Microwave Theory and Techniques
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Module - 11
Lecture – 54

Measurement using Network Analyzer

Hello, welcome to the lecture on Microwave Measurements. In this lecture, we are going to study how to measure the circuit characteristics using test instruments. We will study this into parts, in first part I will explain some fundamental theoretical aspects of microwave measurements and in the second part we will study how to do the measurements practically. Let us begin.

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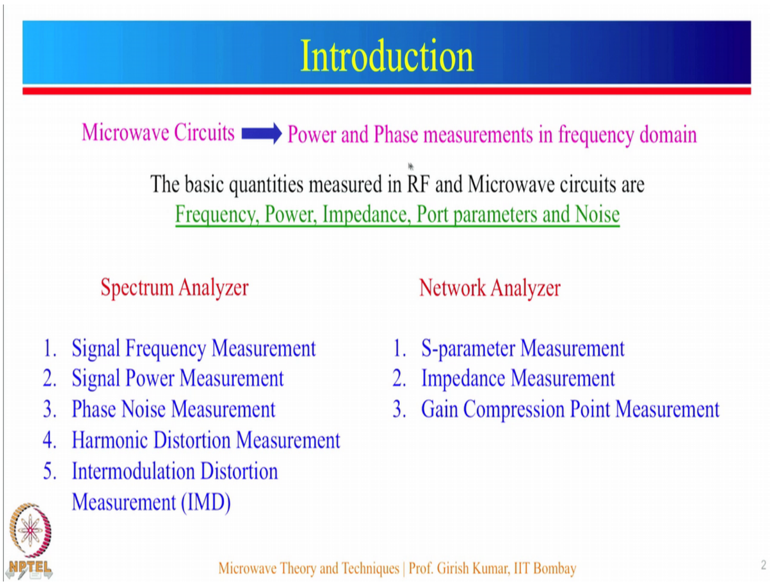

So, unlike low frequency circuits where voltage and currents are measured against time in microwave circuits we usually make power and phase measurements in frequency domain.

So, the basic quantities which are measured in RF and microwave circuits are frequency, power impedance, port parameters which are S-parameters and noise. And these measurements are primarily done by using two main instruments which is spectrum analyzer and network analyzer.

The spectrum analyzer is capable of doing signal frequency as well as power measurements fundamentally, it can also measure the phase noise of a signal, it is also used to measure the harmonic distortion as well as inter modulation distortion. Network analyzers are used for s parameter measurements primarily and it can be also used to measure the impedance of a network which is input or output impedance and it is also used to measure the gain compression point which is p 1 dB of a network.

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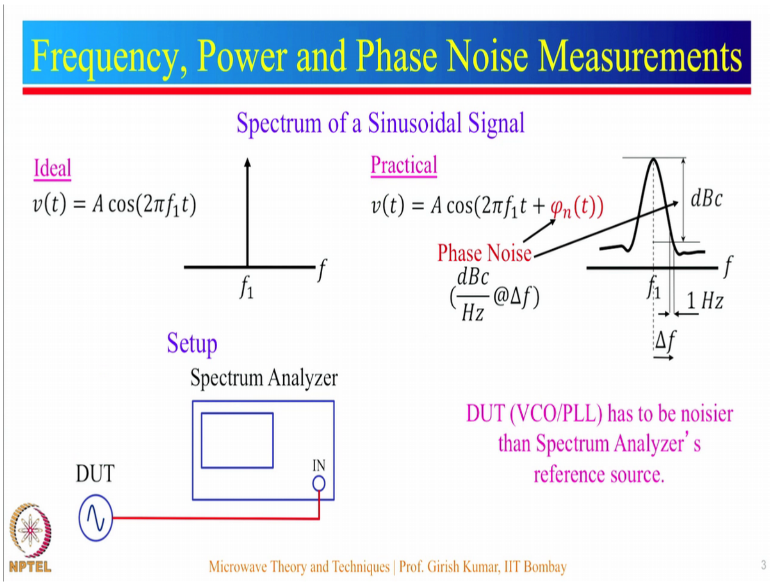

Let us see how frequency power and phase noise can be measured using a spectrum analyzer instrument. So, some basics we have a sinusoidally varying signal v of t equal to A cos 2 pi f 1 of t, and ideally the spectrum looks like this. So, we have an impulse at frequency f 1 and height of this impulse should be A, but practically the impulse is played at the bottom mainly because of phase noise present in the signal and we can see that this phase noise is measured in dBc per hertz at some delta f offset from the centre frequency which is f 1.

The setup is quite simple the DUT which is typically a VCO or signal generator or PLL is connected to the input of a spectrum analyzer and the measurements can be done accordingly.

Now, for phase noise measurements the DUT which is the VCO or PLL has to be noisier than the spectrum analyzers reference source, then only the spectrum analyzer can measure the phase noise of the DUT. The power and frequency measurements are straight forward and we will see these in the practical measurement of these quantities.

