Basic Tools of Microwave Engineering
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Lecture – 03
Measurement of Unknown impedance

The third lecture is Measurement of Unknown Impedance in Microwave Technology.

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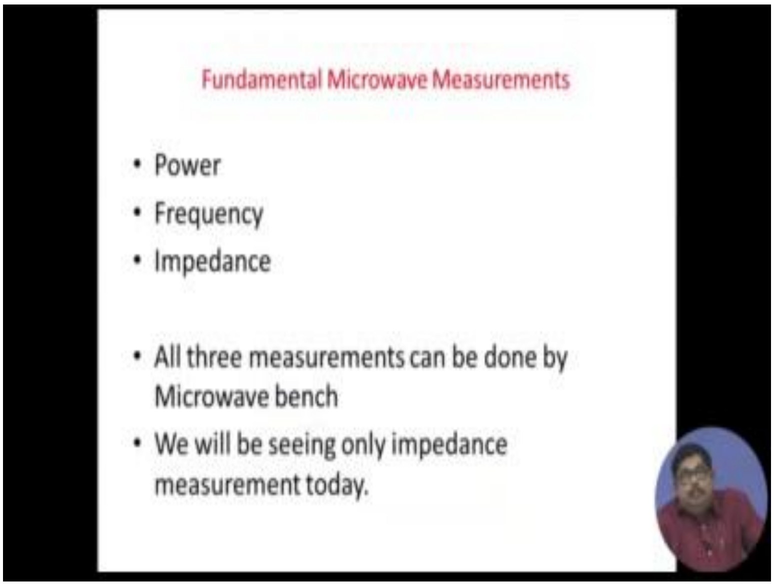

The fundamental 3 measurements are there, because if you want to know as I said that power is a fundamental quantity, also any ac signal description the basic fundamental quantities power. So, you should know how to measure power, also you should know how to measure frequency? Also as I said that impedance is a very important thing because by impedance actually you see both in low frequency and high frequency. This impedance characterizes a network.

It is in network does not get characterized by it is voltage excitation or it is current response etcetera, but the ratio of that; that means, whatever may be your response or whatever may be your excitation, the characteristic of the network is in built in it is impedance. That is why impedance plays such a major role in electronics and we have again said that amongst electronics engineers, RF engineers are very careful about impedance for impedance matching and having the optimum power delivery, these 3 measurements are necessary for understanding what is happening in any RF measurements RF circuit, and this can be done by a single set of apparatus called microwave bench.

Microwave bench can measure these 3 quantities so; however, that is a laboratory component, but here we will be seeing only impedance measurement in today because we consider this is the most important amongst the others because unless and until you know how to measure impedance, an RF engineer will find problem in his career.

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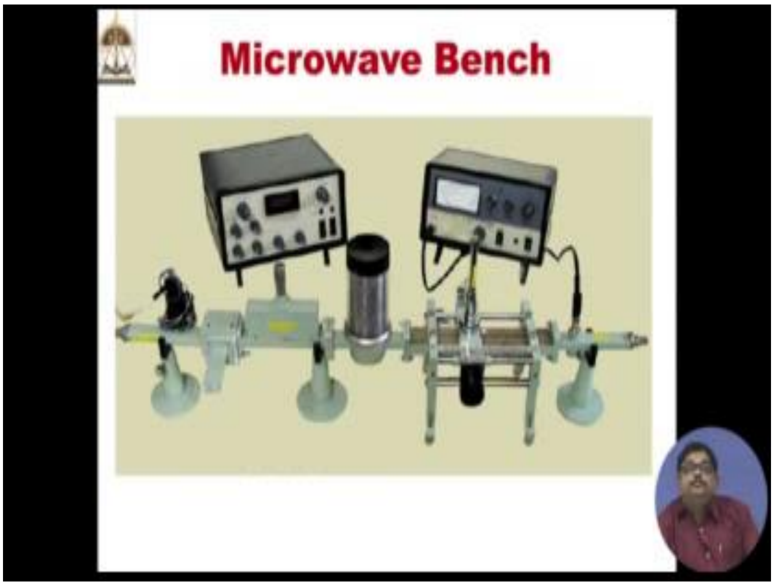

This is a typical microwave bench, I think all of you have seen it in your thing, you can see the left most side there is a this is a klystron source based microwave bench. Generally in laboratories you can have a klystron which is a vacuum tube it is a very stable tube for giving you some milli watts of power that is required in due to this experiments. But there is also a semiconductor counter part of that which is called Gunn diode whose power label power output is a bit low, but you know compared to a vacuum tube semiconductor is more rugged that is why that also is used.

So, here you can see the left the black one with something that is klystron source, after the source there is an isolator, the source needs to be isolated because any source is a low impedance thing, now, if any reflected wave comes then you know that sometimes depending on the impedance level of the load, you can have a power; you can suddenly if you have sizable amount of reflection lot of power can come to the source, and being a low impedance device it can be destroyed. So, isolated is a preventive thing for these, then after that there is a attenuator you can see that attenuator is for changing the power level of the whatever is flowing from the source that you can put attenuation,

Then you can see there is a cylindrical thing that is called a cylindrical microwave cavity. It is a frequency meter where reaction type wave meter also it is called. So, they are there are some graduations on the cylindrical body, and that is the your frequencies are read there this is a mechanical way of reading the frequency, but then we pass that to a wave guide section, a rectangular wave guide which is a basic transport mechanism mean high frequency, particularly in the Giga hertz range and if you have sizable power wave guide is the more not a coaxial transmission line.

So, in microwave generally the fundamental transport mechanism is the wave guide. So, that is why there is a wave guide with a slot cart at the central portion of that through which a probe is inserted. That probe which is a basically point contact diode probe that probe is connected to a meter, this is a new thing it is called VSWR meter. So, there are two boxes you are seeing. The right 1 is the meter where you see the waves various parameters particularly VSWR, which will come next and left side is the power supply for that klystron source.

