Microwave Theory and Techniques

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Module - 06
Lecture – 29
Series and Shunt SPDT Switches and Introduction to Phase Shifters

Hello everyone; in the last lecture we had talked about RS switches. And in the RS switches our main discussion was on the single pole single throw switches and these switches had been realized using pin diodes.

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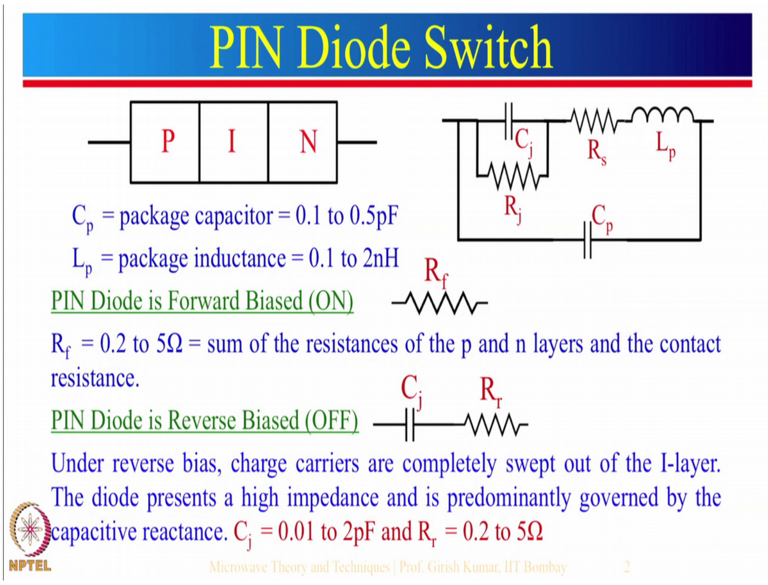

So, we had looked into the circuit configuration of pin diode and we had also seen when the pin diode is forward bias it can be represented by a series resistance and a series inductance. When pin diode is reversed bias it was modeled as C j in series with R r resistance.

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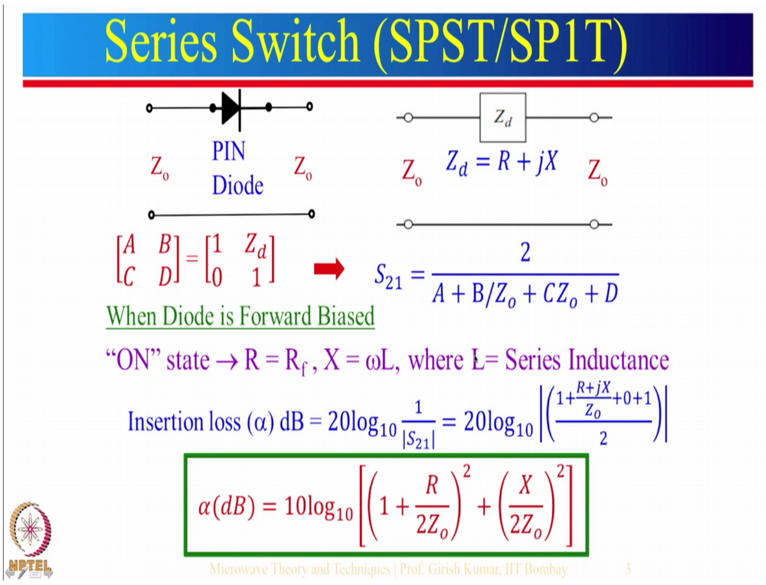

Then we had discussed about several configurations of SPST. So, we had started the discussion with the series SPST switch, and for that we had actually derived the A B C D parameters. From A B C D parameters we found out S parameters and then we had derived the expression for insertion loss and isolation.

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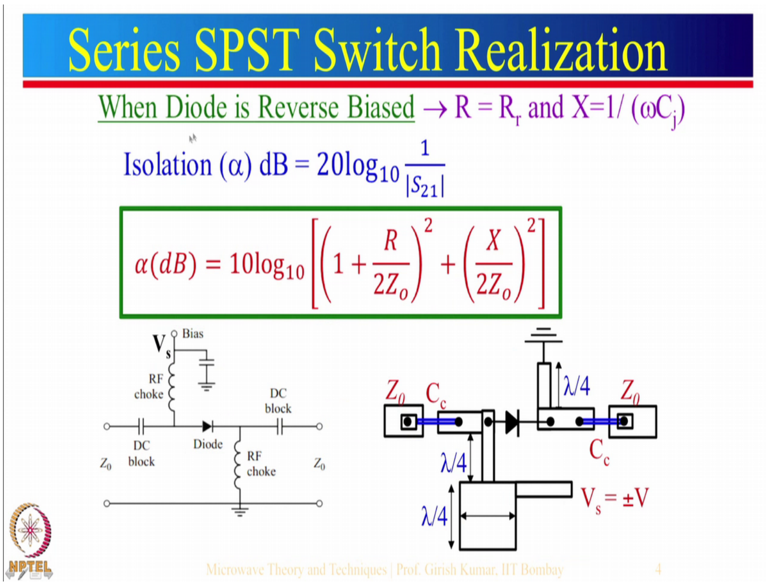

So, insertion loss is defined when switch is in the on position. Isolation is defined for switch in the off position. Then we had looked at the biasing circuit for this particular configuration and then micro strip realization of series SPST. We had also shown you the circuit simulation using ADS software.