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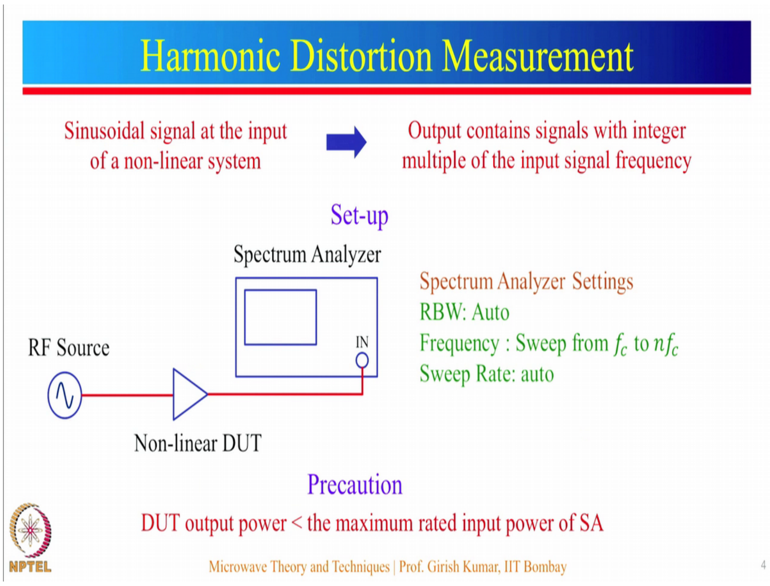

Next is harmonic distortion measurement. So, you have an RF excitation source for a non-linear DUT. The output of the DUT is connected to the input of the spectrum analyzer. Here are some settings of the spectrum analyzer and we have to make sure that the output of the DUT let us say in case of amplifier should not hamper the spectrum analyzer circuitry. In that case you may want to put an attenuator in between the DUT output and the input of the spectrum analyzer. This is the precaution we have to take.

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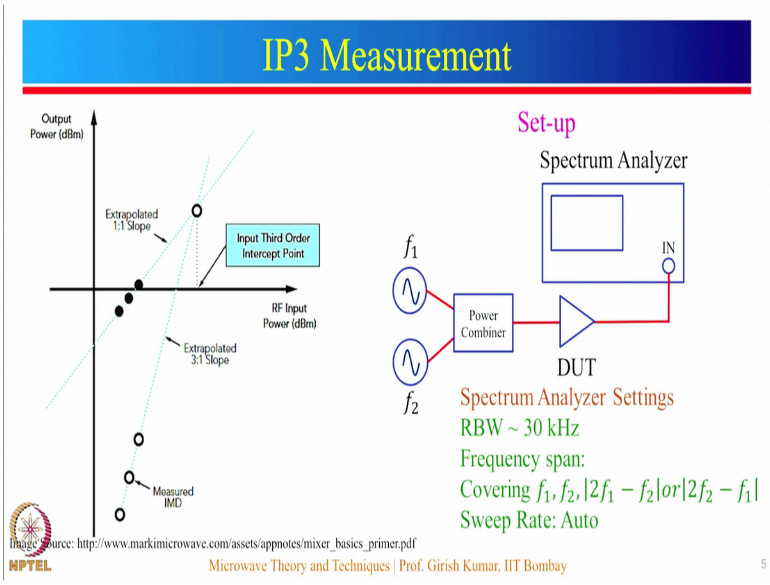

Next is IP 3 measurement. So, there are two tones applied at the input of the DUT through a power combiner and the third order inter modulation product which is nothing but twice f 1 minus f 2 or twice f 2 minus f 1 is present at the DUT output. These are some spectrum analyzer settings. One thing to be noted here the power combiner should give a very high isolation between these two ports and also it should have a very high return loss for f 1 and f 2.

Now, comes network measurements which are done using network analyzers or vector network analyze, VNA.

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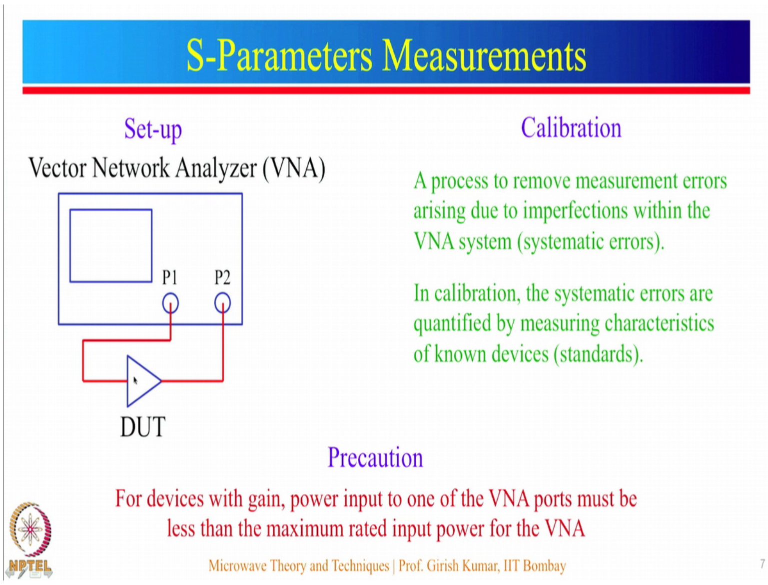

And the DUT to be measured is placed across the two ports of the VNA. In case of two ports DUT in case of one port DUT you simply connected to one of the two ports available at the vector network analyzer.