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Functionally this is the slotted line with carriage this is the rectangular wave guide I was talking, you can see from the left side it is seen that this is a left side rectangular wave guide. But that probe that can move over there that is why there is a carriage. So, by that you can move it in that slot so; that means, you can think of these that on a transmission line you can vary your position of the probe. So, you can sense what is happening along the line, this is the rectangular wave guides thing.

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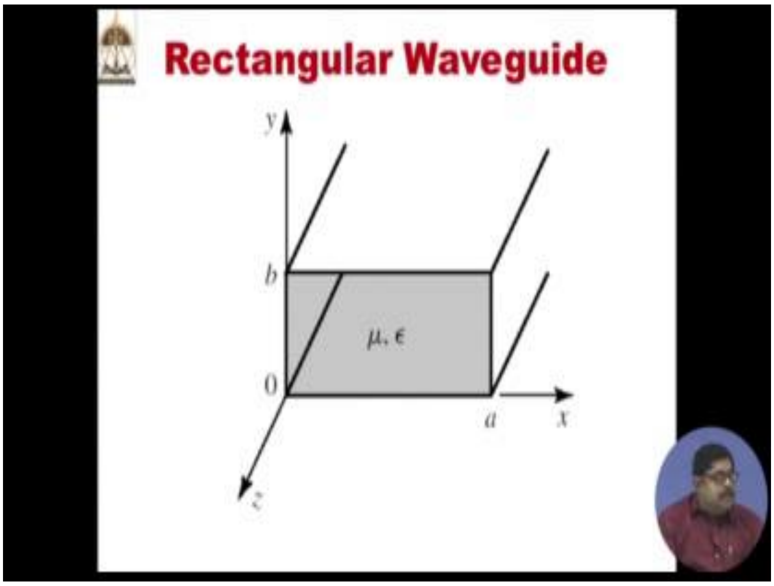

Now, there are some components used in the laboratory.

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These are also required in laboratory you can see adjustable shot adjustable load, bend, ridge guide, adapter instead of power that attenuator, variable attenuator then there are two fundamental things have seen shown here one is a directional coupler; which is very important actually this is the basis for separating these device can separate the a forward wave and reflected wave. And this is the basis of modern days replacement of this microwave bench which is called network analyzer and then you can all see a magic tee, there is nothing magic, but it is a wonderful device it can act as a power divider, it can act as a combiner, it can act as a summer, it can act as a differentiator all in one.

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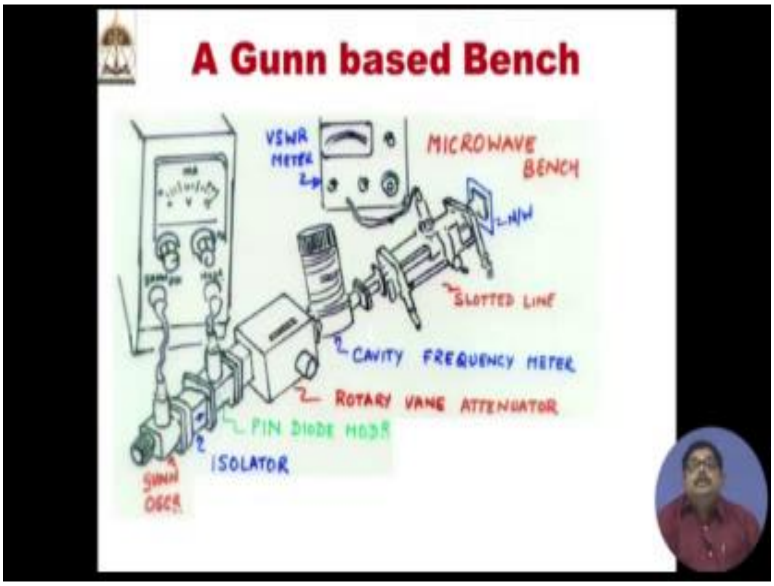

Now, this is a Gunn based bench, as I was saying that instead of klystron if you have Gunn, you Gunn this.

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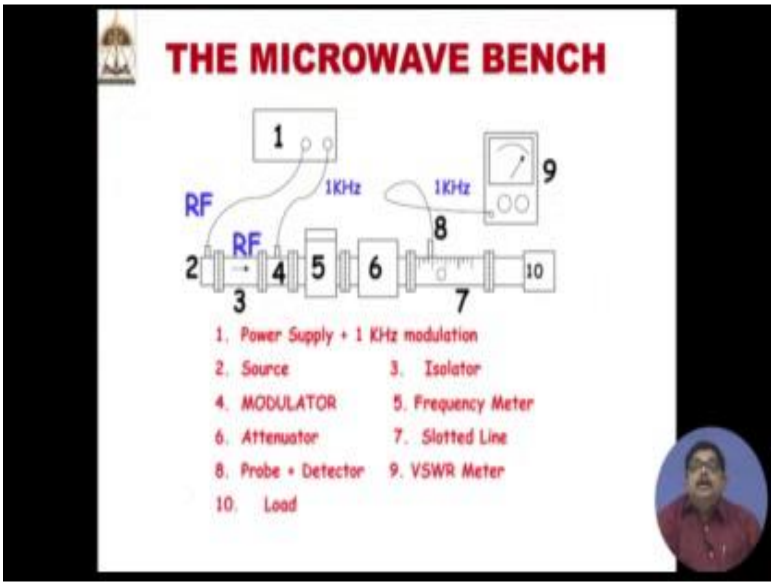

But basically if you look at that you can see these slide that same thing what we have pictorially shown. It is the same thing actually there is an RF source, but we are detecting that RF source with a diode. s I said point contact diode. So, which is on the carriage, the diode cannot detect your microwave, but it can detect a 1 kilo hertz signal.

