Microwave Theory and Techniques
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Module – 09
Lecture - 45
Microwave Mixers – III: Design

Hello and welcome back again. So, in the first two lectures of Microwave Mixers, we discussed about the fundamentals of mixers, how mixer works as a circuit element, how the frequency translation happens. In the second lecture of mixers, we studied how devices like diodes and transistors basically perform as mixes or how fundamentally the mixing action happens using various small signal and large signal models of the diode and the transistor.

Now, after that we discussed various mixer circuits which are commonly used to implement mixers. We discussed about simplest single diode mixer or single transistor mixer. After that we discussed the balanced circuits, which are single balance circuits and double balance circuits. After that we discussed about sub harmonically pumped mixers which are used for very high frequency mixing applications. And lastly, we studied about image reject mixers, which are used to have image enhancement or very good performance for the image rejection.

So, in this lecture, we are going to focus on the design aspects that have to be considered while designing a mixer circuit. So, basically there are two approaches of mixer design, one is component or circuit based design in which you design everything from scratch, you select the mixing device, you select the type of the configuration or type of the circuit that you are going to use. And then, you design the individual components in the circuit to achieve the desired performance. The second, approach is IC base design in which you use a commercially available mixer IC from a one of the manufacturers. And then, you build a circuit around that IC to get the desire mixing performance. So, we will study these two approaches one by one in this lecture. And before going to that it is very important that we analyze and compare various circuits that we have studied so far. Let us begin.

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Comparison of Mixer Circuits

Mixer Type	VSWR			Port-to-Port Isolation			LO Power	IIP3
	RF	LO	IF	RF-IF	LO-RF	LO-IF		
Single-diode	Depends on IMN			Depends on filters			Low	Low
Single Balanced (180^0)	Same as single-diode mixer			Depends on filters	= hybrid isolation	Depends on filters	Moderate	Moderate
Single Balanced (90^0)	Good	Good	IMN	Depends on filters	Poor	Depends on filters	Moderate	Moderate
Double Balanced	Good	Good	Good	Good	Good	Good	High	High
Sub-harmonic	Depends on IMN			Depends on filters	Good	Depends on filters	Moderate	Low
Image Reject	Good	Good	Good	Good	Good	Good	Very high	High

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So, what we have here is a comparison chart between various mixer circuits. So, we have mixer types, single-diode, single balanced, using 180 and 90 degree couplers, double balanced mixer, sub harmonic, and image reject. We are going to compare all these mixer circuit types based on following criteria which is VSWR, port-to-port isolation, which we saw is very very important, LO power required which is used to drive the mixing devices, and IIP3 which indicates the linearity of the mixer.

Now, VSWR represents the reflections that we see at the three ports of the mixer, the RF port, the LO port, and the IF port. VSWR basically depends on the impedance matching networks that we use in various different kinds of mixer circuits that we have studied. And for some of the mixer configurations or mixer circuits, we have used couplers as the input device for RF and LO So, the VSWR in general depends on either the coupling structure or the impedance matching network that we have used for all the 3 ports.

So, in case of single diode mixers, there are no coupling structures use. So, all the three port VSWR actually depend on the impedance matching network. If you observe here for single balance mixers, we get a good VSWR for RF, and LO ports as compared to single balance mixers using 180 degree hybrid, which is the inherent property of a 90 degree hybrid coupler. For double balanced mixers again we use couplers, so we have a good VSWR. Sub-harmonic mixers, we do not use any coupling structures, so it depends on the impedance matching networks. Image reject mixer, also if you recall we use coupling structure, so we have a good VSWR at all the three ports.

Second, is a port-to-port isolation, again it depends on the type of structures that we are using to separate the LO, RF and IF ports. So, at the input if you remember for RF and LO, we mostly use a coupling structure in case of balanced circuits. And we typical use an IF filter in most of the circuits like single diode as a sub harmonical pump. Image reject we use coupling structures at both input and output which are the RF and LO and the IF ports.

So, if you see for image reject mixers, because we use the coupling structures we get a very good performance on the port to port Isolation. Whereas wherever you we do not use the coupling structures the Isolation depends on the filters that we use to reject the undesired frequencies. Then, we have the LO power. LO power is required to drive the mixing devices that have been used in the circuits. And you see that low LO powers or moderate LO powers are required for single diode sub harmonically pumped mixers, and single balance mixers, because the LO power depends on the number of mixing devices that are being used.

For example, in case of diode mixers single diode is only one diode. So, you require low power. In case of image reject mixer or double balance mixer you have a very high LO power requirement, because double balanced mixer contains 4 diodes. Image reject mixer contains two doubly balanced mixers, hence the LO power is very high. IP3 we know that the balance structures have a good spurious response. And hence for balance mixers we get a good linearity. So, the IP3 point is very high, so the mixer is more linear.