So, before starting the measurements of the DUT calibration has to be done for the VNA. Calibration is a process to remove the measurement errors arising due to the imperfections within the VNA system which are called as systematic errors, and during the process the systematic errors are actually quantified by measuring characteristics of known devices which are called as absolute impedance standards. And once these quantified systematic errors are known they can be adjusted in the actual DUT measurements to give more accurate results. We will see how to do the calibration process and how to actually measure the S-parameters in the practical aspect of this lecture.

Hello. Welcome to the second part of the lecture on Microwave Measurements. In this lecture we are going to demonstrate how to use spectrum analyzer and network analyzer to test or major various characteristics of microwave circuits such as frequency, power levels, gain, phase, noise, S-parameters and so on. So, the instrument that we are going to use are mainly the spectrum analyzer and the network analyzer. Along with that we are going to use a signal generator, A DC power supply and here is another signal generator and here you can see the spectrum analyzer.

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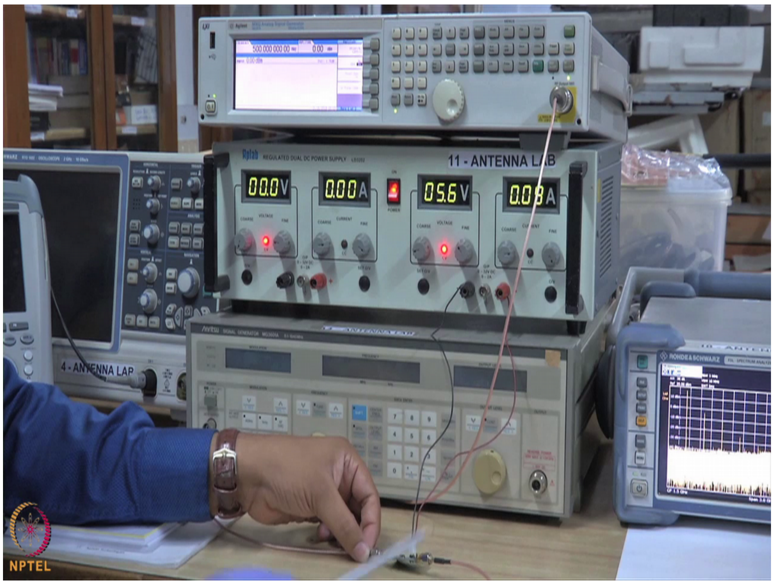

We restart the spectrum analyzer first and then will move to network analyzer measurements. Let us begin.

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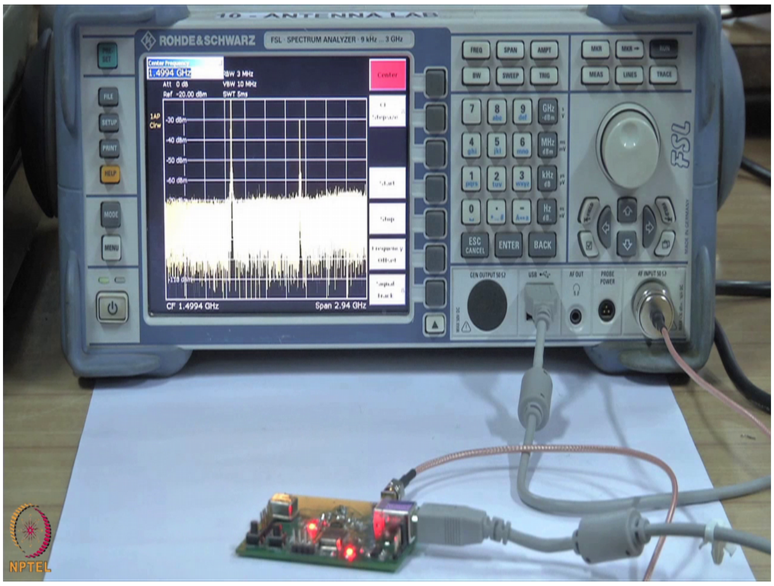

So, we have a road and shorts spectrum analyzer of fsl type. So, the spectrum analyzers frequency range is from 9 kilohertz to 3 gigahertz and as you can see the spectrum analyzer has an embedded display and various controls to enter different settings and measure different parameters. So, the display typically has an x axis and the y axis, on the on the x axis we have a frequency and on the y axis the amplitude level or the power level of the frequency components are displayed.

