anisotropic material most of the time it is made of ferrite, very bulky. Now where it is used in that.

Radars why because radars etcetera. You know that generally most of the radars they have use the same antenna, for both transmitting purpose and receiving purpose.

Now, transmitting time it is sending a huge signal, but receiving side from the radar from a long distance because aircraft etcetera is in a long distance. So, when that signal comes back it is a very weak signal. Same is true about satellite transmission and things that they are very high signal. In megawatt Giga watt of power the same because satellite is far away 20 thousand kilometers away. So, you will reach that. So, very high signal you send transmission sends huge power, whereas from that huge distance up the sky the signal will go then heat that objects and from there it will come back. So, it will come back very small. Signal your receiver will have to listen to that.

Now, the problem is if well you are transmitting, the receiver also listens that time. Then receiver will, because if suppose I am talking something, and I am to someone is talking very hugely and if it comes to my ear, then I will be dump. So, the satellite if on the

transmission time if the receiver also listens, it will be gone out. So, that is why you need to block. So, circulator does that. Circulator says connect suppose any of this you see any of this suppose the antenna is that port 1, the transmitter has port 2 and in is port 3 the receiver is port three.

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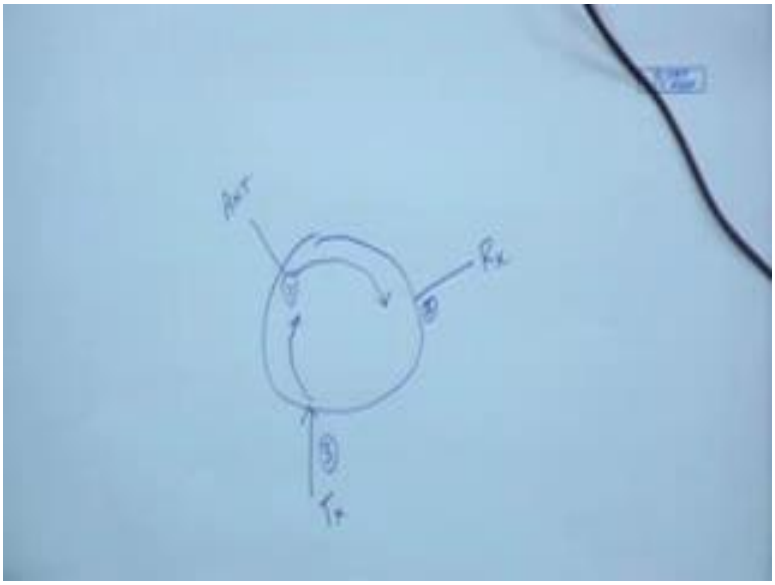

So, let us write this, that suppose antenna here and transmitter is that 3. This 1 and 2, let us say this is transmitter this is receiver. Now I want that when I am going giving to 3, it should go to 1. So, what I will do. I will have a power like this. So, not this one I will use this one. So, you see 3 it goes to 1 then receives reception signal Comes from antenna and; that means, when I give to 1, I need to go to 2, and it should not go to that transmitter it cannot go. So, this is circulatory if I have this thing that with port 3 terms transmitted receiver antenna, I can have that when transmitted is on receiver is out from the circuit, no power is going there whole power is going to the antenna, it is radiating.

Similarly, when that receiving signal is coming, that time it is not going to the transmitter because if it is goes to the transmitter as such transmitter will not be disturbed, but the problem is that, I am a very weak signal is coming out of that, it is some portion goes there then I get less share. So, receiver cannot afford that. So, whole power should come

to receiver. So, this is an application of circulator used in radars satellite transponders etcetera.