Similarly, for the image reject of mixers, however for sub harmonic mixers or single diode mixers. If you observe the IP3 is very low, because there is no balancing action done. For single balance, since it is only balanced in one for one of the signals, we get a moderate IIP3, hence we get a moderate linearity. So, on this various factors we have the performance of all the mixer types. And based on our application what we require in the mixer design, we can select a particular configuration or particular circuit of a mixer which, caters the demands of our application.

So, this is a very important comparative study that has to be kept in mind before we start designing any mixer. So, let us start with the mixer design process now. So, first thing what do we need before we start the design? We need some data to start with, and the specification should be given or known to us before we actually start designing a mixer.

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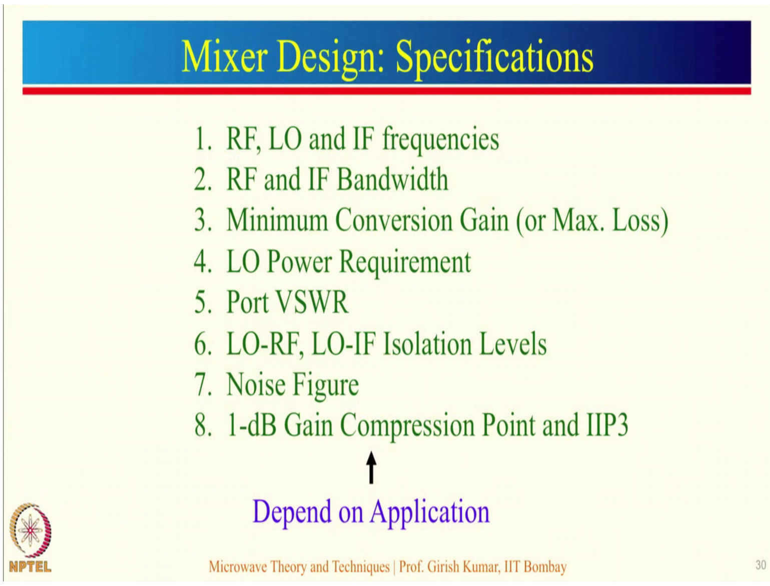

The specifications are nothing but the mixer performance matrix that we studied in the first lecture on micro wave mixers. So, we have or we must know RF LO and IF frequency, we must know the Bandwidth requirements at these frequencies, we should know the Minimum Conversion Gain or Maximum Loss that is tolerable by the mixer, the LO power requirement, Port VSWR s, the isolations noise figure and again IP3 or the linearity numbers. And all these things actually depend on the mixer is going to be used in what kind of application. Let us move further.

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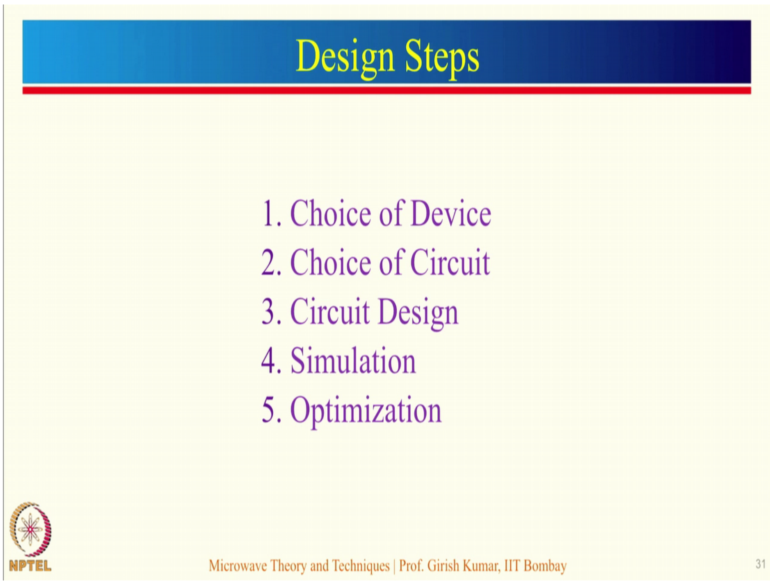

So, there are certain design steps in general that has to be followed while designing a mixer. First one is you should choose the Device which kind of device you are going to use. We have broadly two choices one is diode, another one is a transistor or a FET. If the mixer requires a gain specification, then we will definitely go for FET mixers. If the mixer does not have any specification on the gain part, we can use diodes in that case we will have convergent loss. Choice of circuit is a second step, so once you decide the mixing device then you have to choose or the type of circuit that you are going to use based on what performance you want.

For example, if I if I require a very high input VSWR for the RF and LO ports is my critical concern, then if we go back, you see that a single balance mixer implemented using 90 degree coupler gives us a very good input VSWR. So, this comparative chart comes to rescue, when we decide the type of circuit that we are going to use. The third is you actually you build the circuit, you design the circuit, you design various coupling structures, you design the biasing of the device. And whole lot of other things that goes around the mixing device.