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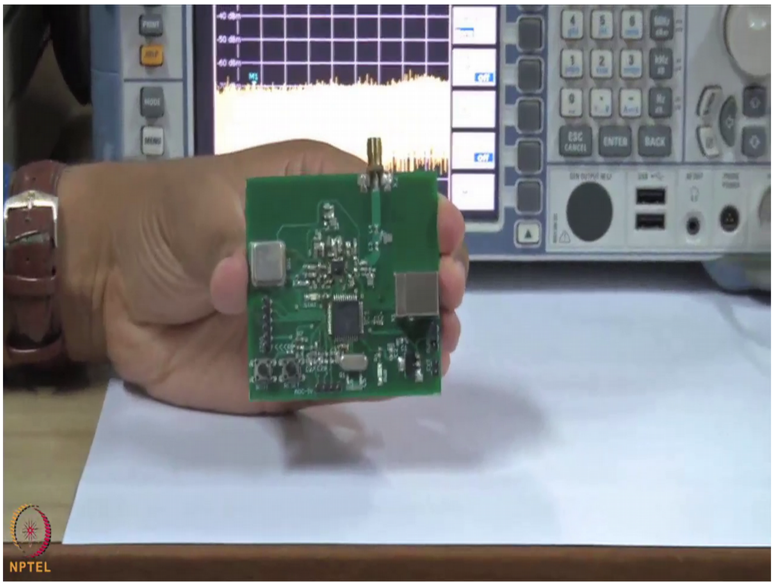

This is VCO come PLL board. So, the IC that you can see here is LTC 6946 its frequency synthesizer along with PLL and VCO. So, we have studied this particular circuit or we have studied this IC based VCO design in the oscillator lecture, and a microcontroller peak 18 f 4550 is used to program the PLL IC. The output of the PLL is taken over here and what you see here is an SMA type connector. This is a USB connector and the entire board is powered using this USB power cable.

Let us power on the board this PLL has been programmed at a frequency of 1 gigahertz, now we wish to measure whether the output frequency is one gigahertz or not. So, for that you have to go to the frequency button press the frequency button and you can enter the desired frequency value which will be the centre frequency value for the spectrum analysis. So, I will enter 1 gigahertz enter. So, now, you can see that the display has been centered to 1 gigahertz. The span currently is 2 gigahertz; I will reduce the span so that I can view this particular thing more clearly. So, I will set the span to let say 200 megahertz.

Now, you see that you can view the frequency component in more details, but still the amplitude level is not correctly shown, for that if you read the reference level is minus 20 dBm and we need to increase the reference level for that go to amplitude and reference level set the reference level as 0 dBm. Now, I can see the peak of the frequency component. To measure the frequency go to markers, set the marker you see that marker m 1 has been placed and the marker reading can be read from these two line. So, m 1 has a frequency reading of 1.000400000 gigahertz which is very very close to the 1 gigahertz value which has in program in this particular PLL.

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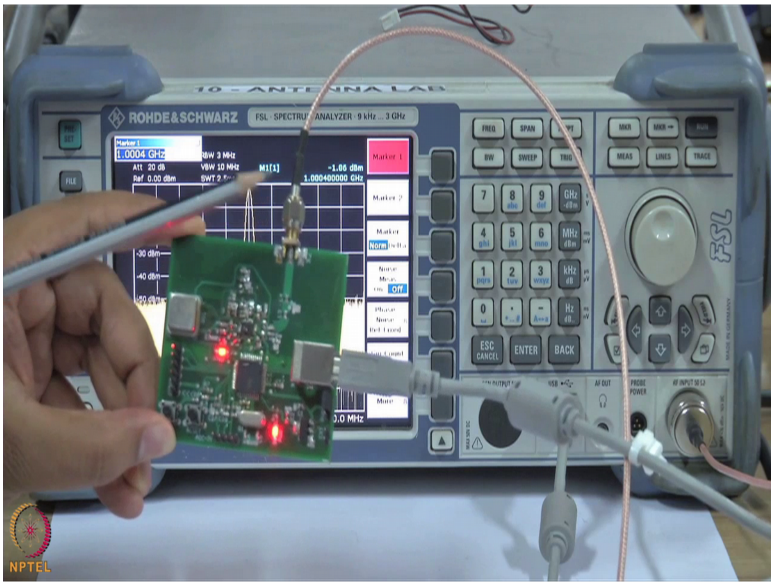

So, the at the output of this PLL we have a frequency component at one gigahertz and the level of this frequency component or the power level of this frequency component is minus 1.85 dBm. The program value or the program amplitude level was 0 dBm and the minus 1.85 dBm, accounts for the cable losses and other losses in the circuit. So, this is how we can measure of frequency and the corresponding power level of a signal using spectrum analyzer.

For phase noise measurements you have to keep the span to the lowest value possible. So, let us reduce the span click on span and span manual and let us keep the span to 50 kilohertz value. Now, you see that the signal can be observed in more detail and you see that the noise level is quite visible now. To smoothen this, let us go to tress, click on tress then click on tress mode and choose the averaging function. So, click on the average and now you see that the things are more stable.