We give a one kilo hertz modulating signal to the r f, and that is why it comes in with a modulation of one kilo hertz the diode can detect that, that 1 kilo hertz and gives you the thing. So, here we have shown which is the RF sections, where is the 1 kilo hertz thing, and you see the wave forms.

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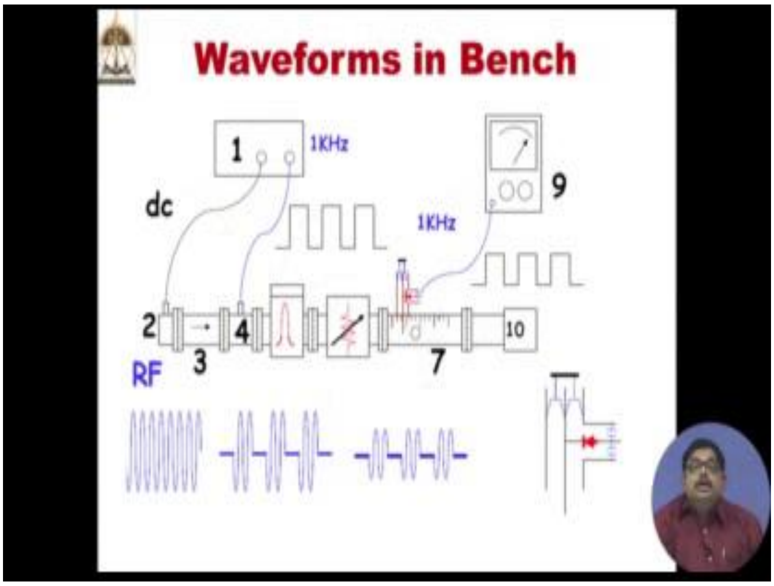

So, you have the RF thing coming from the klystron in the right, then after that after modulation that same RF waveform looks like the next one you see that, it is having some on off modulation of frequency 1 kilo hertz. So, it becomes the second waveform that is shown and then after attenuation it is like these.

Now inside the wave guides there will be this wave is go and it comes back, there is a standing wave created. So, we measure that standing wave thing also you can see the point contact diode detectors etcetera that is shown in this.

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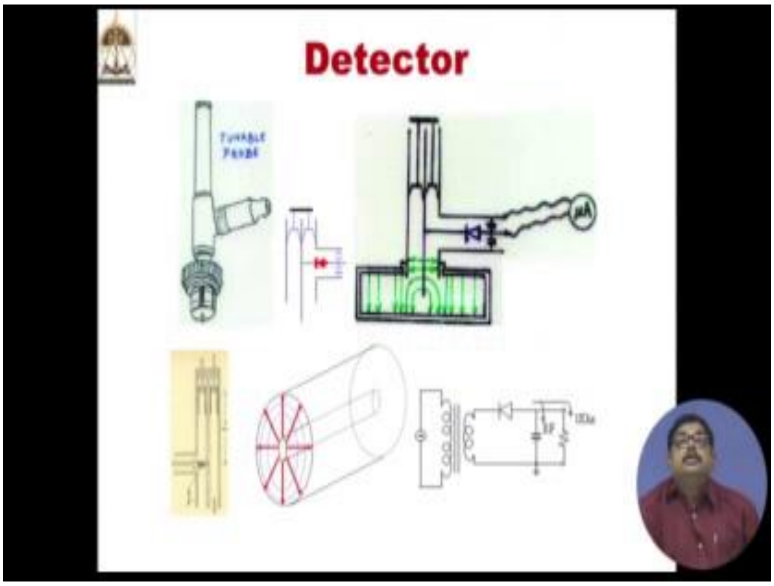

Now, you see the tunable probe we have shown here, this is the field distribution of the detector and finally, it is going to either yours. So, from the current we are sending from the voltage we are the diode is converting that to the current, that current is going and to the VSWR meter.

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Now, measurement of unknown load impedance let us come to our basic point measurement of unknown load impedance. So, the two things you need to know measurement of VSWR of the line so; that means, in that wave guide depending on with which we have terminated means if we go back to our actual diagrams.

You see that at the end there is a termination we give that is the load, what you what load we give depending on the voltage standing wave pattern will be created inside the wave guide and that VSWR, VSWR means voltage standing wave ratio, I think you know from your transmission line theory that it is defined as voltage maximum by voltage minimum the line.

So, that depends on the mismatch; that means, if you have a transmission line with characteristic impedance z naught. If the load is Z L then depending on that there is a standing wave created. So, one criteria one parameter for measuring that is reflection coefficient which we have seen reflection coefficient is z 2 or Z L minus z naught by Z L plus z naught, but another criteria, that a scalar criteria from reflection coefficient then reflection coefficient is a complex quantity, but a measurable quantity, scalar quantity from this is VSWR.

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Which is defined as VSWR is you know, v max by v min; that means, if we have a distribution voltage is varying. So, the maximum to minimum that is called VSWR, also it is related to the, we will see these thing we need to measure from the line and measurement of the minimum position, minimum shift in voltage minima for short and unknown load.

So, this is just to note actually we will discuss what that mean. So, when we see the procedure of the thing. So, if we can see the voltage minima what is the shift in that? In two cases one is if we put a short we will note down the voltage minima position, then we will change that and put a unknown load which we are trying to measure we will find out where is the minima we will note that position, that shift we are calling l mean. So, if you know these 2 you can find out the load impedance which is unknown.