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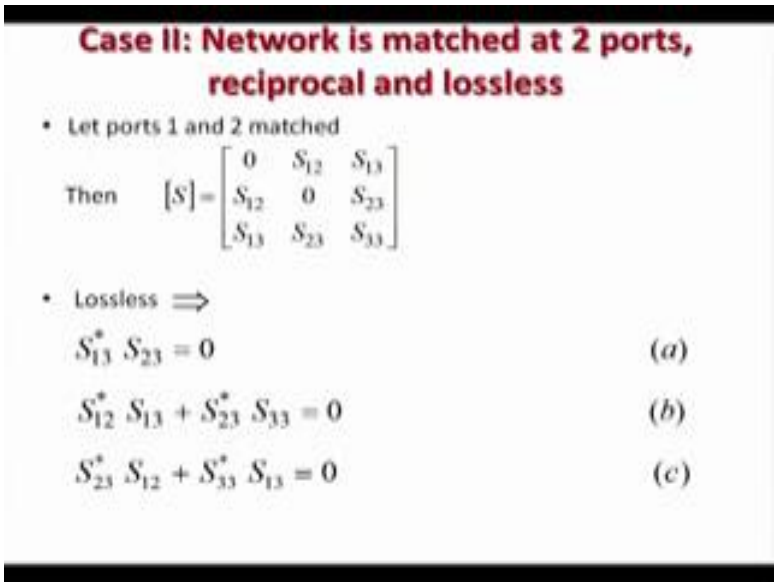

Now, let us come to case 2. That network is we are saying no, no we will use this reciprocal; that means, the isotropic material. So, we will have reciprocal will have lossless, only the ports instead of 3 all the ports, we say 2 ports match 1 ports unmatched. So, let ports 1 and 2 matched and 3 port unmatched. So, there will be some s t p, so s matrix since reciprocal s12, s12, s13, s13, s23, s23. So, this you put the unitary condition because you have lossless. So, this is unitary condition a b c.

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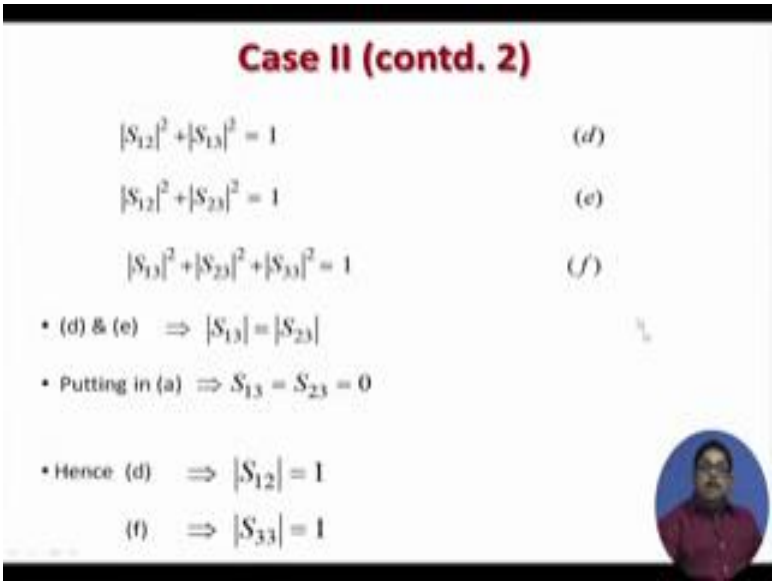

This is unitary condition d e f. Now d and e I am now. Hurriedly, going d and e if you to combine that is say these, then that you putting in etcetera, d e f; this becomes the solution that you put it here.

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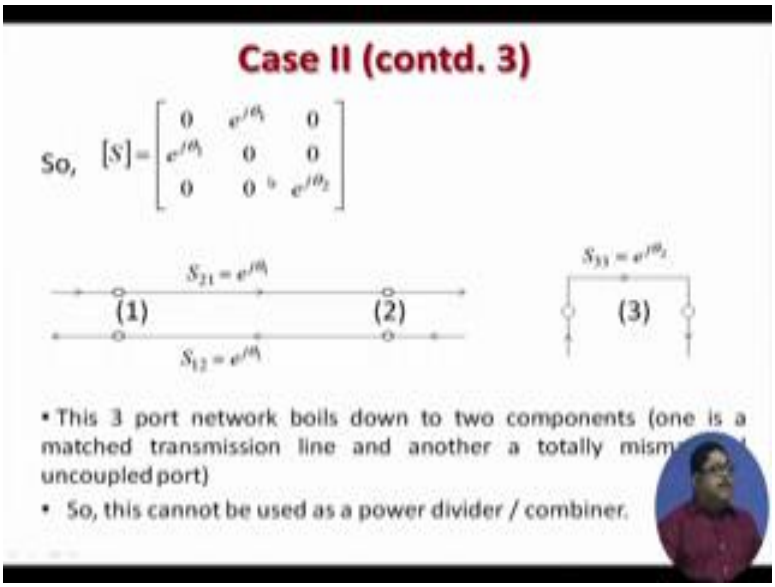