Now, let us go for measurement of the phase noise. So, go to marker, now the marker m 1 has been set to the desired centre frequency which is approximately 1 gigahertz. Now, go to marker 2, market 2 is of delta type d 2 and the delta is displayed over here for phase noise measurement all you have to do is click on this function which is phase noise reference fixed function. So, I will hit on this. And I will see that the offset is currently minus 100 hertz. Remember phase noise is measured at a particular offset frequency which is typically 10 kilohertz, 100 kilohertz or 1 megahertz.

Let us keep the offset frequency to 10 kilohertz. So, I will enter 10 and kilohertz and all you have to do to know the phase noise is to read the d 2 marker measurements which is shown over here. So, if you observe phase noise to which corresponds to market two is around 67 dBc per hertz at an offset of 10 kilo hertz. Now, the rated phase noise of this PLL IC according to data sheet is around minus 85 dBc per hertz but due to the overlapping of am noise and the system limitations of this particular board we get the phase noise measurement of around minus 67 dBc per hertz which is close to the desired value. This is how the phase noise measurements can be done using a spectrum analyzer.

Next I will demonstrate how to measure the harmonic distortion in a non-linear circuit. This is an amplifier circuit developed using mmg 3001 IC and we are going to measure the total harmonic distortion using spectrum analyzer. Let us have a look at the setup. So, we have a signal generator which is generating an input signal of 500 megahertz frequency and the amplitude is 0 dBm. The signal is given at the input of the amplifier circuit over here and the output of the amplifier will be checked on to the spectrum analyzer. Now, this amplifier circuit will be powered using a DC power supply the voltage is 5.6 volt and the current will be drawn accordingly by the amplifier operation.

Let us turn on the amplifier. So, as you can see the voltage is 5.6 and the amplifier is drawing around 100 mill amperes of current which is the correct operating point and now we will observe the output of this amplifier on the spectrum analyzer. As you can observe on the spectrum analyzer display we have the fundamental frequency output which corresponds to 500 megahertz and we have different harmonics of the fundamental frequency appearing into the output because of the nonlinearity present in the amplifier.

Now, we will see how to measure the total harmonic distortion, for that you have to go to measure click on it go to more. You can see harmonic distortion function, select it; you can see that the upper graph demonstrates the fundamental and various harmonics of the fundamental against time and amplitude levels. On below table you see that the first harmonic which is the fundamental frequency is 500 megahertz and this table has a frequency resolution bandwidth and power level. So, the fundamental frequency which is 500 megahertz has been checked or analyze with the resolution bandwidth of 3 megahertz and the power level is 17 dBm.

The second harmonic which is at 1 giga hertz has been analyzed or measured with the resolution bandwidth of 10 megahertz and the power level is minus 23.2 dBc. Now, dBc is the power level with respect to the fundamental power level third harmonic, fourth harmonic, fifth harmonic and so on. So, the total harmonic distortion is 7.9 percent in dB it is minus 21.9 dB. So, this is how you can measure the total harmonic distortion present at the output of any non-linear circuit.

Next we will see how to measure IP 3 point of a non-linear DUT using spectrum analyzer. Let me explain the setup to you.

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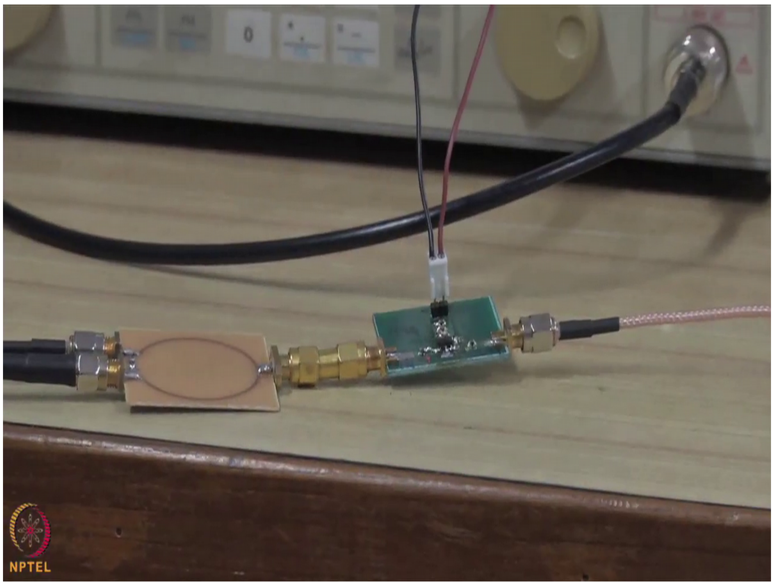

The setup contains the DUT under test which is the mmg amplifier which we have just seen at the input of the amplifier for IP 3 measurements we have to give two tone input which means two frequency input. This two frequency input is given to the input of the amplifier using a power combiner such that the there is a isolation between these two input frequency sources. This power combiner has been designed using the techniques that has been taught in this course and the isolation between these two course is around 25 dB.