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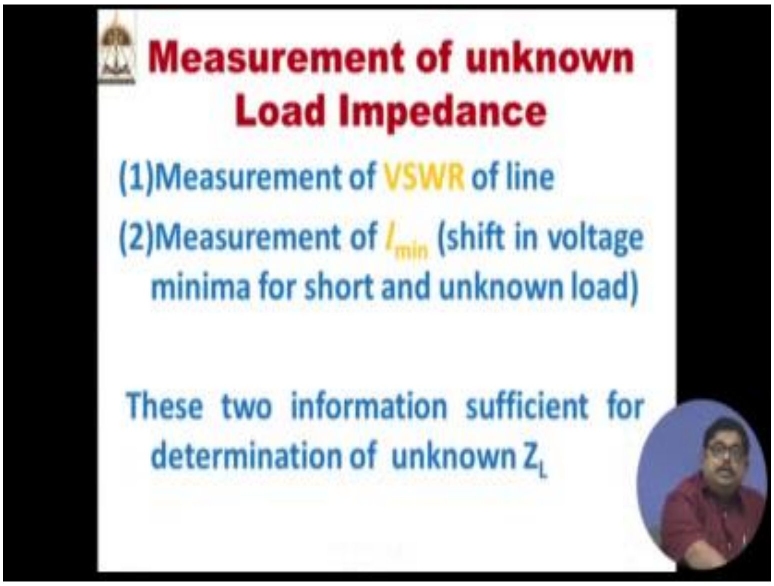

So, this first part; that means measurement of VSWR that is done by the VSWR meter.

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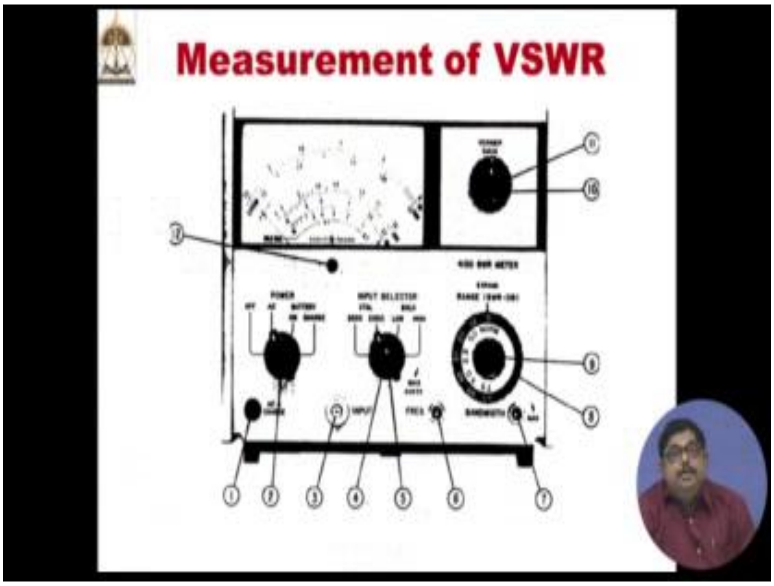

In the microwave bench we are already seen VSWR meter this is a better view of that. So, you have all used it in your labs, you will see that there are various power knobs. So, by that you can connect an AC power or external power etcetera then you can also find out the probe that you are connecting, depending on that probe, that you can get proper impedance.

There are input selector, there are 100 k or a 100 ohm etcetera; that means, depending on your the direct contact probe it is impedance you can change these point, then you can see that number 3 is the input; that means, there you connect the that through a BNC cable you connect from that slotted carriage the signal you take it in input to this, then you can change the frequency of operation; that means, we have seen that you are taking a 1 kilo hertz signal now that frequency you can slightly adjust by the frequency knob which is number 6 and then, number 7 is bandwidth of that signal, 1 kilo hertz is the center frequency.

But there you can play with the bandwidth also, but these are not more important, but the more important at this range knob, that 8 and 9 by which, you give that what are the in d b scale. How much where what VSWR you are giving there and another important thing is these; 10 and 11 those are the gains. Suppose if you are not getting good amount of signal. So, you can give these VSWR meter a gain actually this VSWR meter is nothing, but a tuned amplifier whatever voltage is coming it is amplifying it and showing you, like a tuned amplifier sort of thing and there is the display and also number 12 is the that display all displays you know that, sometimes require a mechanical offset thing because when no signal is given you will means see some reflection. So, that needle that spring needs some mechanical adjustment that is number 12.

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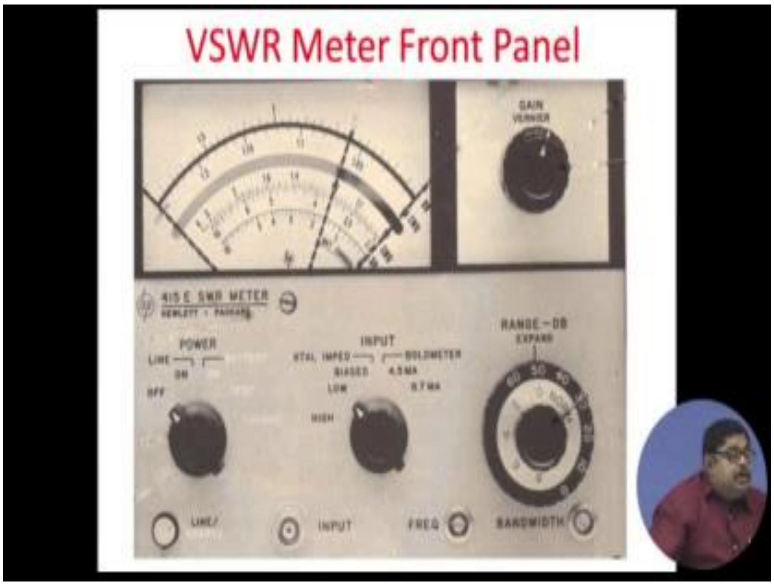

Now, VSWR is measured by this VSWR meter, you can see whatever I said that VSWR meter front panel. So, same model seen more or less and you see that you can measure in that display what is the value of VSWR.