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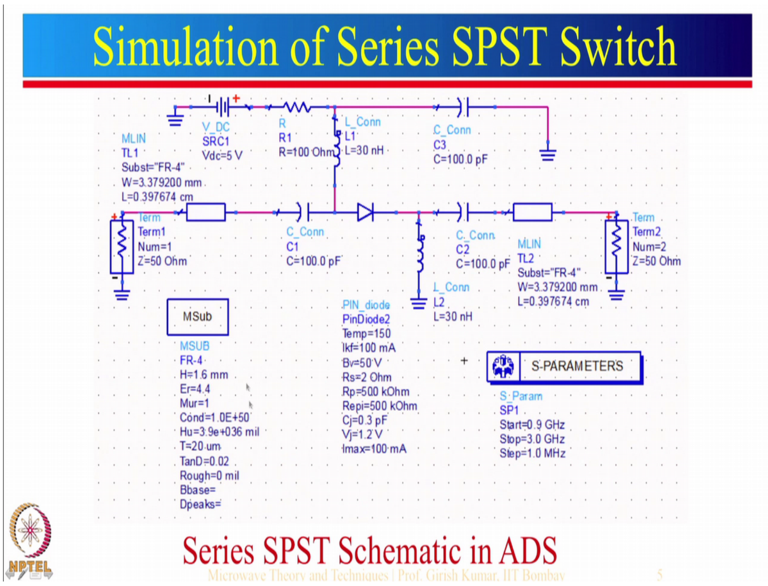

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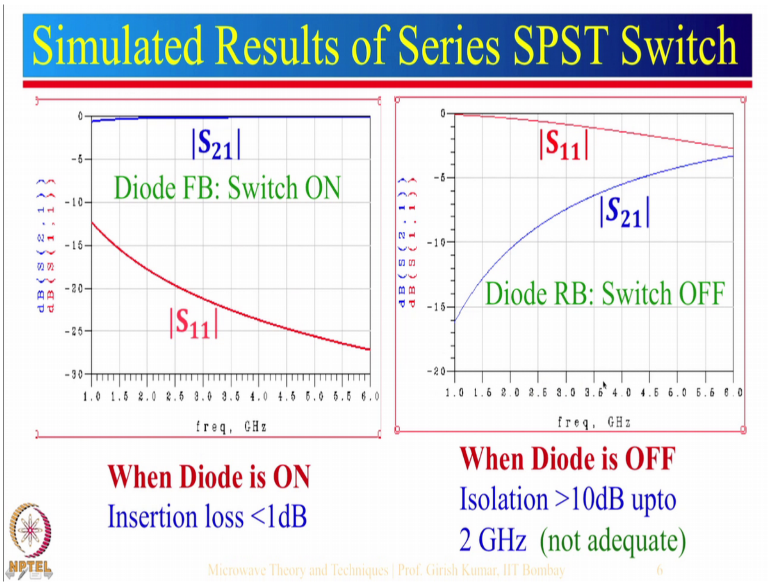

And then we discussed about the results and I had shown you that insertion loss is less than 1 dB when diode is on. But isolation is only about 10 dB or so up to about 2 gigahertz; beyond 2 gigahertz isolation was very poor. So, it is not a very good configuration to be used beyond 2 gigahertz.

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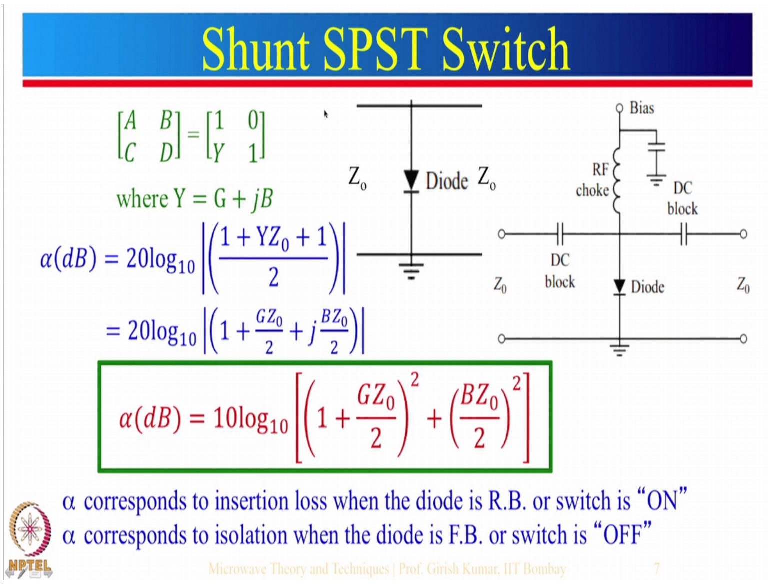

After that we discussed about shunt SPST switch where diode was mounted in shunt configuration. Again we found A B C D parameters and then insertion loss as well as isolation. We had also seen the biasing circuit.

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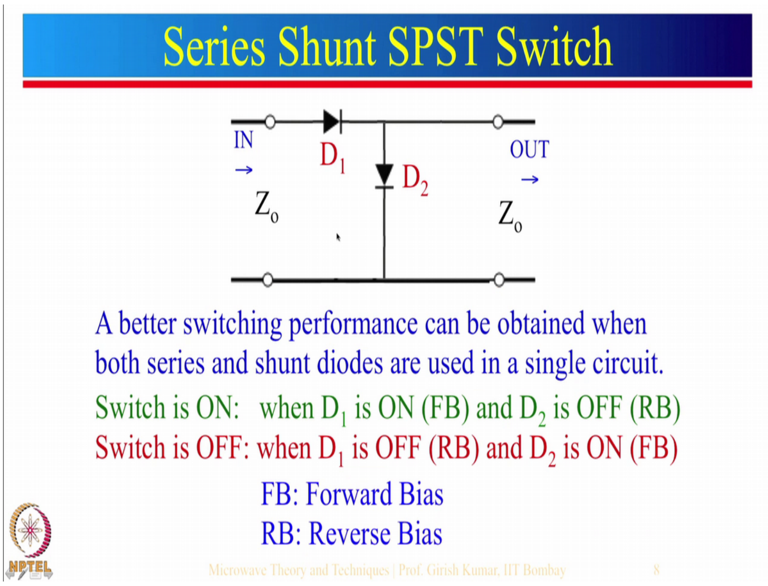

Then we had talked about series shunt switch and this circuit can be analyzed using cascaded A B C D parameter. So, we know that A B C D parameters of series element and we also know A B C D parameters of shunt element multiplying these two and simplifying we get the expression for insertion loss and isolation.