Fourth one is Simulation you simulate the structure for various performance parameters such as conversion gain noise figure. Then you have Port to Port Isolation and the input VSWR for all the 3 Ports. And the fifth one is if you do not need those specifications after simulation results are out, then you have to optimize the circuit, you have to tune the impedance matching networks or the coupling structures the yellow signal level or the DC biasing to get the desired output. Moving ahead so there is a general design rational which we follow while designing any mixer, and that rational is as follows. So, we have a typical circuit once you choose the mixing device.

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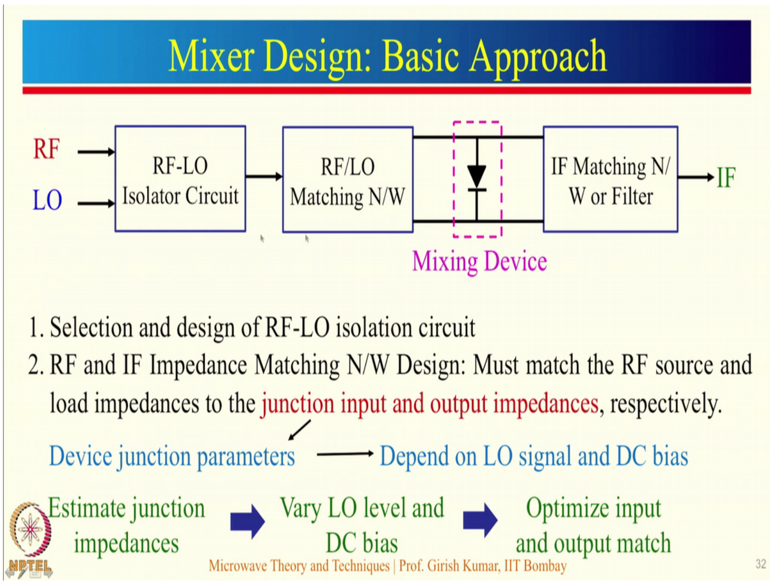

All you have to do is you have to take care of the Isolation part, you have to take care of the matching part, and you have to take care of the filtering part. These are the three main aspects you have to focus on. Let us say first you design a coupling structure or diplexer to a separate out the RF and LO signals, so that design is one part. This design will depend on the frequency of operation what are the desired frequencies of RF and LO you require.

The second, and the very important or the critical one is the RF and IF impedance matching network design, which should match the RF source and load impedances to the junction input and output impedances of the mixing device, but the question is who is going to provide the junction input and output impedances. We know that when a diode is pumped with an LO signal, the diode current is modulated it changes right from 0 to its maximum value. And hence the diodes input impedance actually varies from a very low value to very high value. And it is not a straight forward impedance matching network design problem where we have two fixed impedances. In this case, we have one impedance which is fixed, for example, 50 Ohm which is normally the case.

While the junction impedance which is the input impedance in case of RF impedance matching network design. And output impedance in case of IF matching network design. Both these impedances vary with the LO signal level and with time. So, it is very important or critical to choose what impedance you will use to start the design process, so that is why the device junction parameters actually decide this junction input and output impedances. And these device junction parameters depend on the LO signal and the D C bias applied.

So, this is what we do we estimate the junction impedances to vary the LO level and DC bias to optimize the input and output match, so that we get desired matching performance. So, you have to start with some impedance level. You see the performance then you vary the LO level and DC bias, so that you get the desired performance in the matching network design ok. So, this was the basic rational behind mixer design using either diode or transistor. The design process for diodes is mainly focused in this lecture. It is slightly deviates when you go for transistor base design. We will focus on the diode circuits in this lecture moving forward with the help of an example.

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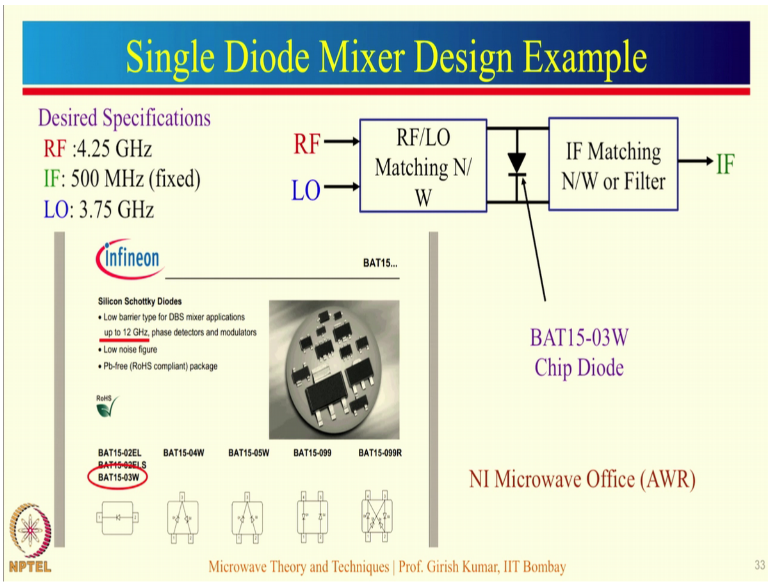

Let us design a single diode mixer for an input RF frequency of 4.25 gigahertz. The IF is fixed at 500 megahertz. And the LO requirement from these two things will be 3.75 gigahertz. In this case we have chosen LO which is below the RF frequency which might be specific to an application. And the circuit that we are going to build is of this type. So, in this example for the illustration purpose and not to make it more complicated. We are going to skip the RF and LO Isolation part, but we will focus more on the RF matching and IF filtering part.

