Basic Building Blocks of Microwave Engineering

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Lecture – 16
Microwave Detector and Switching Diodes

Welcome to the 16th lecture of the course on basic building blocks of microwave engineering. Now in previous three modules we have seen first the characterization or model for the microwave transmission. Then in the second module we have seen various transmission structures, which can carry microwave signal.

In the third module we have seen various passive microwave devices used for playing with microwave power divide combine etcetera, and in this final module we will see some active microwave devices, which are used for various operations in microwave circuit. In this particular lecture, we will see the active devices used for detection and switching.

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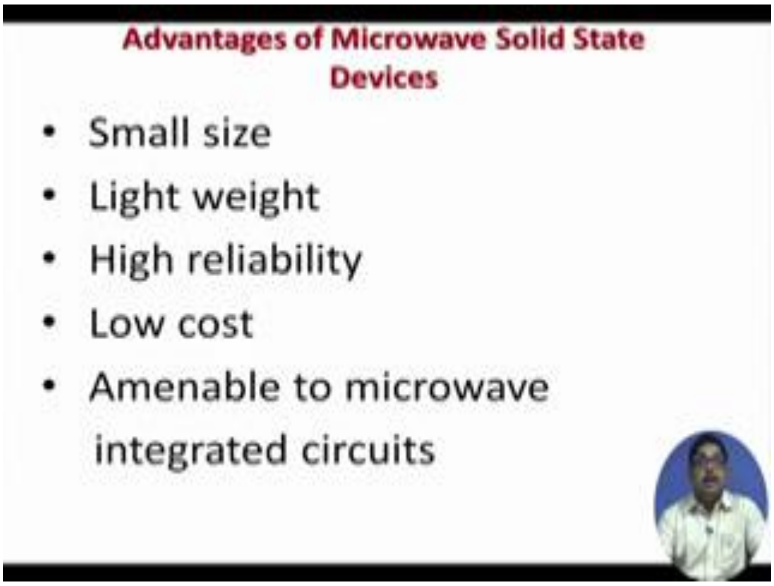

Now, advantages of microwave solid state devices that they are small size, they are of light weight, and a solid state device, they have high reliability, they have low cost, and amenable to microwave integrated circuit is; that is why solid state devices are heavily used in microwaves.

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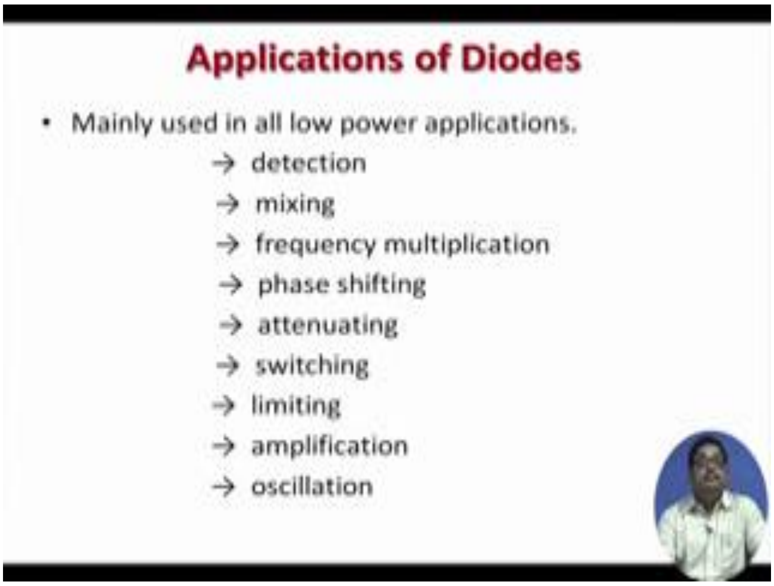

Now, first we start with diode, the simplest solid state device. now mainly used in all low power applications in microwave, like for detection, then mixing; that means, changing the frequency of the signal, then frequency multiplication, phase shifting, attenuating, switching, limiting, limiting the amplitude, amplification, oscillation. So, diode can do all that