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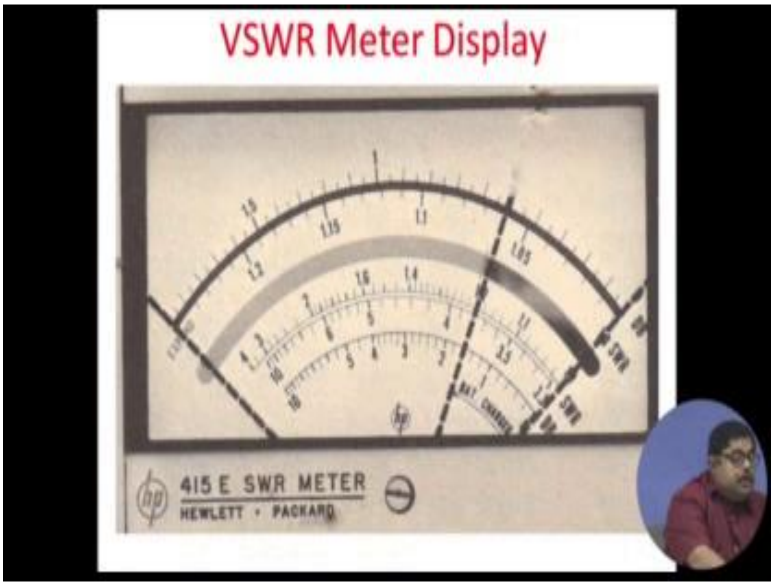

This is the VSWR meter display. It you see the right hand side is the VSWR, I think you know that you can vary from one to infinity, if you have a match load then VSWR is 1. If you have a short or open VSWR is infinity. So, 1 to infinity this scale, but at 1 both they are not giving that scale.

So, the topmost 1 is 121.2 or 3 something they are giving. Then if you have more VSWR you switch over to 1 to 4. If you have more you can switch over to up to 10 etcetera. More than ten generally we do not measure. Though theoretically it can go up to infinity, but in that time there is no point because that circuit is useless, if you have so much of.

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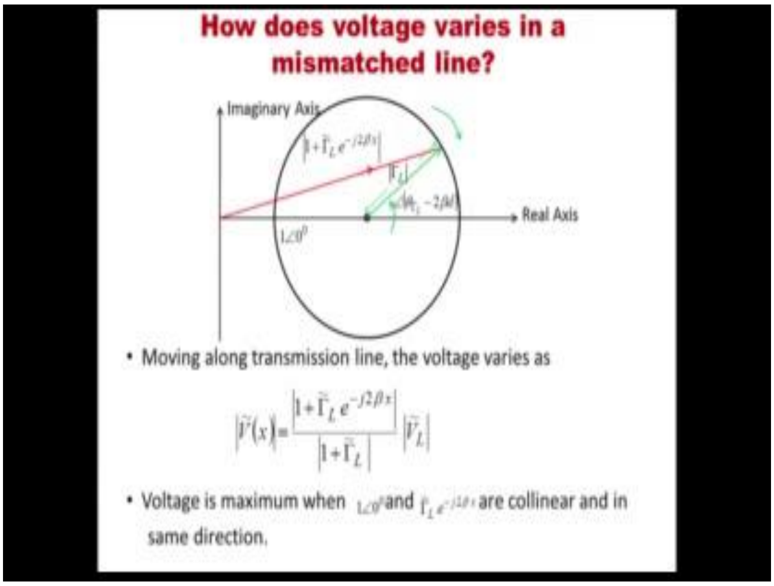

Now, these I just ask you to replace your transmission line thing, and in a trans this is transmission line stuff, that if we move along the transmission line, you can find out these that you see any good transmission line theory book and the voltage in the line voltage means this total voltage; that means, the incident voltage plus the reflected voltage that is called the total voltage.

That is given by this formula that v x it is magnitude, v x is a phasor it is magnitude is one plus the load reflection coefficient e to the power minus j two beta x where x is your distance from the load, load is at x is equal to 0. So, you are at whatever x is equal to distance then the denominator is 1 plus gamma l and then the v l is the voltage at the load. You know that in a transmission line if I move along the line from the load towards generator then, the whatever the voltage I am seeing at load then everywhere the voltage is changing that is called line voltage.

So, everywhere the current is also changing, everywhere the impedance line impedance is also changing, but in the whole game one also the reflection coefficient; line reflection coefficient also changes, but who is invariant the invariant quantity is VSWR that depends on the mismatch at the load and this voltage will change, but v max by v min this ratio VSWR that is invariant. So, if I move along the line VSWR does not change, that is why if we can measure we can find out what is the load. So, voltage will be maximum if you look at these the variation along the line; that means, the x variation is coming from the numerator only that 1 plus gamma l e to the power minus j 2 beta x that is the only variable thing others are all constant because load deflection coefficient is load sting.

Once I start moving the variation is the upper 1. So, maximum of that you see a 2 phasor, 2 vectors or 2 vector quantities are 2 phasor quantities; 1 is 1 0; that means, a real axis line and another is gamma l e to the power minus j 2 beta x.

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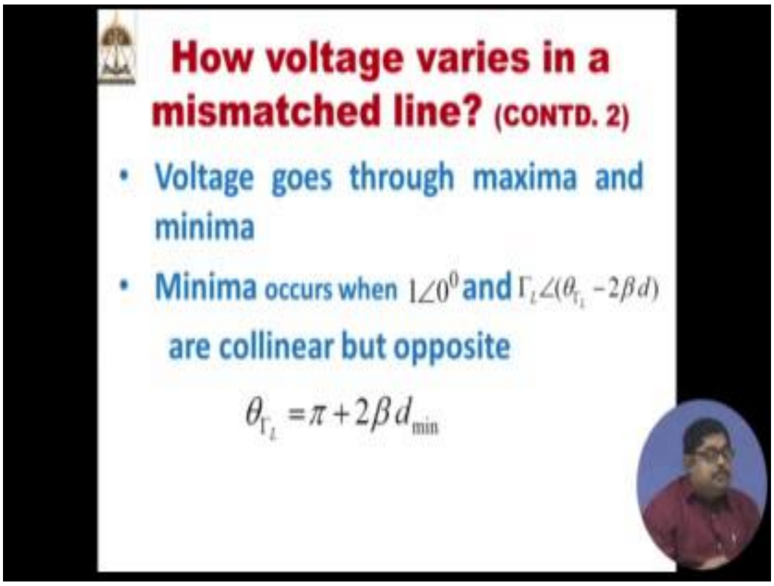

So, actually gamma l it is a complex number. So, we can call it as gamma l bar some angle that we are calling theta gamma l and then you see that e to the power; that means, I will get a 2 beta d. So, this 2 beta d or 2 beta if I have a distance d.