So, in this case we are going to use a BAT 15-03W chip diode which is a Schottky diode from Infineon technologies. Here is a snapshot of the diode datasheet. If can read the diode can be used up to 12 gigahertz, which fits our requirement. And this is the footprint of the diode it is a chip diode. So, it can be soldered using a standard assembly technique. And hence it is very useful for micro strip design which we are going to cover next. So, we are going to use a simulation software named Microwave Office by national instruments also called as A W R.

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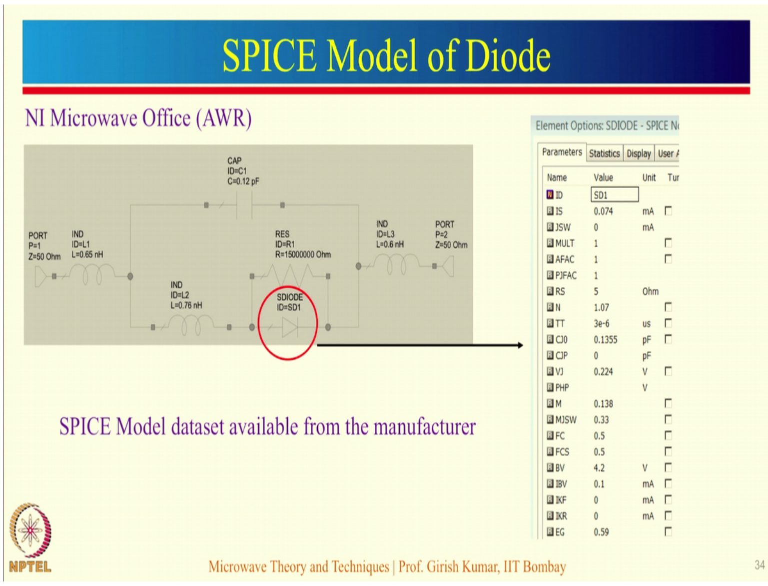

Let us start the design the first part that we are going to focus is the SPICE model of the diode, because the diode simulation is very critical. If you can see this is the actual SPICE model of the diode, and the SPICE model actually let us you enter all the different diode parameters related to the junction. For example, you have a saturation current specification, you have the junction capacitance for 0 bias, you have the maximum junction voltage, then you have a reverse breakdown voltage the energy band gap and so on.

The all these specifications you can get from the SPICE model which is available on the internet mostly by the manufacturer. Once you get that SPICE model file you can take that model or import that model into the software can put in all the parameters. And then this particular diode will be simulated using this configuration. Now, around this diode what you see are the components which account for the package parasitic. So, we have also included those into the diode model. Now, once the diode model is done.

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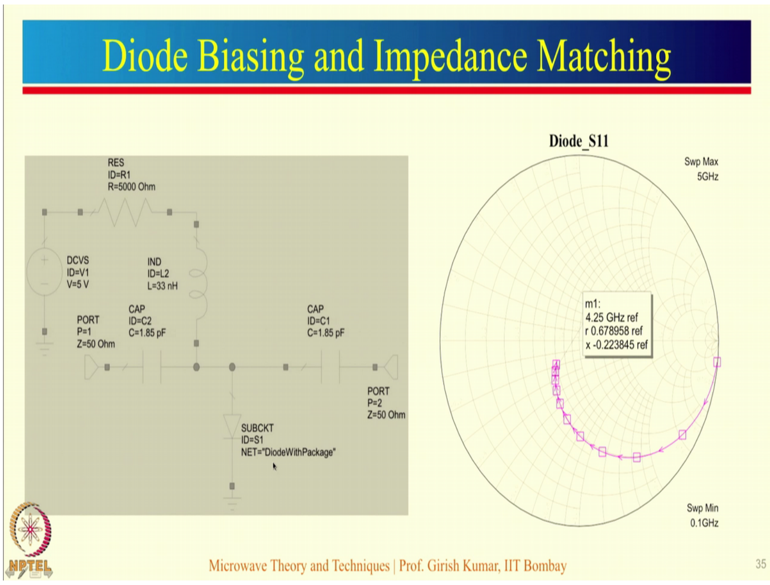

The next step is to bias the diode. So, here is the biasing circuit. We have a diode here. We have DC voltage source of 5 volt have a resistor to control the current. Inductor to avoid high frequency signals to enter this path. And then we have these DC block capacitors. Now, this biasing is done for the diode current of approximately 1 milli Ampere or little less than 1 milli Ampere. And we see that we have applied a port here, and port here to see the operation of diode with this particular biasing. Now, this biasing helps us to estimate the first value of the RF input impedance that the RF signal is going to see at the diode junction.