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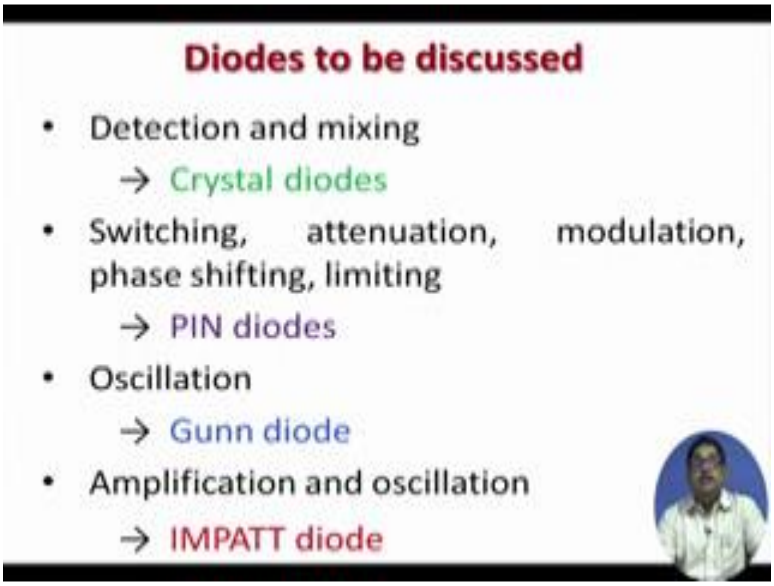

Now, in this lecture the diodes that we will be discussing. We have chosen few applications which are important. First, for detection and mixing generally crystal diodes are used. So, we will see crystal diodes. So, there are other diodes like Schottky diode etcetera. Then for switching operation actually, the switching is also called modulation that for one off switching the attenuation, modulation, phase shifting limiting, PIN diodes, are used. So, we will see PIN diodes in microwave. in a typical microwave bench this PIN diodes are used for one off modulation of RF signal by a 1 kilo hertz signal, because the detector is crystal diode that cannot detect the high frequency signal, but the one off modulation of 1 kilo hertz that it can detect, and the b s w r meter is also tuned amplifier, tuned at 1 kilo hertz.

So, PIN diode does that modulation, actually it is on off switching. So, that will be discussed. Then we will see oscillation. So, for oscillation solid state diodes are GUNN diodes. So, we will see that. Also we can have use IMPATT diode for oscillation, and also for amplification this impact diode can be used. So, we will see these four diodes in this lecture. Out of that the GUNN diode and IMPATT diode will be discussed in a subsequent lecture, but in this diode basically will be seeing the first two diode, detection, detecting diode and switching diode, mainly crystal diode and PIN diodes.

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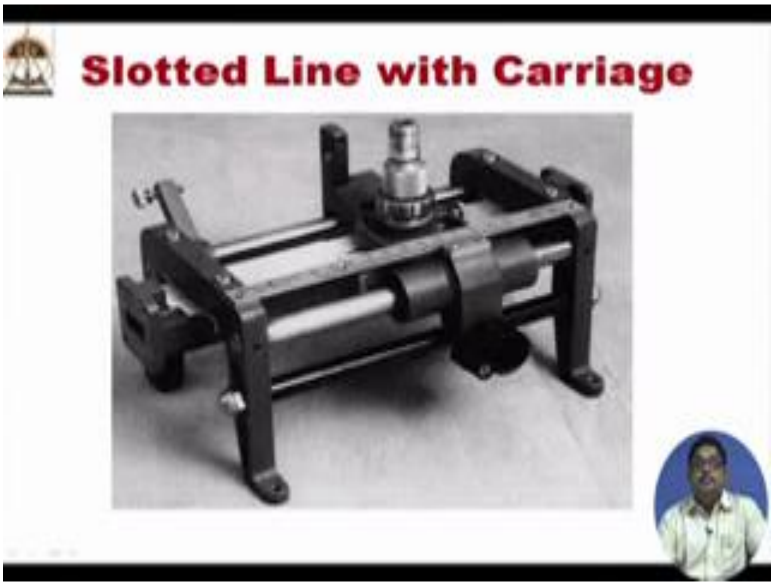

So, this is the picture of a crystal diode, very simple structure. now you see this is familiar that in, this is the slotted line the wave guide, that is the slot card there, and this is the mount in this the detector feeds, so that detector can detect. We have discussed in case of rectangular one zero modes that in the middle we cut a slot. So, there is a slot card and in that slot, this carriage when it moves basically the detector is moving, and it can sense the electric field. Electric filed is also highest at the minimum. So, it has a good sensitivity to detect that.

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Now, this is a typical microwave bench. Here you see that these this is the detector diode is here inside this mount, there is a coaxial mount and from that sorry. This is the detector diode here, and to this detector diode the signal is taken to the.