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Series Shunt SPST Switch (contd.)

$$\text{Insertion Loss} = \left|\frac{1}{2} + \frac{(Z_0+Z_h)(Z_0+Z_l)}{2Z_0Z_h}\right|^2 \rightarrow \text{Switch is ON}$$

$$\text{Isolation} = \left|\frac{1}{2} + \frac{(Z_0+Z_h)(Z_0+Z_l)}{2Z_0Z_l}\right|^2 \rightarrow \text{Switch is OFF}$$

Configuration	Insertion Loss (dB)	Isolation (dB)
Series	0.147	8.3
Shunt	0.063	7.5
Series-Shunt	0.108	20.2

And then we had seen that for series shunt and series shunt switch what are the performances? So, we had seen that for the combination series shunt insertion loss is of the order of 0.1 dB, whereas, isolation is of the order of 20 dB.

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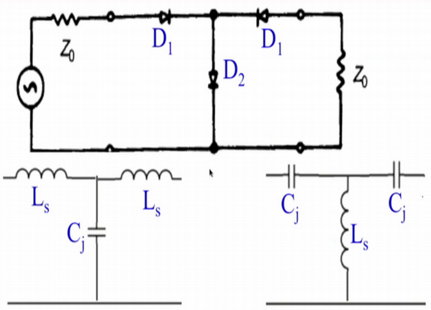
Wide Band Series-Shunt-Series Switch



Switch is ON: LPF Switch is OFF: HPF

(Forward and Reverse Bias Resistances are not shown)

Switch is ON: When D_1 is ON (FB) and D_2 is OFF (RB)

Switch is OFF: When D_1 is OFF (RB) and D_2 is ON (FB)

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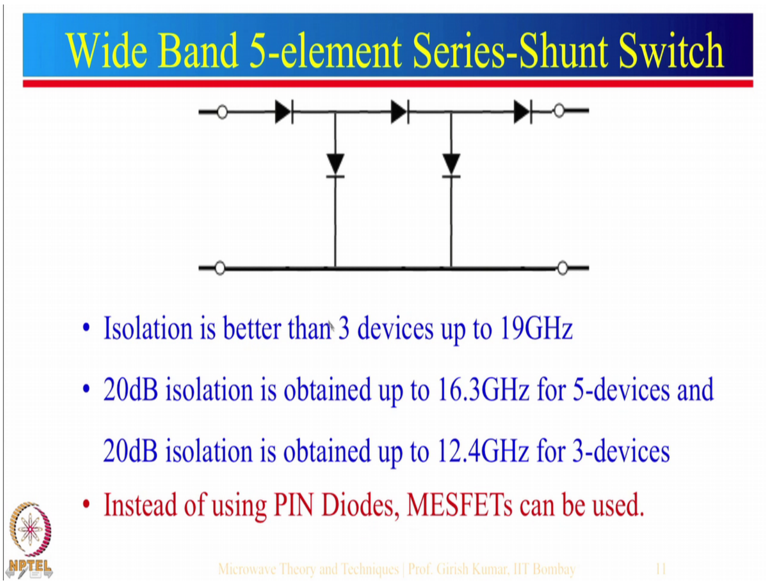

After that we had looked at 3 elements pin diode switch. And 5 elements pin diode switches. So, today we are going to discuss about next configuration which is series single pole double throw.

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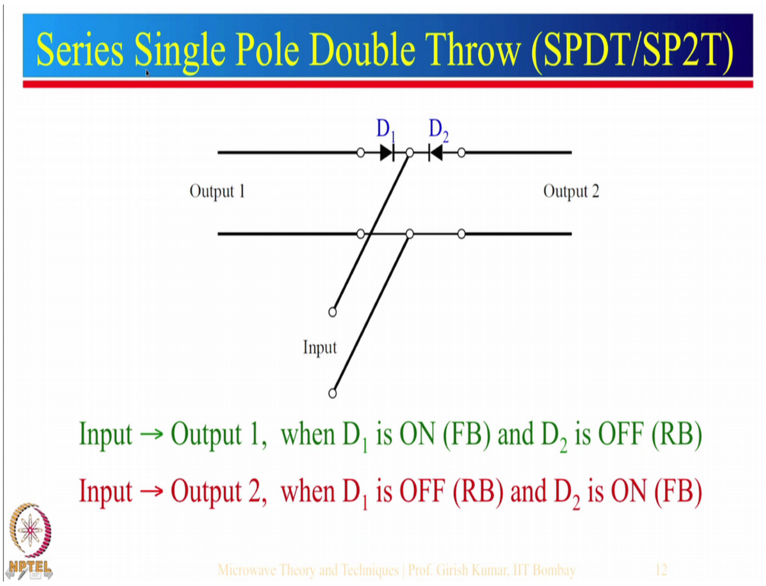

So, Single Pole Double Throw is abbreviated as SPDT and also commonly known as SP2T. So, here let us see what is the concept? So, input is given at this particular port and it may go to output 1 or it may go to output 2 depending upon how diodes D 1 and D 2 are biased. So, if D 1 is forward bias and D 2 is reversed bias it is important.

So, when D 1 is forward bias input will go to output 1. So, input will go to output 1 when D 1 is on and D 2 is off. See please ensure that both of these should not be on if both of these two are on then this will be more like a power divider network and both of these diodes are off then everything will reflect back to the input side. So, when we want to send the input to the output 2 in that particular situation D 2 should be forward bias, and D 1 should be reverse bias.