So, if we simulate this particular structure, and we observe the S11 at the desired RF frequency which is 4.25 Gigahertz, we see that the normalize r and x are these. So, r is around 0.67 and x is here minus 0.22 in normalize case. So, what we are going to do is we are going to take this impedance as the first estimate of our RF input impedance for the diode. And we are going to build a matching circuit using this impedance. Let us do that so we have studied the impedance matching network design using single stubs or shunt stubs, we are going to follow that.

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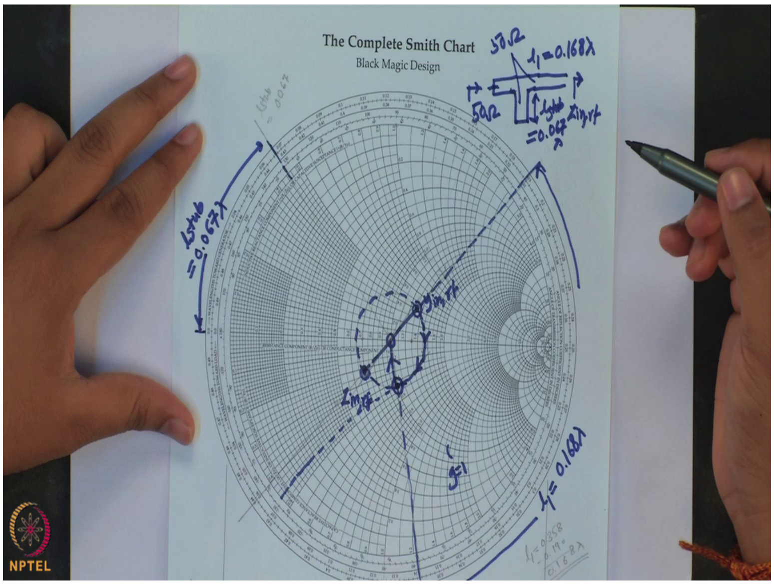

And let us see what we have here. So, the impedance that we see which is r is equal to 0.67and x is equal to 0.22 is at this point. Now, using standard single stub matching technique, what we are going to do is we are going to draw a constant VSWR circle from this point. Then we are going to take the diagonally opposite point for this particular load which is this point which; so, if this is my Z in for the RF signal, then this will be y in for the RF signal.

Now, we are going to match this particular point to the centre which is 50 Ohm. We will follow the standard procedure. So, from this point, I will move towards the generator, and I will stop at a point where I cut the g equal to 1 circle. So, this is my point at which I will stop. From this point I will go in this way to the 50 Ohm point. So, now, this value of susceptance which is approximately here has to be cancelled out by the stub. Hence, we choose the corresponding point on the positive side which will be right here right. And we see the marking on the wavelengths scale. And we see that from this point. If we see the length, we get l stub equal to 0.067 lambda.

So, this is a stub length, and for the line which is in series with the load or y in RF. We have to go for these lines. We see this we measure this on the wavelength scale. And we see that l 1 is nothing but 0.168 lambda. So, our final design will be like this. So, at this point I have some Z in RF which we have seen from the S11 simulated chart. And then I will have a series line with length l 1 equal to 0.168 lambda. And then I will have an open circuited stub, because I started from this point. And this length l stub will be equal to 0.067 lambda and then I will have my 50 Ohm looking into this port. Now, the characteristic impedances of both this line is 50 Ohms. This is our matching network design for the RF frequency for given impedance value.

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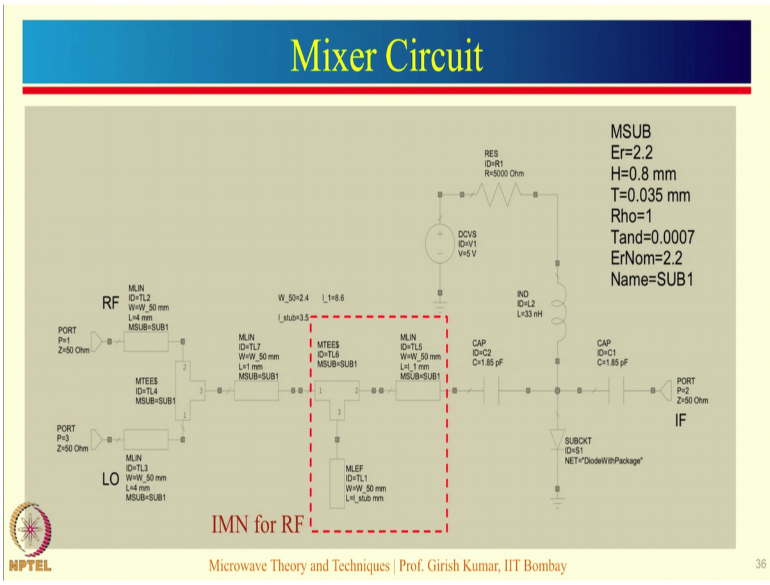

So, moving ahead this is a circuit that we have built using the impedance matching network and the device. So, this is our mixing device a BAT 15 diode. This is the biasing circuit. These are the DC block capacitors. And we have a series line and the open circuited stub which represents impedance matching network for the RF frequency. We have the connectors here, again a connector here again a connector here. And the RF input is from this end the LO input is from this end. And right now we are interested in observing what happens directly at the mixer output which is the IF port. We are not processing the mixer output we want to observe the bear mixer output without any processing. For this particular design the substrate that we have used is epsilon r equal to2.2. The height of the substrate is0.8 mm. Copper thickness is 35 micron. and we have tan delta for this particular substrate is 0.007.