The first tone which is at a frequency of 500 megahertz and an amplitude level of minus 5 dBm is given to one of the input of the power combiner. Now, make sure that the amplitude levels of these two frequency tones has to be very close to each other or nearly equal. The mmg is powered using a DC power supply with a 5.6 volt input and the current drawn is around 90 milliampere which shows correct operation. Now, with the two tones at the input of the amplifier we will observe the inter modulation distortion at the output of the amplifier and the IP 3 point is measured by measuring the level of the third order modulation products which is twice f 1 minus f 2 or twice f 2 minus f 1 frequency components relative to the fundamental frequency amplitude.

Let us see the response of this circuit on the spectrum analyzer display. So, this is how the output of the amplifier on the spectrum analyzer looks like. So, as you can observe there are two fundamental outputs which correspond to the two tone input signals and along with the along with those you can see various spurious signals generated and we are interested in the third order spurious signals or third order distortion signals which are at 200 megahertz and 1.1 gigahertz to the input signals of 500 megahertz and 800 megahertz. So, twice f 1 minus f 2 or twice f 1 will give us the values of 200 megahertz and 1.1 gigahertz.

Verify that we get some signals at this frequencies for that let us go to markers and we have marker m 1 you can move the marker like this, and you observe that at 200 megahertz we do have some signal is nothing, but twice f 1 minus f 2 where f 1 is 500 megahertz f 2 is 800 megahertz and at 1.1 let us see if you have any signal. So, even at 1.1 gigahertz we do have some signal at an amplitude level of minus 35 dBm and the TOI which is third order intercept point can be measured by using inbuilt functionality of the spectrum analyzer. For that again go to the major tab so click on this button measure and you see that you have a TOI function here just select that function and you observe that there are two markers m 1 and m 2 at the fundamental frequencies. So, m 1 is at 505 which is close to 500 megahertz, m 2 is at 800 megahertz approximately and m 3 and m 4 should be at the desired third order products.

So, let us move the markers slightly. So, that they are at the exact level. So, m 2 or m 3 I will move it to 200 megahertz, and m 3 I will slightly move it to 1.1 gigahertz, ok. And the third order intercept point as you can read from this line is 29.6 dBm. The data sheet mentions the TOI to be 32 dBm which is the output IP 3 point and the major value by using this spectrum analyzer and this setup is 29 dBm which is very close to the specified value.

Hello. Here we will be using vector network analyzer to measure input impedance, S-parameter, and VSWR, and phase. So, you have been taught many micro step circuits like power combiner, filter, coupler etcetera. In this case vector network analyzer suing is a two port vector network analyzer.

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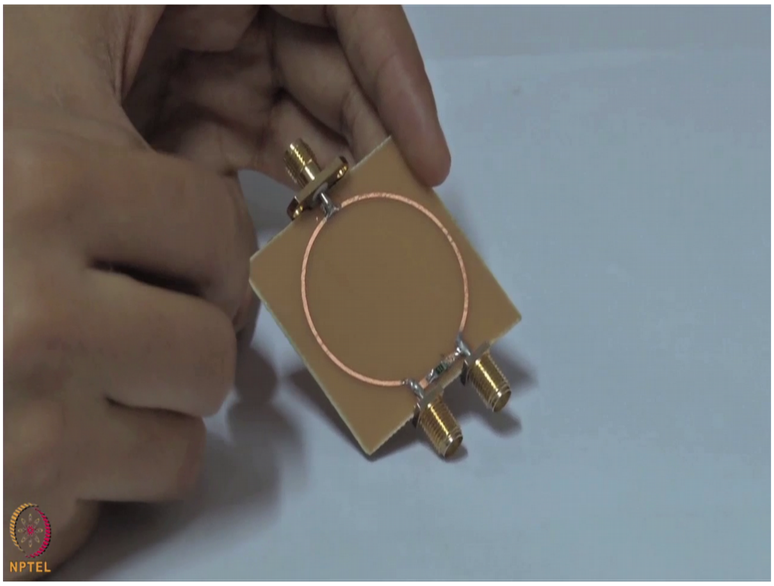

So, we will be using this power combiner measure the S-parameters input impedance and VSWR.

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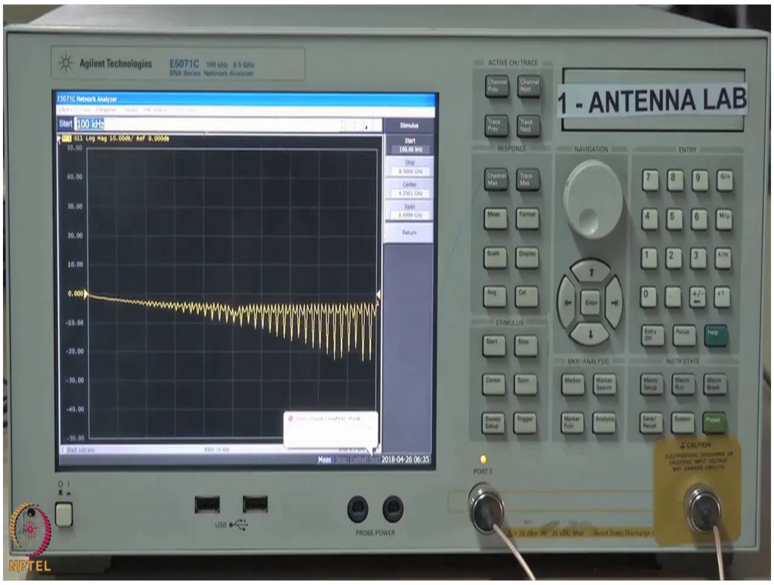