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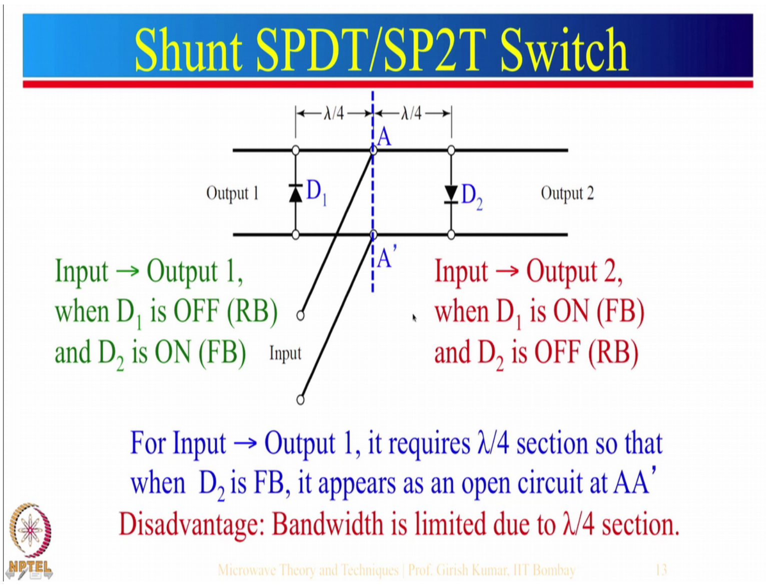

Now let us just look an alternate way of realizing the same SPDT, but by using shunt configuration. So, you can see that here we have a diode D 1 and diode D 2 and they are connected in shunt configuration. However, there is an additional thing here which you can see there is a line length lambda by 4 here, line length lambda by 4 over here.

So, I will explain you what is the purpose of these line lengths over here. So, let us say now when input is coming from this port here, and assuming that D 1 is on and when D 1 is on this should be off ok. So, when this is off so what will happen?

This is off so input will go from here to this side and when this is short circuited nothing will go to output 1. But if we did not have this lambda by 4 what will happen in that particular case? If D 1 was connected right here and if it is forward bias which means it is short circuited then nothing will go over here in fact, everything will reflect back.

But by putting this lambda by 4 length what happens now? When D 1 is forward bias; that means, it is short circuited then impedance looking along A A dash will be open circuit corresponding to D 1. So, D 1 is shorted this will act as an open circuit. So, there will be no loading on this side and D 2 is off so; that means, input from here will go to output 2. And the reverse will happen when D 2 is on and D 1 is off.

So, when D 1 is off all these things will go from here to output 1 and D 2 is short circuited that time or forward bias. So, this short circuit will act as an open circuit. So, it will not do the loading for this particular input it will go to the output 1 only. So, the disadvantage of this particular configuration is that due to lambda by 4 section bandwidth is limited; however, for narrow band application it is a fairly good circuit.

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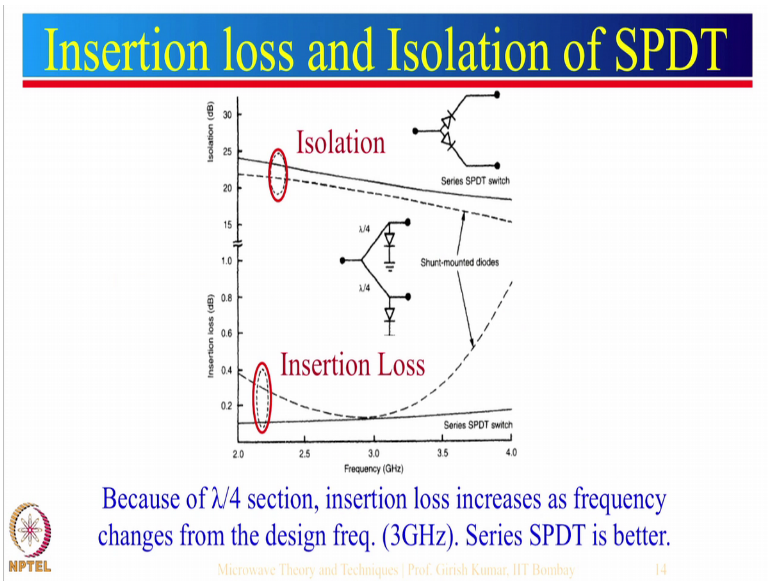

Now, let just look at the responses of these 2 particular configurations. So, here you can see these 2 pin diodes are connected in the series fashion and here 2 diodes are connected in parallel fashion. And these are the typical insertion loss for series and shunt and these are the results when switch is off; that means isolation.

So, let us see what we have over here. So, this is first series SPDT configuration you can see that insertion loss is relatively flat it is of the order of 0.1 dB which is pretty good. But; however, due to this lambda by 4 section insertion loss is lowest at the center frequency of around 3 gigahertz and as we deviate insertion loss increases.

But you can see that even from 2.5 to up to about 3.5 gigahertz insertion loss is still of the order of around 0.2 dB which is acceptable for most of the application let us look at the isolation. So, one can see that isolation is fairly good it is more than 20 dB in the lower frequency region, but; however, it decreases at the higher frequency points. So, again this is useful for the lower frequency region and isolation becomes poorer in the higher frequency region.