Now, what is this you see I am giving power to port 1; it is going to port 2, with a e to the power j theta 1; that means, way type of thing. So, this is a transmission line port 1 if it is here port 2 is here, you see, it is saying that s21 is it is going like this. Similarly power is given to port 2. It is coming to port 1 it a wave like thing; that means, when I am giving power 2 here it is coming here, but to this business you see port 3 is not connected.

So, there is no connection between 1 2 and 3. 1 2 are connected among themselves and what happens to 3. If I give power their whole power with some phase change it is coming to here. So, you see the 3 port devices generated to 2 separate things. 3 port network bolls down to 2 components. 1 is a matched transmission line it is a matched line you see no reflection of power when the power is coming here or here. So, these 2 ports are matched and another totally mismatched, uncoupled port here. You see totally mismatch, because what you a giving to the port 3. The whole power is coming; that means there is complete mismatch. Nothing is going to inside from port 3 it is coming. So, this cannot be used as our basic that 3 port device. It is not a not 3 port device it bolls down to 1. 1 port and no 2 port device, you cannot make anything. So, that condition is useless case two.

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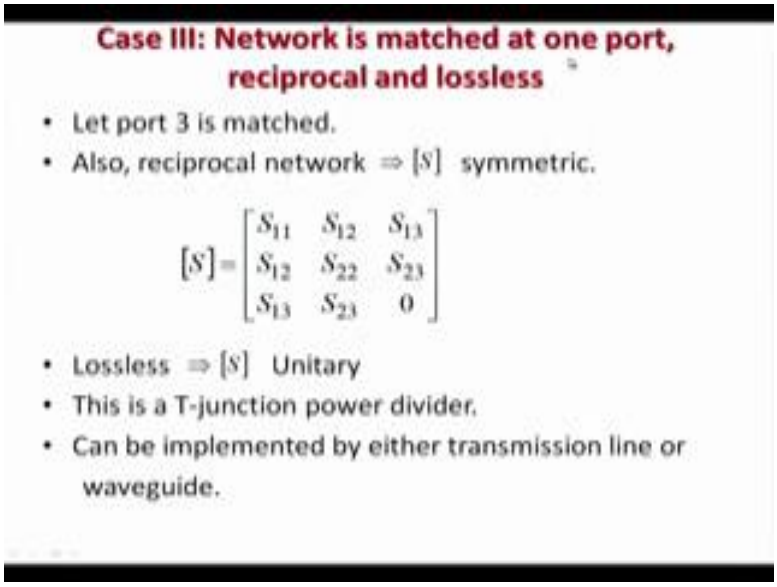

Now, let us go to case 3 networks is matched at 1, port reciprocal and lossless network is matched at 1 port reciprocal and lossless. So, we are saying that instead of 2 port matching, we are still reducing matched at 1 port, let port 3 is matched let us say that arbitrarily we are taking this that port 3 is matched.

So, also reciprocal network, s symmetric, this becomes the structure now lossless. So, s will be unitary over this will put the unitary condition now this is a realizable thing that will see will discuss now this is a power divider this is called a this type of thing were port 3 is only matched 1 and 2 ports are unmatched and a reciprocal; that means, it may obvious passive thing and lossless. So, no loss inside the thing, this can be implemented by either transmission line, or wave guide and name of this device is t junction power divider.