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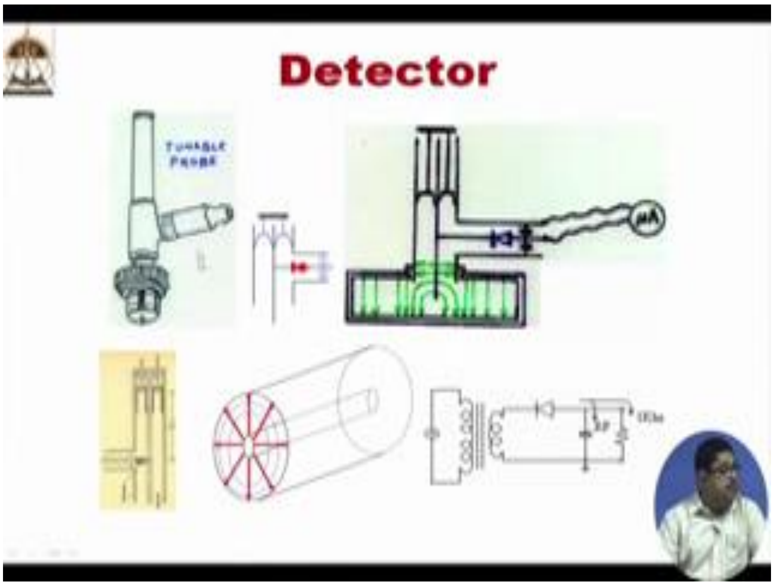

So, this is the detector diode and through this it is taken to the p s w r meter, for finally, displaying. So, detector this is the, you have a tunable probe. Now inside that you see this detector is there, and when the detector is sensing, it is basically sensing the field here in the slot there, it is sensing that field that is taken and then it is taken to either an emitter or a p s w r meter. So, it has an RF by per stroke and 1 kilo hertz signal is per square. So, RF signal is bypassed here, whatever RF signal is still present after detection that is choked here. So, this is the diode detector diode you can see this is the tunable probe.

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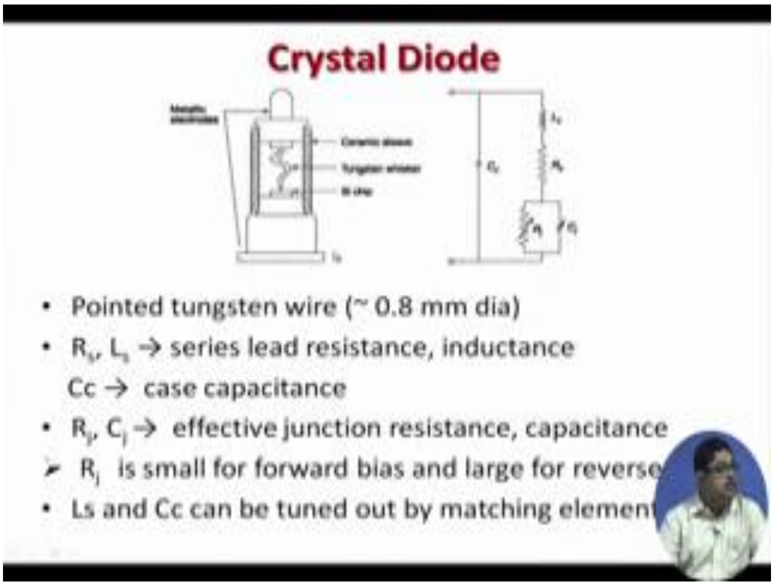

Now, what is this detector? This is basically a crystal detector. There is a pointed tungsten wire. So, this is also called sometimes point contact diode. Diameter is roughly 0.8 millimeter dia. now this is a silicon chip, the tungsten make a contact with that silicon chip, and that access diode metal and silicon. So, just like Schottky barrier you have this semiconductor and metal they are contact, so you get a diode there. Now in the diode circuit already with the diode there are leads etcetera as you can see in metallic electrode etcetera.

So, in high frequency you know that they give rise to the some inductance and some resistance. So, the leads etcetera of the diode, they give this L s and R s, but basically this is the diode. The diode any semiconductor junction, so you have a resistance there in the junction also, you have the capacitance because that is in the junction there is a gap created. So, that is why r j and c j, and r j is small for forward bias that is the diode and large for reverse bias. Now, this l s also there is a throughout the thing there is a coupling capacitor. So, l s and c c can be tuned out by matching elements. So, what remains in the circuit is basically this resistance, lead resistance and this r c circuit, parallel r c circuit of the junction.