So, the vector network analyzer that we are using is E5071C, the frequency range for this vector network analyzer is from 100 kilohertz to 8.5 gigahertz. So, to a start the measurement firstly, you should be knowing about your DUT, what is the frequency range in which you want to do the measurement.

So, this device that I showed you power combiner is design for GSM 900 band the bandwidth that it provides is from 400 to 1.4 gigahertz. So, we will select the frequency range accordingly. In order to select the frequency range select start give the start frequency range that is 400 megahertz then give stop frequency range is 1.4 gigahertz, then you need to do the calibration. In order to select the frequency range use this option start click here then give the start frequency range that is 400 megahertz.

Then you find stop frequency range use this option stop give the stop frequency range that is 1.4 gigahertz. So, you have selected the frequency range, next you need to do the calibration. So, select cal then you should selected cal kit that you are using for the calibration.

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So, the calibration kit that we are using is 85033E. So, the manufacturer provides you open load and short terminals so firstly, I will tell you what is the calibration.

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So, the calibration accounts for the extreme condition like when the cables are connected to open load and the short, and the account for the losses in these terminals and then accordingly it adjust the measurement results. So, select the calibration kit you can use this option cal kit then select the cal kit that you are using, we are using the 85033E. So, we are selected this number then press calibrate.

Now, we know this is a two port network analyzer and we are doing measurement for power combiner or power divider. So, we need to do the calibration for two port. So, press two port calibration, then press reflection, then you should connect the cables with open load and short. So, first connect with open and then press this option then click on this option port 1 open. Next you connect the port 1 to short after connecting this cable with shot again click on port 1 short, then again connect this cable to load and then click on port 1 load and similarly you replicate the procedure for port 2.

Now, after doing the calibration for reflection you should check the calibration for how much power is going from this cable to this cable. So, use this transmission option and connect these tables using the female adaptor. Now, connect this adaptor to connect these cables you see here these are the cables which have SMA male on both the ends. So, connect these cables using SMA female adaptor. After connecting this, just click on this option port 1 to port 2 through we had just connected these cables. So, s 21 and s 12 ideally it should be 0, but it is showing some value which is because of the losses in the cable.

However, if you see s 11 and s 22 they are well below 20 dB throughout the range. After doing this just press done and disconnect the adaptor. So, after doing calibration this vector network analyzer accommodate the losses in the cable. So, here you can see this is s 11 is 0 you can also see s 21. So, it is less than minus 50 dB. So, it is calibrated. Now, you should connect your device to these cables to do the measurement you can also save this calibration state using this option save recall, then select save type state and cal then select state only and save state and you can define whatever name you want to define. So, I will just maybe the name as 1 2 3 4 5 and then enter. So, at the later stage n if you do not want to repeat the calibration you can we call this calibration state. In order to recall select save and recall then recall state and then from file dialogue box you can use the sate that you have saved, ok. Now, you connect these cables with the DUT.

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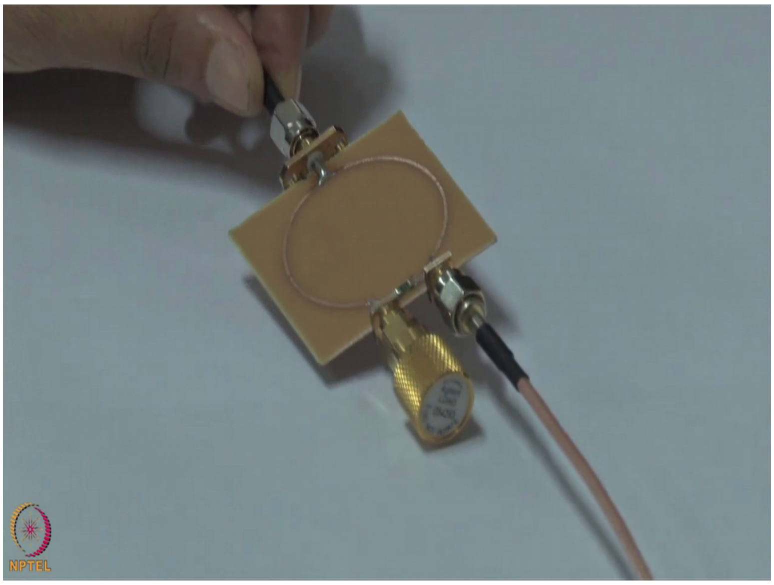

Since we have only two port vector network analyzer so we will have to terminate one port with load. So, here I have connected these cables at the two ports and I will terminate the third port with load, then you can see s 21 that is the transmission from port 1 to port 2. So, this is s 21. If you want to see s 11, s 21 all the transmission and reflection coefficient in one window then just select this display and select the number of traces s 4 and then you define these stresses. In order to define select measure then let us say for the first trace you will give the value s 11, for the next trace we will define s 21 and for the next trace again we will define s 12 and for last trace we will define s 22, ok. Now, after educating all the traces that is s 11, s 21, s 12 and s 22 you can see here all the transmission coefficient and reflection coefficient in one window.