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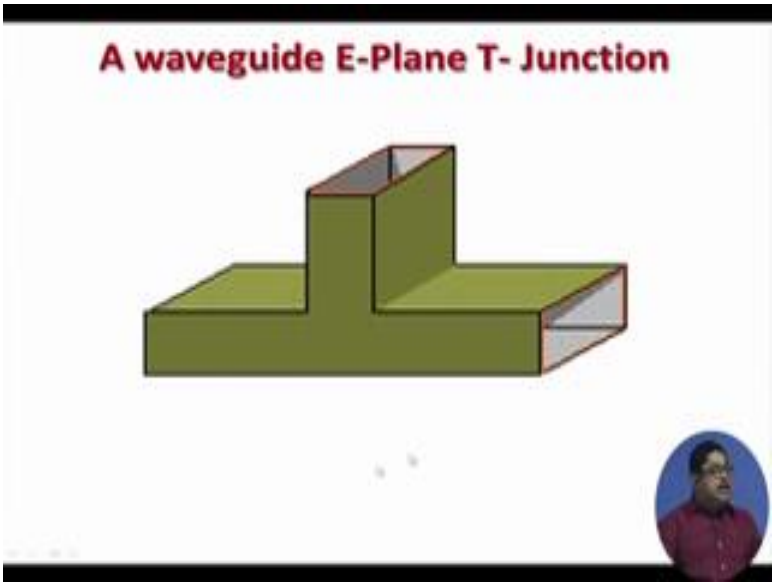

This is an example of a wave guide implementation. You see it is a show like a t. Generally this t is this part; that means, the vertical part that this port generally we called port 3, port 1, and there is a port 2. So, this 2 arms we say collinear arms. So, collinear arms they are unmatched port and this matched port that is generally we call it also auxiliary arm.

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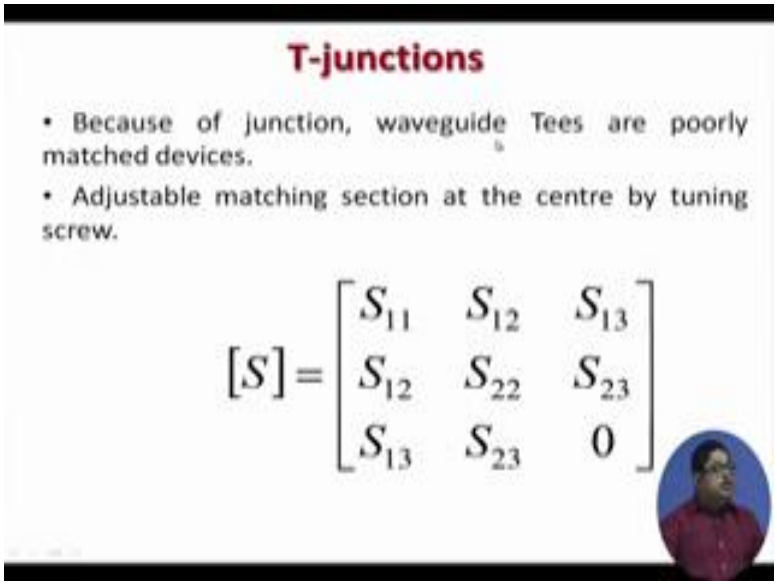

So, because of junction wave guide tees are poorly matched devices; obviously, you know you have junction here. That this 1 is there is a junction. You know the meaning of junction same as railway junctions. That line was going them suddenly another line was taken here. So, here is a junction any junction means a geometric discontinuity. So, they are we have seen that there will be if the wave guide is propagating. So, due to the junction there will be some in modes that will come up and any modes we have seen that it is impedance is react, if it is does not have any real component, the impedance of this junction that will be purely imaginary.

So, and that there will be some reactive powers put there. That is why we say that because of junction wave guide tees are poorly matched that there will be some problem there matching. So, adjustable matching section at the center by tuning screw is needed.

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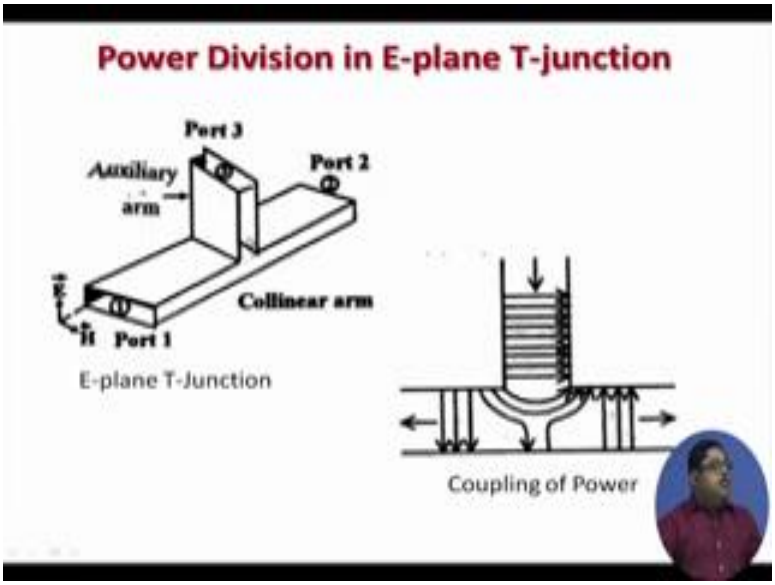