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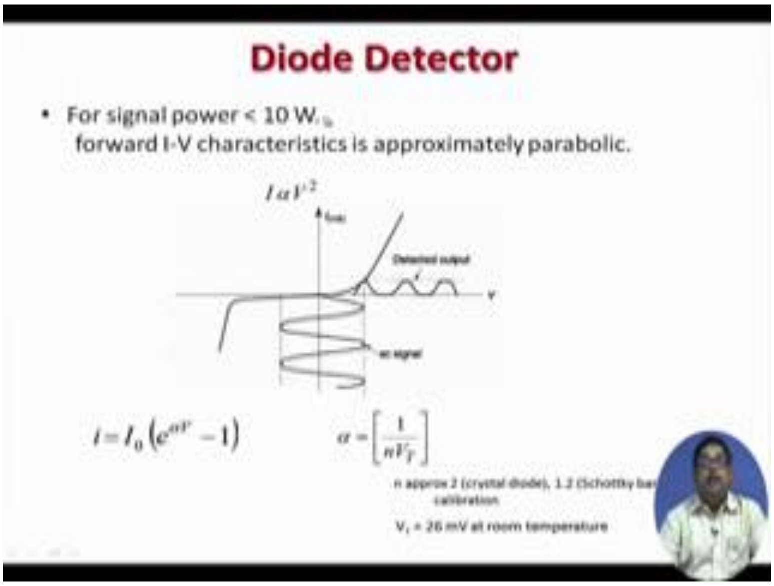

Now, diode detector this up to 10 what of power it can handle, it can detect. So, it is I v characteristic is a well known I v characteristic of diode, and you know that at very, in the forward bias region, just when the signal is small, you have this is I is proportional to b square this is the (Refer Time: 08:44) region, after that when the signal is further increased this becomes almost approximately the linear region, so that is why below this 10 watt up to this you can use the diode. Now this is the famous diode iteration all knows that I is equal to I naught (Refer Time: 09:03) circulation current e to the power alpha v minus 1. This alpha all of us know that it is 1 by n v t, v t is the thermal equivalent voltage; that is 26 milli-volts at 17 degree rooms temperature, and n is a parameter it depends on the diode

Now, for crystal diode it is approximately 10. For schottky barrier diode it is 1 1 2, 2 2 4 applies for various diode, but for crystal diode it is 2, but still it is not always 2. So, since it is precisely if you want to measure the signal, we have an experiment in our lab that calibration of this. So, basically what we do with the diode, we put it into the various voltages and note the currents in an emitter, and plot this graph and from the slope of the graph we find out what is the value of n. now typically in all labs we get 2.2 2.3 in that range, but; obviously, it is voltage dependent. So, of the voltage of a particular source, you can always calibrate the diode, that gives accuracy to the detection.

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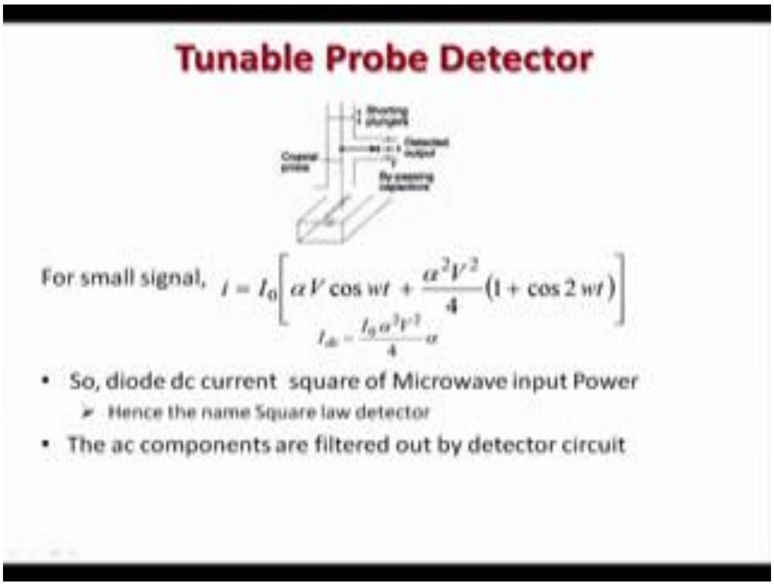

Now, this is what is showing, now this is the coaxial probe is there. So, the there is a probe the inner conductor with that the diode is connected, and then you have this signal taken. Now there is this diode, then detected output, as in that circuit I explained the bypassing capacitances is; therefore, putting the RF etcetera and also there is a shorting plunger. So, by this you can just move the penetration dip of the diode, because sometimes you do not get good signal that time you penetrate it further. So, that you can send some signal, but it is always advisable to very loosely penetrate it, because if you penetrate much, this coaxial probe that field will disturb the actual diode field, but if you do not get signal; that means, signal is weak, that time you need to penetrate it further.