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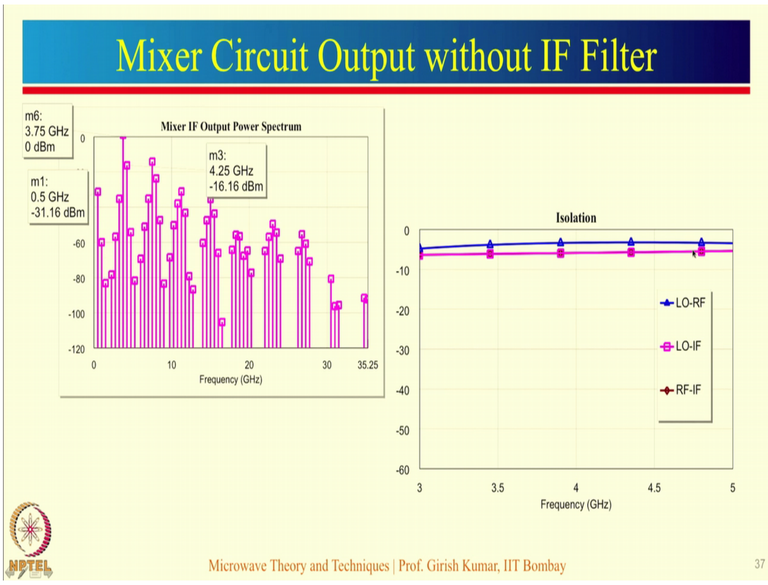

Now, let us see the results at the output of the mixer you get these. So, if you can observe, you have a signal at 0.5 Gigahertz which is 500 Megahertz which is nothing but our desired IF frequency, and you get all other frequency components which are undesired. So, you can observe that you have LO signal leaking into the IF output. You have an input RF signal leaking into the IF output. Along with that you have all the spurious signals which are present in the IF output. So, we basically need a filter to filter out all these things. And the filter will also help in the isolation, because we see here the Isolation levels LO to RF, LO to IF, RF to IF are well below 10 d B which is not a good number. So, now, we are going to see that how a simple filter addition in the IF output port can dramatically improve the results.

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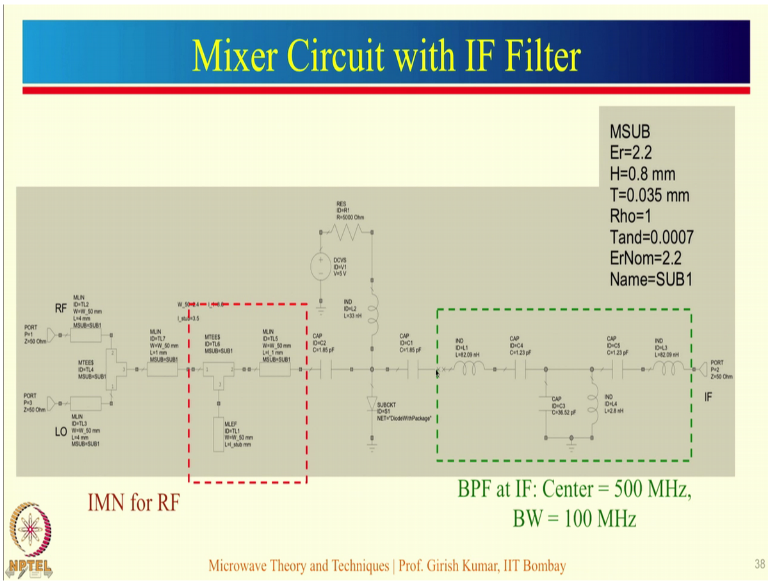

So, here is what we do at the output of the mixer which was this point which we earlier observed. Now, we have designed a Band Pass Filter centered at 500 Megahertz with the Band Width of 100 Megahertz. And you have a simple l c structure and the rest of the circuit remains the same.