In the phasor diagram this is called crank diagram. Here we have shown that that 1 is your 1 0 phasor and then there is it is summed with another phasor of the green one. So, the resultant is this red 1 phasor. So, that is changing the maximum value of that when that red thing will fall on the real axis; that means, you will be collinear with 1 0; that means, when both these red and green they are collinear you will get a voltage maxima, when they are collinear, but opposite; that means, the after another 180 degree rotation the green one will be oppositely directed to 1 angle 0.

So, that time we will get voltage minima. So, voltage is maximum when those 2 are collinear and same direction. So, now, we can see that there will be voltage goes to maxima and minima if we move along the line. Minima occurs as I said when these 2 phasors are collinear, but opposite.

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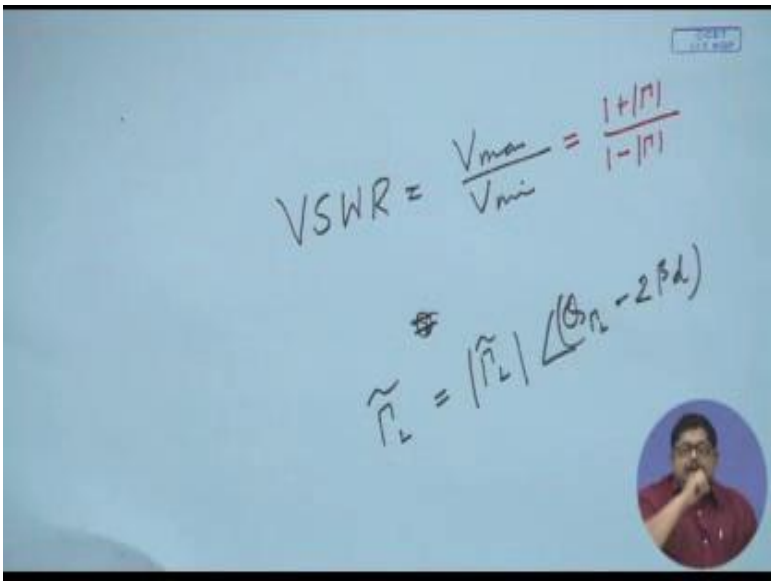

So, you can do that; that means, opposite means this theta gamma l minus 2 beta d that should be a angle pi then, only they will be the 2 phasors will be opposite. So, from this you can find out this theta l is pi plus 2 beta d we are calling that d minimum.

So, voltage goes through maxima and minima minima occurs we have seen and also we have seen that whole game will be if the phasor covers a full rotation full rotation on the any phasor rotating full means, actually it is by a rotation of lambda g by 2. Where lambda g is a guide wave length along line, voltage minima repeats every lambda g by 2 along line. So, what is the maximum value for that, this v max if you do now that, when they are collinear if you put that value it will come out that v max is this and v mean is this. So, this ratio v max by v min it is given by this.

So, when we wrote earlier that, VSWR is this thing, you see we have defined these, now we are finding that in any general transmission line it is related to the reflection coefficient as 1 plus reflection coefficient's magnitude by 1 minus reflection coefficient's magnitude. So, you see that VSWR which we said that it is constant along the line it also is related to reflection coefficient. So, it is as we know from our smith chart knowledge that. So, it is also related to the impedance. So, from these we can always find out the unknown impedance if we know VSWR and it is a measurable quantity. So, that is there.

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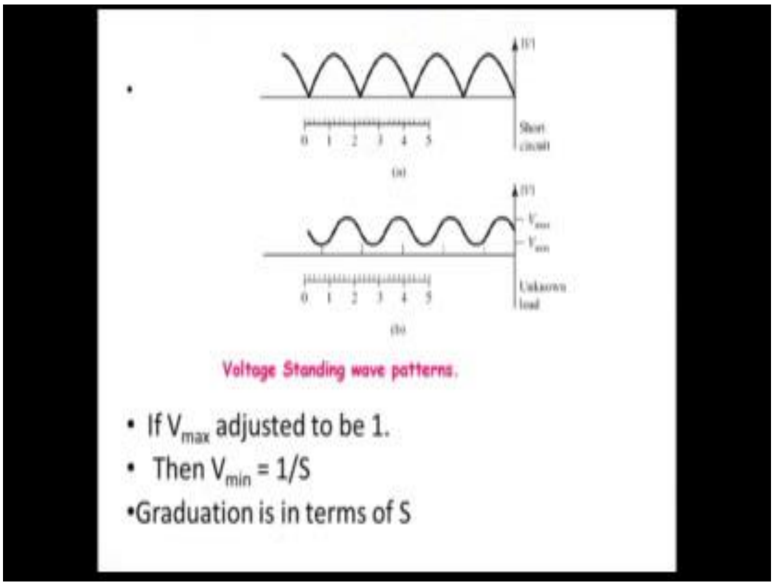

So, what is done that as I said that first you put a short circuit as a termination. So, you see the upper graph that from that you know that if you put a short circuit, there the voltage will be 0. Then if you move along the line towards generator, it will go to maxima, minima and that thing is from this crank diagram it can be proved that you will have a variation like that. So, in the carriage of the microwave range you have these scale attached. So, from that you can find out what are the positions of the minima when, I have connected short circuit then you remove short circuit and put an unknown load.