Now, this is the s matrix of the any t junction. Now 1 t junction this is called there 2 varieties of t junction. Because these junctions we can make in a wave guide as I saying you see here wave guide this plane is e plane. Because if e field lies here in the x y plane. Yesterday we have seen in the dominate mode. The rectangular wave guide dominate mode the e plane is the x y plane. So, in the x y plane you see; that means, in that transfers plane what in earlier lecture, we have colline there, we having the junction the junction is there. So, that is that is why it is called a e plane junction e plane t junction. So, this is as I said port 1 this port 2 this is 3. This is auxiliary arm this is collinear arm. So, if the power is generally in this mode if I want to do power division. Then power is given to the port 3. This is a matched port. So, no reflected power outside will come whatever power we are giving will see that this will be divided into 2.

So, this is the field structure. You see the electric field is going like this. Yesterday seen that all electric fields from the top plate to the bottom plate it comes. And in the junction what will happen they will still grow, but due to the junction they will curve this curvature will yet some re activeness here, but ultimately here, but you see that while doing that since from this plate to this plate this was going. So, if I do this ultimately in the field lines in the 2 ports they will be anti symmetric; that means, this 1 is like this, this 1 is like this. So, power will be going like this.

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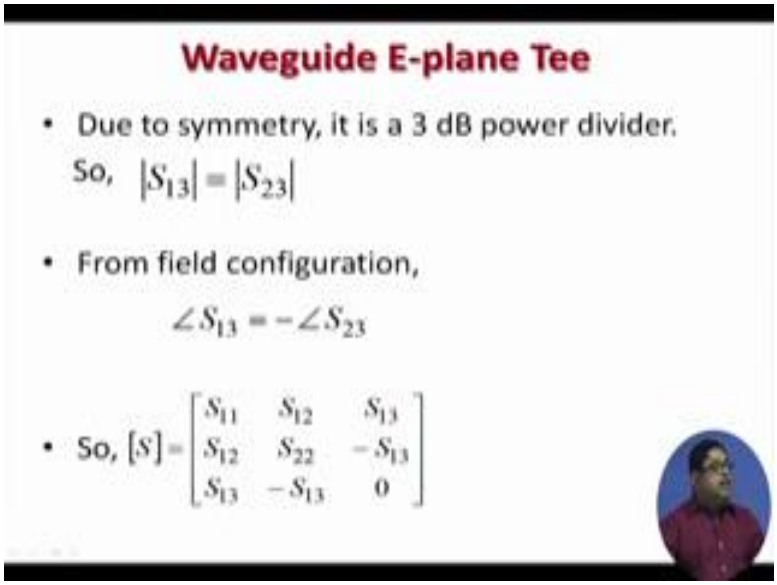

Now, wave guide e plane tee, the whole structure you see is geometrically symmetric. So, due to that symmetric if we say that there are no reasons to believe that the power level here and power here their different. So, it is a equal power; that means, if since it is a lossless device whatever power we are giving, half power will go here half power will go here.

Actually called 3 d b power divider; 3 d b means half, s13 magnitude and s23 magnitude. 3 means we are giving power 2 3. S13 means the voltage that is coming here fraction of that voltage, if I give 1 here s12 amount of voltage which will come here. S23 amount of voltage will come here. That is why we saying that these 2 magnitudes are same, but we from field configuration we can say, the phase of s13 is 180 degree out of phase with s23 phase. That is why minus s23. So, s matrix becomes like this you see matched port here reciprocal, but only this information we have put if this is a s13. This will be minus s13. Because s13 and minus s13 they are magnitudes are same, but the phase are different.