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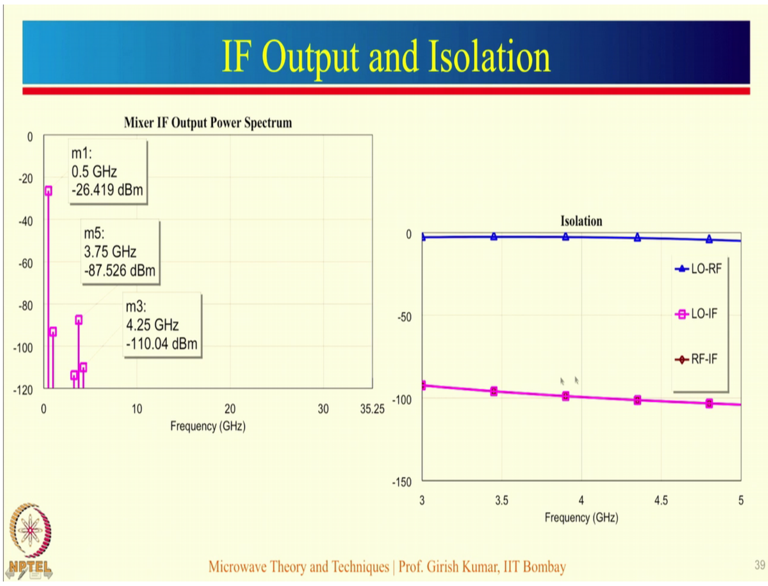

Now, if you see the IF output at this point, you observe the following. Can you see the difference; all the rest of the spurious components have been dramatically reduced. You get an IF which is the highest amplitude signal over here. And you also see that the LO power and the RF power that is available. At the IF port is very very low. Along with you have some spurious signals, but all the signals are well below 80 d B. So, with a good filter design you can achieve a very good performance.

And if you see on the Isolation front, the Isolation between LO and IF, and RF and IF which is this graph is very high. So, it is around 100 d B. Now, this number is practically not possible, but because the filter is ideal in this case you get this number, but if you do a good filter design see the amount of Isolation, you can achieve between LO IF and RF IF. Now, the Isolation between LO and RF is still poor, because right now we have not done anything to Isolate the RF and LO ports.

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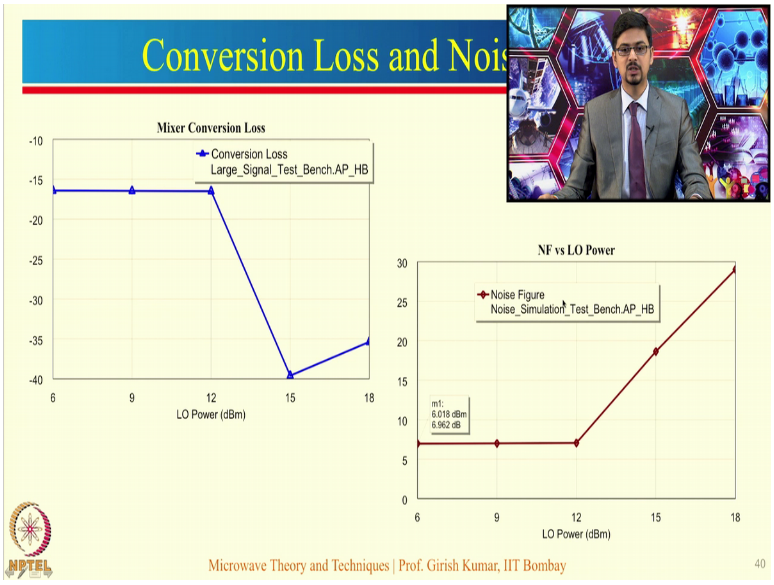

Let us see the conversion loss and noise figure. We get a conversion loss of around 16 d B for LO powers of 6 dBm, 9 d BM till 12 dBm. After that you get a decrease or increase in the conversion loss which is certainly not desired. So, this graph represents the effect of LO power on the mixer conversion loss performance. The noise figure that we get from the circuit that we built is around 7 dB. And you see that as you increase the LO power after 12 dBm the noise figure also increases which is undesired. So, again the LO power is a critical component it affects your conversion loss as well as noise figure performance.

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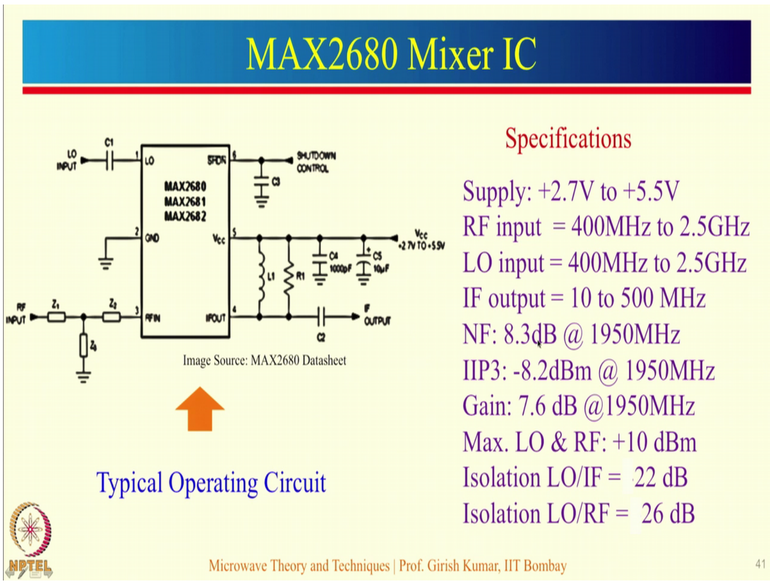