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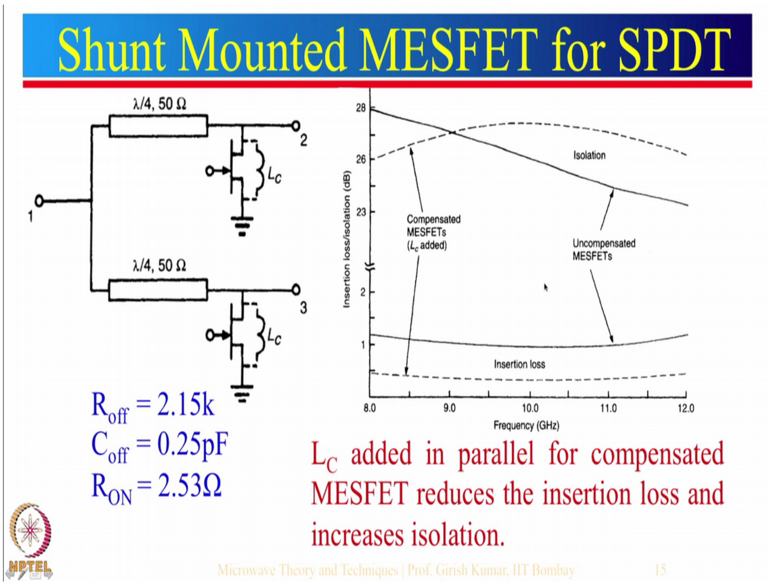

Now, instead of using pin diode one can use MESFET as I had mentioned earlier you are familiar with MOSFET. MOSFET is Metal Oxide Semiconductor Field Effect Transistor. Whereas, MESFET is Metal Semiconductor Field Effect Transistor So, instead of using pin diode you can use MESFET.

So, here is the configuration for shunt configuration. So, you can see that MESFET is connected in the shunt configuration and we have a lambda by 4 section here lambda by 4 section over here input is given over here. So, if this is off then input will go over here at that particular point this should be on, so that nothing goes to port 3. And when the input has to go from port 1 to port 3 then this should be off and this should be on.

Now for MESFET there is a large capacitance associated at the output terminal. So, to compensate the large capacitance and inductor can be placed and by placing the inductor performance can be improved. So, let us see the results here so, here is the insertion loss without compensation and you can see that the insertion loss as reduced because of the compensated L C.

Now, let us see the results for isolation. So, this is the result for uncompensated MESFET and these are the results for compensated MESFET. So, you can see that for compensated MESFET isolation is better than 25 dB over this entire frequency range of 8 to 12 gigahertz.

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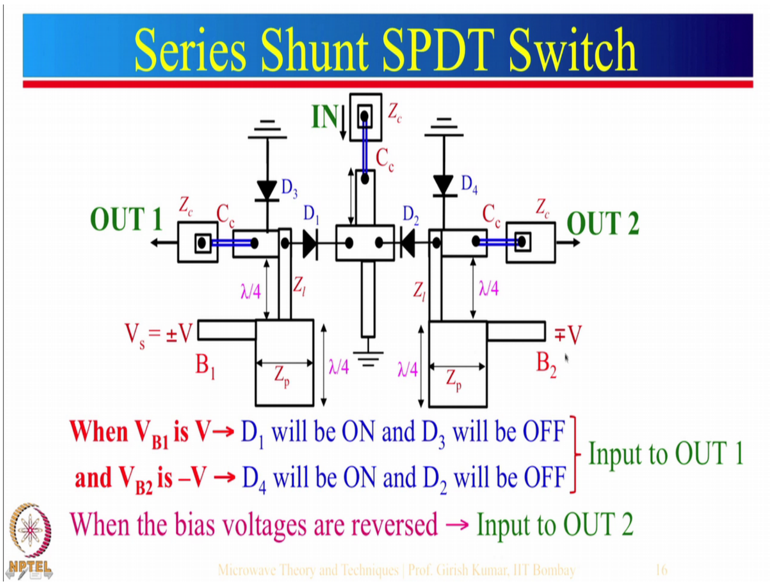

So, now instead of using series only or shunt only one can use the combination of series shunt SPDT switch so, let us see how this has been realized. So, here is a microstrip version of series shunt SPDT switch. So, let us just look at this carefully so, input is coming from here you can see that when input is coming over here there is a coupling capacitor. This coupling capacitor is provided to block the DC voltage and then from here input comes over here. Now this input can go to output 1 or it can go to output 2 depending upon what are the conditions for the diodes.

So, let us say we want to send the input to output 1. So, in that particular case we have to give a voltage here which is plus volt here and at that time this should be minus volt. So, let us see what happens? So, when we give plus volt here. So, this plus voltage goes through here so this diode would conduct through this particular path over here and when this is plus here. So, this diode will be in the off situation. So, this is off, this is on so, input will go through this particular path to output 1.

However, at that particular point this should be reversed bias and this should be forward bias. So, how that is achieved? So, let us see when this voltage is negative. So, this negative voltage ensures that this diode will conduct. So, this will be forward bias means shorted and this negative voltage would mean that this is reversed bias that would mean diode is off. So, nothing goes from here to here and if we do reverse of that; that means, now this voltage is plus V and this is minus V.

So, when this is plus V this diode will conduct through this particular path and when this conducts this will be reversed bias ok. So that means, this path is now clear for output 2, at that particular time this is now minus. So, when this is minus this diode will conduct so; that means, this will provide short circuit path and this diode will be open circuit. So, input cannot go to output 1.

Now, there are few additional things I want to mention and these are the things for biasing; how biasing has been done and what are the roles of these lambda by 4 section? So, let us say here the voltage is applied through a narrow microstrip line which will provide some amount of inductor and this inductor will provide higher impudent at AC frequency.

Now, this patch here will provide a capacitance between the top layer and the bottom ground layer. So there will be capacitance from the top to the bottom layer which is good for suppressing the transient. So, let us see then this is open circuit here and we have a lambda by 4 length. So, open will act as short then again we have a lambda by 4 section. So, this short will act as open so; that means, for AC circuit this will be relatively open circuit. Similarly same configuration has been used in this side also ok.

So, basically the purpose of these things is that to provide a smooth DC path and also act as an open circuit at the desired AC frequency. Again if you see this particular portion this length is also equal to lambda by 4 so that when this is short circuited here this will act as an open circuit. So, nothing will go to this side here ok. So, here just to repeat input will go to output 1 when V s is positive and input will go to output 2 when this particular thing is positive.