Obviously; if this load is not short or open or anything, it will also have that standing wave pattern only thing is at that position in a short circuit at the position of the load. We have a 0, if you have an open circuit at the position of the load you have an infinite value of volt or voltage maxima, but in an unknown load in general load you have something it may be maxima, may be minima. So, it will be there that you see we have the second graph is showing that how it looks like for an unknown load, but here also you can find out by moving your probe that what is the minima position. What is the maxima position? look at those minima.

Now, to make VSWR measurement you need to do a calibration that calibration is you you first find out in when we have connected the load what is the maximum voltage you are getting now v max now you there are gain knobs and others in the VSWR meter. So, you make it adjust to one the moment you adjust to one then v minimum that becomes one by s you can see from here that, when we have said these that you see if I make v max one then basically v minima is becoming one by s. So, that is what we are writing that v minima is one by s now the VSWR meter scale is graduated in terms of this s s tends for VSWR. So, from here you can measure that.

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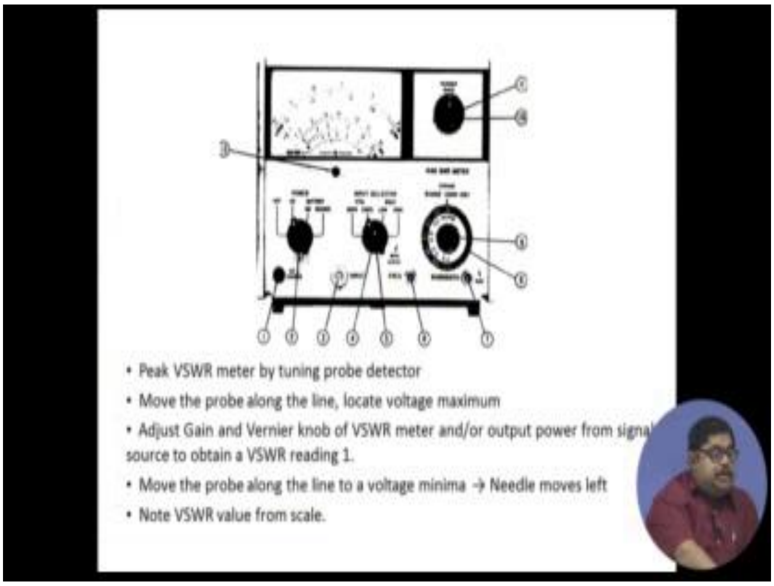

This instrument helps you to measure VSWR, what you do again I am repeating the procedure peak VSWR meter by tuning your probe. Move the probe along line locate voltage maximum, adjust Gain and Vernier knob of VSWR meter or output power to obtain a VSWR reading one move the probe along the line to a voltage minima; that means, you are moving your needle is on the VSWR display is moving left and the point where you are getting minima then note the VSWR values from scale that is the VSWR of the line.

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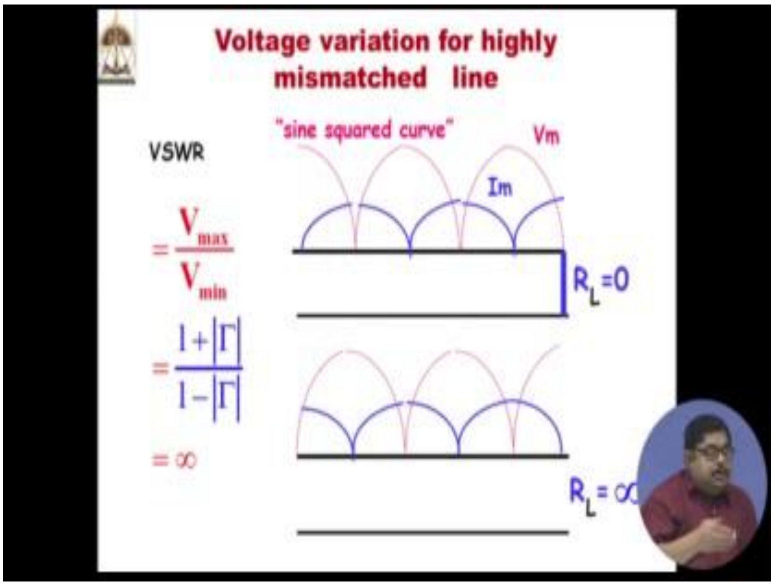

So, this is shown here that how the voltage the red colored one voltage varies for a shorted one how it varies for open one, how it varies in the general case this we have already seen.

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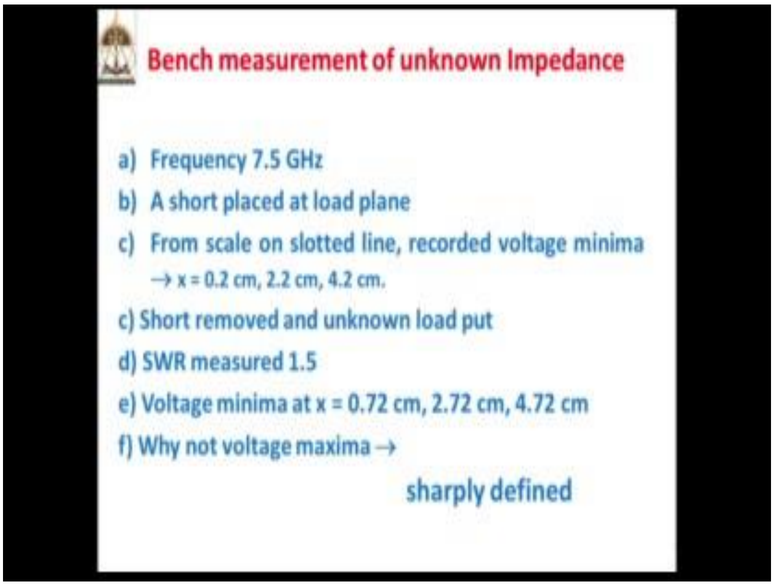

Now, typical measurement scenarios suppose frequency of operation is 7.5 Giga hertz, a short placed at load plane. Let us say we have done this experiment let us say this is recording of one of those students here measured. So, recorded when the short is placed at load plane the scale minima positions he has noted like this short removed and unknown load put VSWR we measured by the method we said let us say it is one point five voltage minima.