Now, we will see the second approach of mixer design which is IC based design. There are lot of commercially available mixer IC s which can be used to design a mixer circuit. All you need to do is check out your designed specifications. And you have to find an IC that meets those designed specifications. So, let us take a case you have an IC from MAX semiconductor which is MAX 2680. The specifications are it requires a supply voltage of 2.7 to 5.5 volts, the RF input and LO input are can be in the range of 400 Megahertz to 2.5 Gigahertz which is quiet broadband, IF output is from 10 to500 Megahertz, Noise Figure is 8.3 dB at 1.95 Gigahertz, IP3 is not that good, but it still 8.2 dBm at 1.95 Gigahertz, Gain is around7.6 dB. So, this indicates that all these ICs that are available. If they are providing gain, you must guess that these are, of course built using transistors.

The maximum LO and RF power can be plus 10 dBm, at Isolation you have 22 dB and 26 dB for LO IF and LO RF respectively. So, this is a typical application circuit. This is a IC. You have an LO input through a coupling capacitor. You have an RF input through a matching circuit. So, remember matching circuit for RF is very very important. So, we have an RF input, we have IF output which is taken over here and these are the biasing components.

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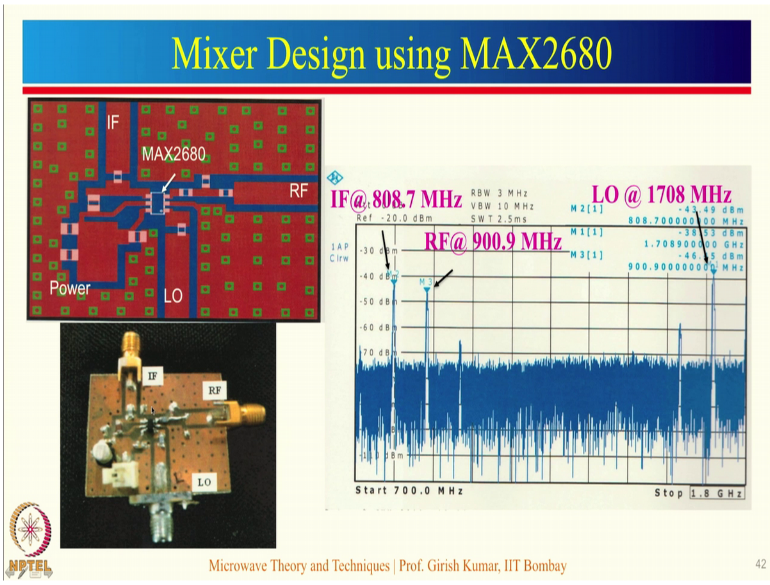

So, let us see the performers. So, we have fabricated PCB using this IC. So, you can see the PCB snapshot. Here is the IC, then you have the power circuitry over here. You have RF input. This is the matching network that we just studied. And you have the LO signal which is coupled using a coupling capacitor and the IF output is taken over here. So, this is a photograph you have IF output RF input and LO input. And this is the power supply input.

The performance is like this here is the snapshot for a particular level and frequency of the signals. So, you have an input signal LO at 1708 Megahertz. You have an RF at 900.9 Megahertz. And you get an IF output at 808.7 Megahertz which is the difference between these two signals. Now, if you see the level of IF is very close to that of RF, and the frequencies are also very close to each other. This is a very good example how critical IF filtering is. So, if you do not have a good IF filter, if you do not have a sharp rule of, the RF signal might leak into the IF port. And you will have in adequate RF to IF Isolation.

So, along with IF you see some spurious signals you also see and LO signal in the IF output. And all these things have to be eliminated by using a proper IF filter design. So, these are the various aspects of mixer design that we studied so far. Just to recall there are two design approaches, one is by using component or circuit based design, where we do everything from scratch. We select the device, we select the type of the circuit, and then we design the individual circuit components to achieve the desired performance.

In the second design approach, we will choose a commercially available mixer IC which can fit our desired requirements or specifications. And we build a circuit or PCB around that IC, and we test it to get the required performance. So, these are the two design approaches that are available for Mixer Design. And it is very very important to choose right devices or right ICs before we start the Mixer Design.

With this I will stop here. So, this concludes a discussion on Microwave Mixers. So, just to recap all the three lectures; in the first lecture, we discuss the Mix of Fundamentals. In the second lecture, we discussed devices and various circuits that are used for mixer design or mixer implementation. And in this lecture which is the third lecture we discussed the performance comparison of various types of mixers, various design methodologies that can be followed to design mixers. And we also looked at these things using simulation examples using simulation examples. With this I conclude.

Thank you so much.