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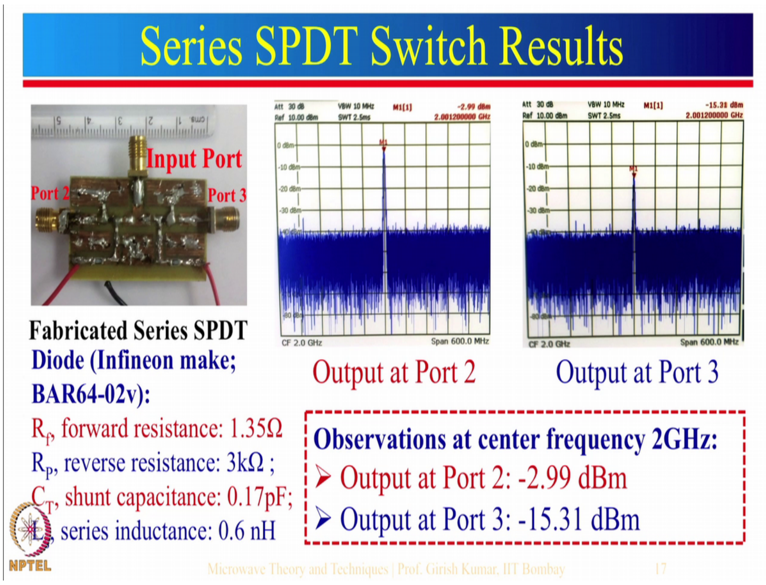

So, we have fabricated this particular configuration and let me show you the fabricated result. So, you can see that this is the photograph of the circuit which we have fabricated. For series SPDT switch we have used Infineon pin diode the forward resistance reverse and other parameters are given over here.

So, let me tell you what are the results? So, input port when we give the input here this was designed around 2 gigahertz frequency the results are shown here for input of 2 gigahertz. And let us see what do we get at port 2 and port 3? So, when this diode is forward bias and at that time this should be reversed bias then input will go to the port 2. So, you can see that this is the response of port 2 at that particular point relatively nothing should go to port 3 however we can see that some power is going to port 3.

So, let us see what are the values we are getting? So, output at port 2 is about minus 3 dB. So, you can say that insertion loss is of the order of 3 dB whereas, output at port 3 is about minus 15.3 dB so; that means, the isolation between this port and this port is nothing, but just 15.3 minus 3 which is about 12.3 dB.

So, it is not a very good switch in the sense that isolation between the port 2 and port 3 is only of the order of 12.3 dB ok. So, better design has to be done and in fact, I did mention that one can use combination of series and shunt that will provide better results.

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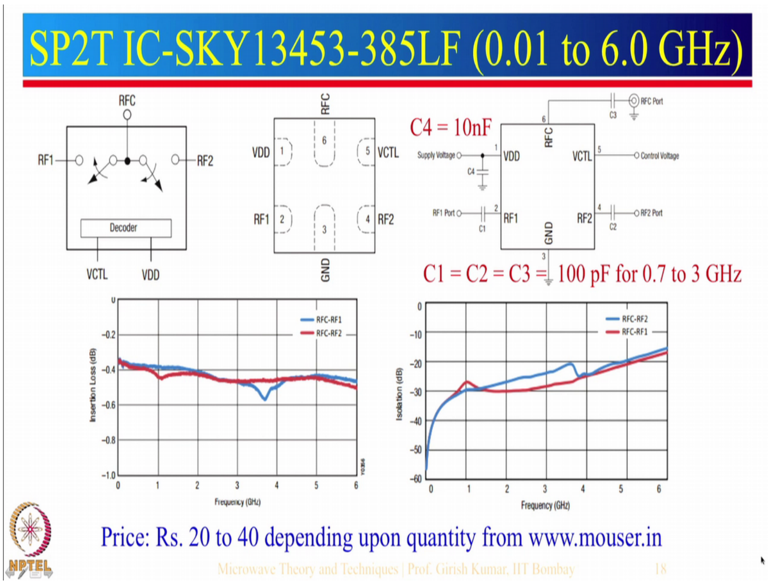

So, let us just now look at one of the commercially available switch. So, this is SP2T IC which is available from sky works that is the number here. Now they have mentioned that this switch works from 0.01 to 6 gigahertz. However, I tell a few interesting things to realize this particular thing here first let us just look at the pin numbers of this particular configuration.

So, you can see that there are total 6 pin numbers are there. So, one can see here this is VDD. So, you connect the supply voltage here. So, here input is given at this particular port here output may go to this side or it may go to this side depending upon this control voltage over here.

So, let us see how this IC works? So, here is the input so depending upon if the switch is in this position then input will go to RF 1, and if the switch is in this position then input will go to RF 2. So, we have a VDD voltage and this is what is the control voltage.

So, let us see what is the performance of this particular configuration? So, one can see that the results are given from 0 to 6 gigahertz insertion loss is of the order of 0.4 dB across the frequency band. Let us see what is the performance for isolation? So, one can see that isolation is very good up to about 1 gigahertz which is about minus 30 dB isolation, but as frequency increases you can see that isolation degrades. So, isolation is about 20 dB at around 5 gigahertz.

One another thing I want to mention here how you choose these capacitances? So, I have actually mentioned here C 1, C 2, C 3 is 100 picofarad for 0.7 to 3 gigahertz frequency range. The reason for that is let us see first of all where these capacitances are connected ok.

So, these capacitances are connected at the input port as well as the 2 output ports. And then there is a capacitance C 4 which is equal to 10 nanofarad basically this capacitance is to reduce the ripples or the transients, but I would still advice that instead of using single capacitance one should use about 3 capacitors.

So, I recommend that one should use 3 parallel capacitors one could be of the order of 1 microfarad that will be useful for reducing the ripple, 10 nanofarad which is given here. And another 100 picofarad capacitor to kill the transients please recall that these switches are going to be forward bias and reverse bias. So, there will be a transient from 0 to 1 or 1 to 0.

So, to suppress these transients it is important that you put another 100 picofarad capacitor over here. Now these 100 picofarad capacitance values have been chosen in this frequency range because they provide relatively low impedance in this particular frequency range.