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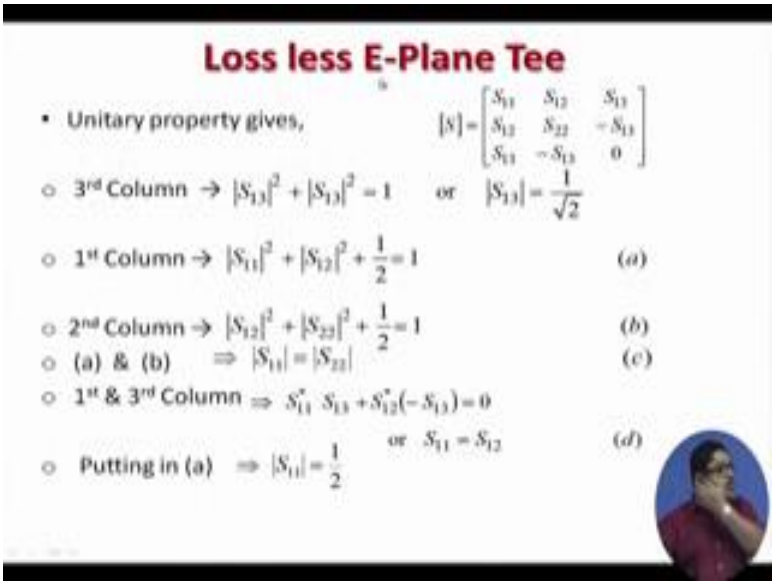

Now, we put the loss less condition unitary property. So, from this is mathematics, but what we are getting third column we are proving whatever we have said physically that the half of the voltage, that to we will get there, that will be 1 by root 2 magnitudes. So, it will 1 by root 2. That is a power will be half. Now this proves this 2. Then s11 is equal to s22; that means, we know that power of that 2, this, this port and this mode are not matched. Collinear arms their ports are not matched. So, some reflection will take place s I am replacing take place, s what is saying that reflected voltage levels in these 2 ports will be same. S11 magnitude is equal to s22 then we are proving that there phase also will be same, and reflected ports and then this value is half. So, this is the s matrix of the e plain power divider.

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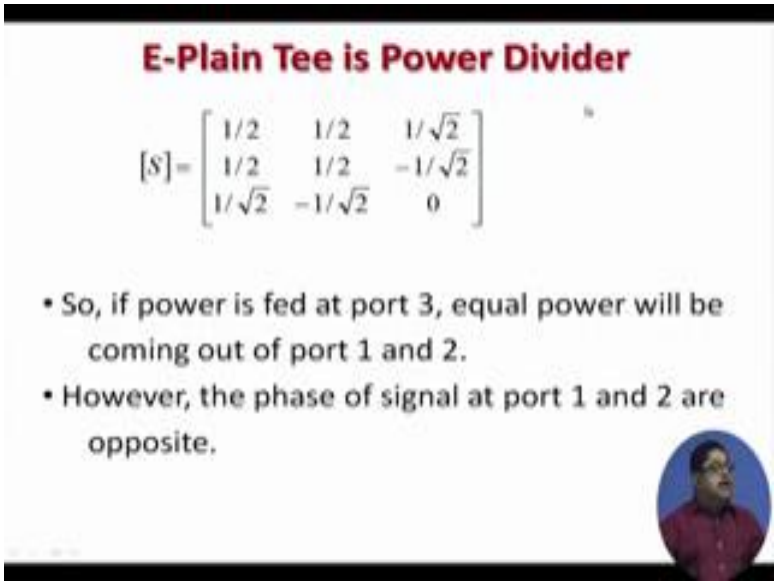

Now, you see that e power is fed at port 3. So, power is put a port remains will have to see this column. What is happening? Half of the voltage is going there. So, half power half power is going to this port. This is voltage. So, half power is going to port 2. So, port 1 getting 1 by 2. Port 2 is getting 1 by 2. That means half of the power is going that is a proof that is why we have said that time it will be 3 d b. From symmetrical we said now from mathematics we are proving, that equal power will be coming out of port 1 and port two.

However, in terms of signal phase, you see power does not have any power is a scalar quantity. But signal phase if you see that signal at port 1 and port 2 are opposite phase or they are anti symmetric.