Now, the voltage minima is shifted. So, he has again find out these. So, now, here one question, that why we not why we measured the minima's we could have measured the maxima also both of them repeats after a lambda g by 2, but you have seen that maxima near that if you do the derivative of the curve which is a sensitivity for maxima it is 0 Because near that curve the slope is 0. So, if you perform an experiment there and suppose you miss the maxima the error committed will be it is very insensitive the probe is there whereas, in place of minima the sensitivity the slope is quite high that is why the sensitivity of the measurement is good.

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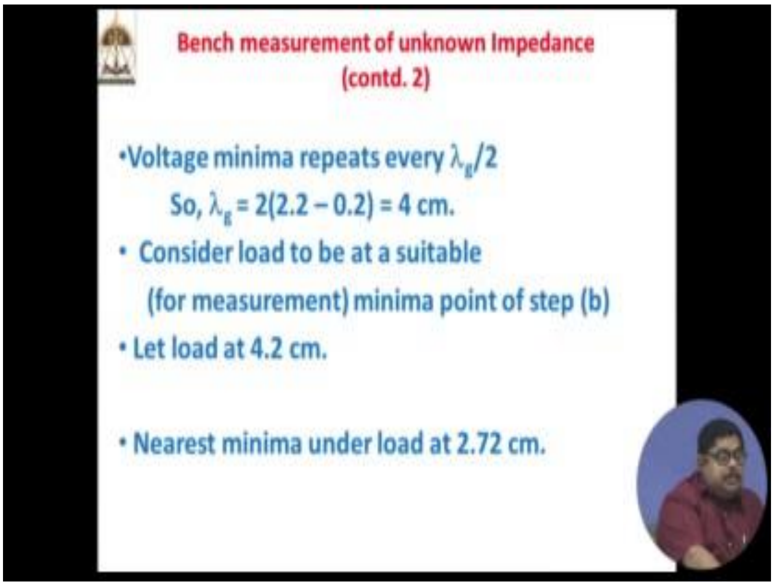

So, that is why instead of maxima we always measure the minima points. So, because it is sharply defined the voltage is at the maxima, it is flat that is why it is not, sharply defined. So, let us continue that measurement voltage minima repeat every lambda g by 2. So, we can find out by finding the difference between 2 minima position we can calculate what is the lambda g in this case it is coming out to be 4 centimeter.

Now, consider. So, let load be at 4.2 centimeter actually load position is not accessible to you have seen that because, in the carriage where the load is put the scale is not there, but since everything is repeated. So, you can find out any one as the minima there are several minima's any one you take. So, that is what we have said that let we take that load it at 4.2 centimeter. So, when we have changed that to unknown load then nearest minima under load is at 2.72 centimeter only thing from the curves I have shown you will have to find out that whether, it is that when it is getting changed suppose this minima is changing if I take this minima, you see that these minima is towards load it is shifting. If I take these minima from here it is towards generator, that you need to be careful in the measurement that whether it is that.

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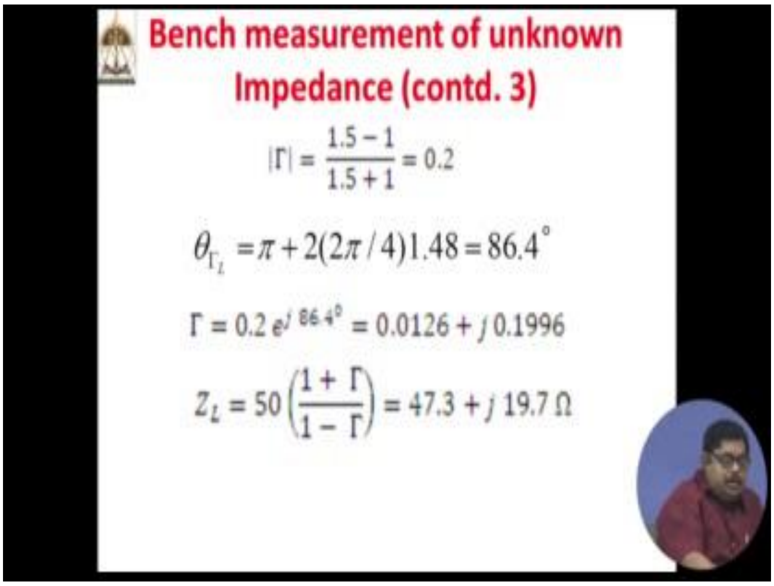

So, from this I have got that l min which is 1.48, I have noted it towards generator then here we are not taking the help of Smith Chart, you can do these calculations that, gamma magnitude reflection coefficient magnitude is related to VSWR by this, this is the formula that we have seen VSWR is equal to 1 plus gamma by 1 minus gamma. So, it will change the sides gamma is equal to VSWR minus 1 by VSWR plus 1.

By this you are getting this 0.2 is the reflection coefficient magnitude then theta you can find out because beta means 2 pi by lambda we have given frequency from that you can find lambda and we have to see that shift is 1.4 centimeter. So, angle wise it will come as 86.4 degree then gamma will be gamma magnitude into e to the power j 86.4 degree. So, that if you convert two rectangular things it will be like these. So, you have got gamma now Z L the reflection coefficient is related this is the basic relation of Smith Chart. So, this is always true. So, what is the corresponding Z L this is this. So, you can find out the unknown value of the impedance.