If you to want to operate this at very low frequency of 0.01 gigahertz for 0.01 gigahertz these coupling capacitors should be at least 10 nanofarad or more. And if you want to operate the switch at around 5 to 6 gigahertz then 100 picofarad should be reduced to maybe even 47 picofarad.

So, let us look at what are the applications of this particular. So, let us look at what are the applications of SP2T. So, let us just see that this is a VCO 1, let us say this is VCO 2 and we want to send this signal in this particular direction. So, do not think that this can be only used as input here and output here or output here. This can be also used as input 1 here input 2 here and output can go over here depending upon the switch position.

So, assume that this is a VCO 1 let us say that VCO works from 0.7 gigahertz to 1.4 gigahertz and this VCO works let us say from 1.4 gigahertz to 2.8 gigahertz. I have use the frequency ratio of 1 is to 2 for each VCO. So, when we want to send 0.7 to 1.4 gigahertz signal here switch should be connected in this position. When we want to send the signal from 1.4 to 2.8 gigahertz then switch should be on in this particular position in that particular case input will go to this output port then.

So, remember these input and output ports are interchangeable the reason for that is simple when the diode is forward bias. So, then signal can go in this direction or it can go in this particular direction. So, just to summarize in the previous lecture we had talked about SPST switch in that we had discussed about various configuration, series configuration, shunt configuration, and combination of series shunt series configuration.

Today we talked about SP2T switch in that we talked about series SP2T, we talked about shunt SP2T, and we also talked about series shunt SP2T. In fact, there are other types of switches are also there are switches like SP4T, SP8T they are also available. So, basically SP4T there you give 1 input and that input can go to 4 different outputs depending upon which switches connected. And similarly SP8T will have let us say 1 input and 8 different output. So, depending upon switches connected to which particular output.

So, it can go to output 1, 2, 3, 4, 5, 6, 7, 8 and as I mentioned that input can become output and output can become input. So, we can give 8 inputs and one of these 8 input can go to the output port. So, we will look at some more applications of these switches when we talk about next topic and that is phase shifter.

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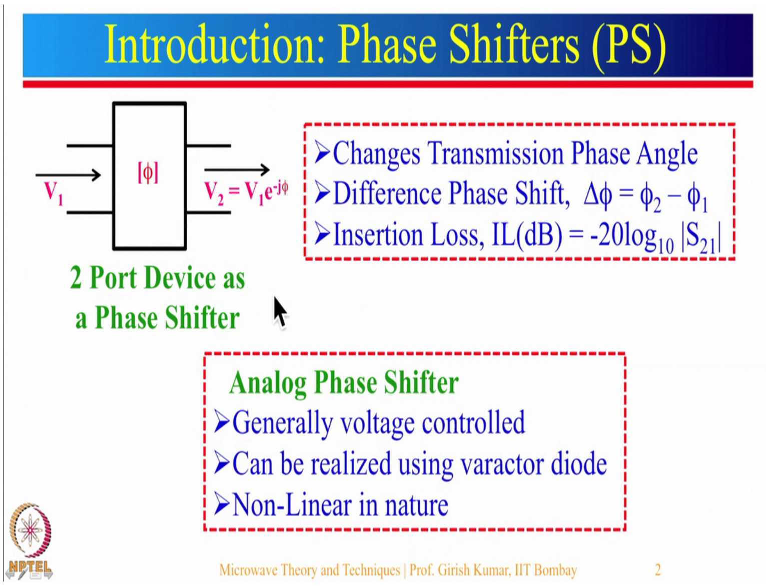

Now, we are going to talk about microwave phase shifters where these switches will be used. So, what is the phase shifters? So, this 2 port device can act as a phase shifter let us say we are giving a input voltage V 1 here and if the output voltage V 2 is nothing, but V 1 angle some phi, so that will be nothing, but phase shift of phi. However, the way it is realized it changes the transmission phase angle.

So, the difference between the two transmission stages so; that means, in 1 stage let us say we have a V 1 angle say phi 1 and in the second stage if we have V 1 angle phi 2. then the phase difference will be delta phi which is phi 2 minus phi 1. Now these phase shifters are defined by its insertion loss which is nothing, but minus 20 log S 2 1, where this is port 1 and this is port 2. Now there are two types of phase shifters, one is analog type, another one is digital type.

So, analog phase shifters are generally voltage controlled and these can be realized using varactor diode. We have seen that for a varactor diode if we change the reverse bias voltage its capacitance changes change in the capacitance actually means phase angle changes as we will see in a short while.

Now, these analog phase shifters are non-linear in nature the reason for that is the capacitance of varactor diode varies in non-linear fashion as we change the reverse bias voltage.

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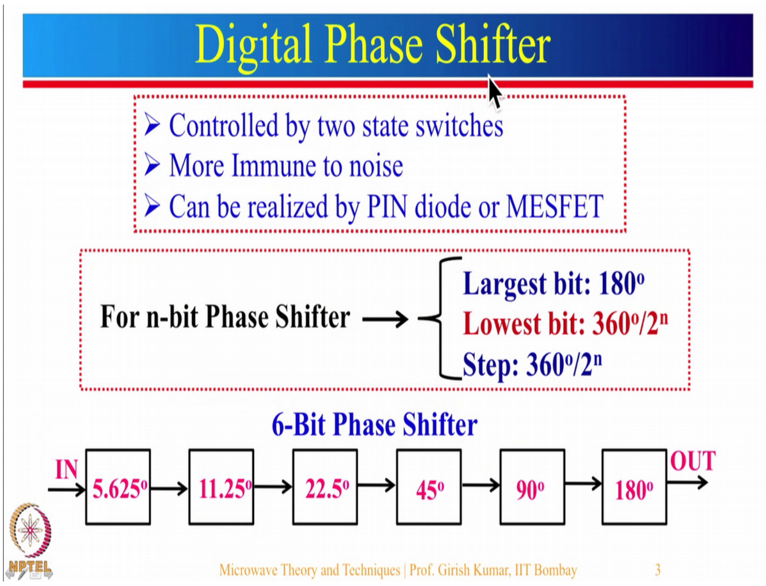

Now, let us talk about digital phase shifter. So, basically digital phase shifter is controlled by two states of switches it can be on switch or off switch. So, digital phase shifters are more immune to noise the reason for that is that these are defined in terms of logic 0 and 1.