Now, just to locate the value of these transmission coefficient or reflection coefficient select marker press marker 1, then you can move the position as per your desired frequency point, ok. So, our case just maybe selects 900 megahertz. So, here you can see the value of green curve that is s 22 at 900 megahertz. Now, if you want to see s 21 all you need to do is move to next trace, ok. Now, here you can see the value of s 21 is minus 4.4 dB. So, ideally this power divider should provide minus 3 dB, but this power divider is designed on FR 4 substrate which is lossy. So, that is why you are getting minus 4.4 dB, and s 11 you are getting minus 17 dB you can see here it is well below 10 dB throughout the frequency range. So, this is how you calculate the transmission coefficient and reflection coefficient.

Now, I want to show you that when you connect the output ports of these power divider how much will be the isolation. Now, if I connect these two cables at these two output ports and terminate the other port with the 50 ohm like this, then I should get the isolated power that is how much power is going from this port to this and that will be the measure of s 21. Now, you come to window here you the blue line or the pink line it shows you the value of s 21. So, if you just try to locate one more marker go to marker then select one more marker and then just try to locate it this give the value 700 megahertz and for marker 1 maybe give value 1000 megahertz.

So, here you can see that the isolation between these ports is less than 20 dB throughout this particular frequency range. So, we can say that the output ports are isolated. So, this is how you can measure the various parameter of your device whether it is a one port device or two port devices.

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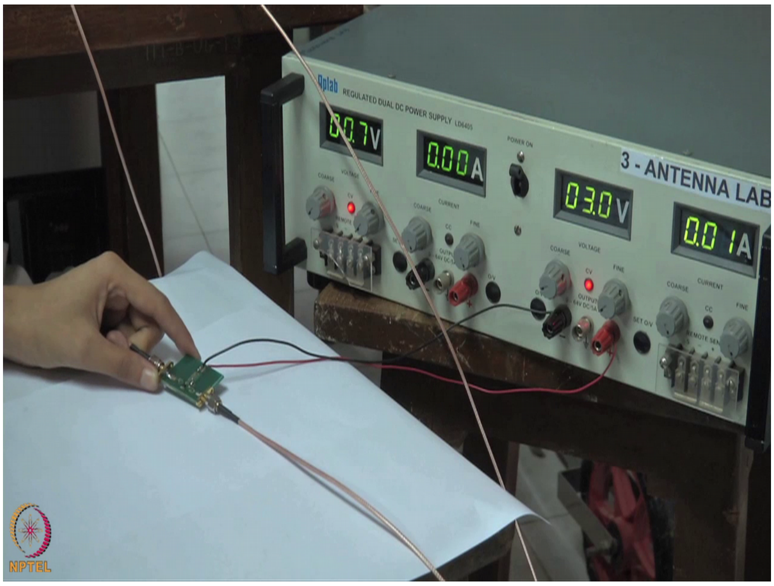

Now, we would like to do the measurement for active device. So, the active device that we are using is low noise amplifier. Here this is the IC of low noise amplifier the IC number is SGL 0622 the voltage requirement for this IC is 3 volt and it withdraws 10 milliampere current. So, here we have given 3 volt as voltage and the current withdrawn by this it IC is 10 milliampere. So, I have connected first port to the RF in of this IC and the second port to the RF output. Now, this vector network analyzer can receive the power up to 17 dBm. So, we should reduce the RF in power, so the gain for this IC is around 33 dBm. So, by default the network analyzer power is 0 dBm if we give 0 dBm power then it will show you wording because it will saturate. So, we will change the power level from this options sweep then go to power then give maybe minus 40 dBm, ok. Then go to measure and you see here.

If you see here it shows you the variation of s 21 and this is a variation of s 12 and this is the variation of s 11 and s 22. So, that is the reflection coefficient at input and output port and this is the transmission when the power is given to port 1. So, here you can see how much is the gain of this particular low noise amplifier by just locating the market. So, here you can see from s 21 that the gain provided by this particular low noise amplifier is around 33 dB at 570 megahertz. So, this is how you can check the gain of this active device in the frequency range of your interest.

To summarize at microwave frequencies instead of measuring voltage and currents against time or in time domain we measure the signal power and phase in frequency domain. And for different microwave circuits that we have been studying in this course we can measure the S-parameters, the gains, the noise figure, the linearity using spectrum and network analyzes. And we have studied how frequency, power, port parameters, impedance values can be measured simply using these test instruments. We will stop at this point.

Thank you.