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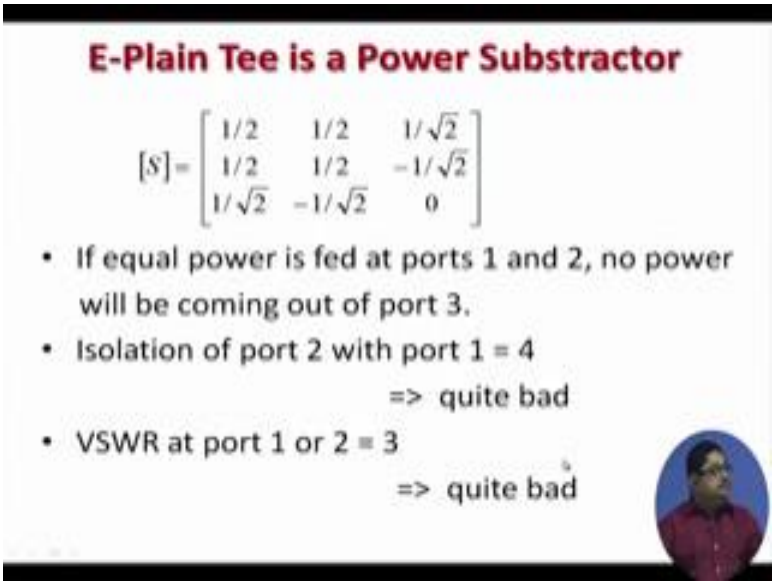

So, also you see from the thing we can say that we can by that is a power divider thing, but as a power combiner also we can use this tee, but time it will be used as a substractor instead of power combining or adding it will power substractor.

Suppose instead of giving the power at port 3 as you doing power divider. In the same device if equal power is fed at ports 1 and two; that means, you see I am putting power at 1. So, how much is going to port 3- 1 by root 2. So, power is half similarly when I am giving power to port 2. The signal voltage is minus 1 by root. So, power is 1 by r, but remember 1 thing that. So, if I give simultaneously power to port 1 and port 2 then how much power is coming to port 3 these, but remember power does not have super position. Super position is only for voltage. So, if I give power here port 1 and power here same power suppose equal power is a fed a port 1 and 2. So, port 3 voltage will be 1 by root 2. Due to the power at port 2 port 3 voltages will be minus 1 by root 2 totals voltage will be 0. So, power will be 0. No power will be coming out of port 3. Super position principle please remember this a basic thing in electronic. Super position applies only for voltage or currents not for power do not have super position. Because if power has super position we cannot say this is a power substractor.

Because then will say 1 by root 2 going here. So, half minus 1 by root 2 that is square is half. So, half plus half 1, but physically that is not true. The reason is super position is applies for on the signals amplitudes, or sorry signals voltage current etcetera not for power.

So, now what is isolation of port 2 from these? We can see what is isolation of port 2 with port 1; that means when I am giving power at port 1 how much I am getting here, you see when I am giving the signal to port 2 port 1 is getting how much port 1 is getting half. So, power is 1 by 4. So, isolation is defined as input power, but powers to the port were you are trying to find isolation; that means, p in by p in by 4 that is four. So, isolation value will be four.

Now, generally we want that when we give power to 1 device the other device other port to when I give power to 1. Port other port should not get any power. So, isolation ideal value is infinity. 4 is quite a bad value because half of the power 1 fourth of the power 20 5 percent of the power is going to another port which it is a bad isolation.

Similarly, what is since port 1 and 2 were mismatched. What is the v s w r. You see there - s11 is half. S22 is also half. So, half what is the v s w r. 1 plus 1 plus reflection coefficients magnitude by 1 minus reflection coefficient magnitude. So, this is 1 plus half by 1 minus half. So, v s w r is 3 - 3 is quite bad; that means, you say that quite a good amount of power is going into the mismatched. At is obvious from here also see that when I give something one-fourth of the power is coming out. So, similarly if I give power here also 1 fourth of the power is coming out, but you see if give power port 3 it is matched. So, is v s w r is perfectly matched that is why 1. You see reflection coefficient 0. So, 1 plus 0 by 1 minus 0 that is 1 v s w r is 1. So, e plain tee this is the.

So, this we conclude here will continue discussion because there is one more case left in the next lecture also.