So, let us take an example of it TTL configuration which is defined by 0 volt and 5 volt. However, 0 is defined for 0 to 1.5 volt or may be 0 to 2 volt whereas, logic one may be defined from 3 to 3.5 volt up to 5 volts. So, if the noise is between let us say 0 to 1 volt or 1.5 volt then it will still be considered as logic 0.

And if the input voltage is between 3 to 5 and the noise may be super riding on that it will still be defined as logic 1. Whereas, the range between 1.5 to 2 volt or 3 to 3.5 volt is defined as noise margin.

So, these digital phase shifters can be realized using pin diodes or MESFET. So, typically a digital phase shifter may be a n-bit phase shifter. Here the largest bit will be about 180 degree, the lowest bit will be 360 degree divided by 2 to the power n and each step will be 360 divided by 2 to the power n.

Let us take an example of a 6 bit phase shifter. So, you can see that here input is at this particular port there is an output at this particular port in between you can see that there are several phase shifters are there. So, we can see there is 1, 2, 3, 4, 5, 6.

So, 6 blocks are there that is why it is known as 6 bit phase shifter and these numbers can be obtained by using this particular thing here. So, when n is equal to 1; 360 divided by 2 will be 180 degree, 180 divided by 2 90; 90 divided by 2 45; 45 divided by 2 22.5; 22.5 divided by 2 11.25; 11.25 divided by 2 will be 5.625 degree. So now this 6 bit phase shifter is controlled by let us say these parallel 6 lines ok.

Now, of course these phase shifters are also available in the form of series phase shifter, but let just look at parallel phase shifter here. So, let us assume that this bit is one all these are 0, in that particular case what will happen input will experience of phase delay of about 5.625 degree.

If suppose this bit is 1, and all these are 0 then output will have a 180 degree phase shift. Suppose if this is 1, and this is 1, and this is 1 then total phase shift will be 180 plus 90

270 plus 45 315 degree. So, that is how you can change the phase shift. So, now comes the next question what is the application of these phase shifter?

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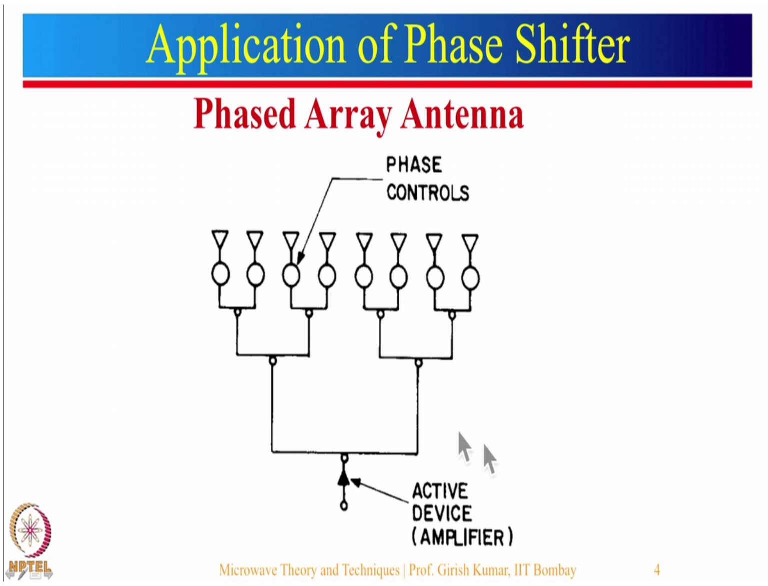

So, I am going to talk about one of the application where these phase shifter are used very widely. So, we have not discussed about antennas yet which we are going to cover later on, but right now let us just look at the concept part. So, here we have 8 different antenna which are represented by this symbol here. So, 1, 2, 3, 4, 5, 6, 7, 8 so let us say that we have a signal over here which is amplified and this signal is divided into two ways.

We have already talked about two way power divider, then another two way power divider then another 2 way power divider. So, you can see that this entire combination is nothing, but 8 way power divider and then we have 8 phase shifters connected over here. And these phase shifters are connected to 8 different antennas.

Now, when all these phase shifters are exactly at the same value in that particular case all these antennas will be fed with same amplitude and same phase so, then the radiation will be in the broadside direction. So, now let us say we change the phases and generally speaking the phases are change in steps. So, if this is let us say 0 then this will be delta this will be 2 delta, 3 delta, 4 delta, 5 delta, 6 delta, 7 delta.

So, you can think about let us say the phase shift. So, let us say this can be 0 degree, then this can be let us say 10 degree, then 20, 30, 40, 50, 60, 70. So, what will happen? In that particular case we will shift like this if we now increase the phases instead of step of 10 let us say we increase the steps by 20 degree then the beam will shift like this here.

Similarly, if we change the phase values from plus to minus then the beam will shift in the other direction. So, we can scan the beam from this direction to this particular direction. In fact, in this particular case antenna is not at all moving it is only the phases behind the antennas which are changing.

So, just by changing the phase difference of these elements we can scan the beam in this particular direction. Of course, this is an example of a linear array one can use planer phase array antenna in that particular case one can scan the beam in this direction as well as in this particular direction.

So, we will conclude today's lecture over here. So, we just introduce you to the concept of phase shifter. We talked about analog phase shifter we talked about digital phase shifter and then we talked about phase array antenna. In the next lecture we will see how to realize these analog and digital phase shifters.

Thank you very much.