Now for a small a c signal we know that we have I is equal to I naught this, but there are also higher order term, because diode is basically that portion is a non-linear thing. So, you can, if your signal is b equals omega t, you can put it into this series. This is actually taking some higher order term, and from there I can see that the d c signal; that the diode sends you that are proportional to v square. So, diode d c current square of microwave input power; v square means microwave power. So, the diode detection's in d c current that is square of microwave input power. Hence the name this is also called square law detector. So, a c components are filtered out by detector circuit that we have already seen, that this higher frequency is harmonic this calls omega frequency to omega frequency, they are filtered out by detector circuit.

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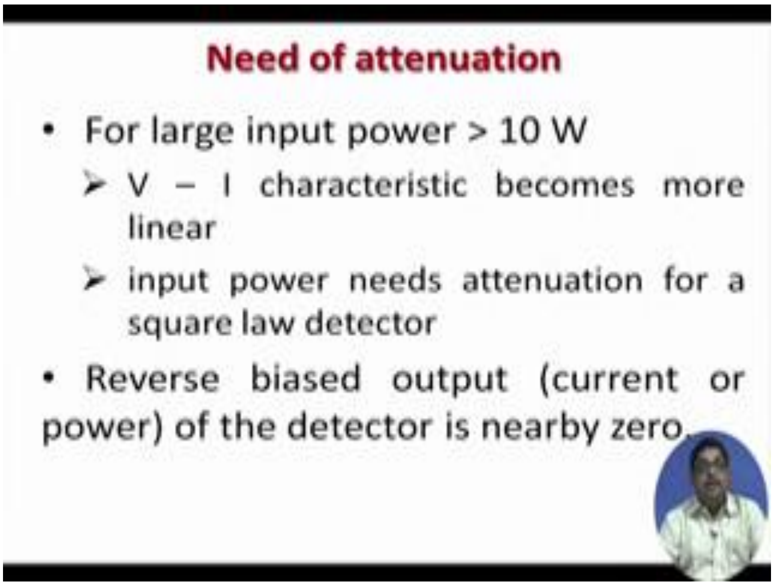

Now, for large input power greater than 10 watt, the v I characteristic as we have already seen that they become more linear, the square law does not hold there. So, that is why if you want to use it in that case, please attenuate the signal, so that typically it is below 10 watt or from your whatever purchased I v, or purchased detector diode ,you see the I v characteristic roughly where it is up to which it is square, to restrict your input power to that, and; obviously, in the reverse bias output case; that means, when you have a reverse biasing on a modulation that time it is, it does not detect or give us any power it is current, so nearby zero.

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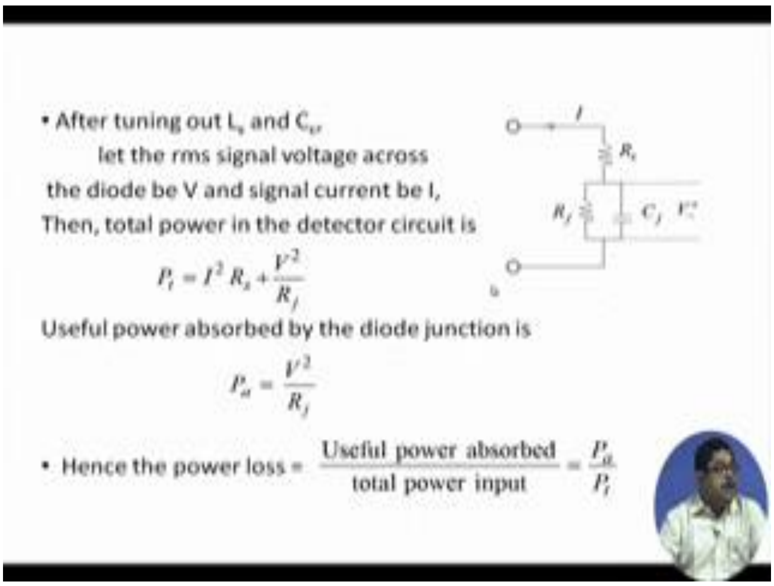

Now, as we said that we can tune out externally that l s and c c, but this circuit remains. So, this is the diode detector circuit. So, let us assume that the voltage across the diode sensed; that is v, and diode has created a current i. So, total power that has come to the detector circuit we can easily find p t total power is, I square r s plus this v square by r j, and useful power absorbed by the diode junction, we can write that p a is power absorbed; that is v square by r j. So, power loss is, useful power absorbed by total power input, so p a by p t, and that expression if we do it is like this.

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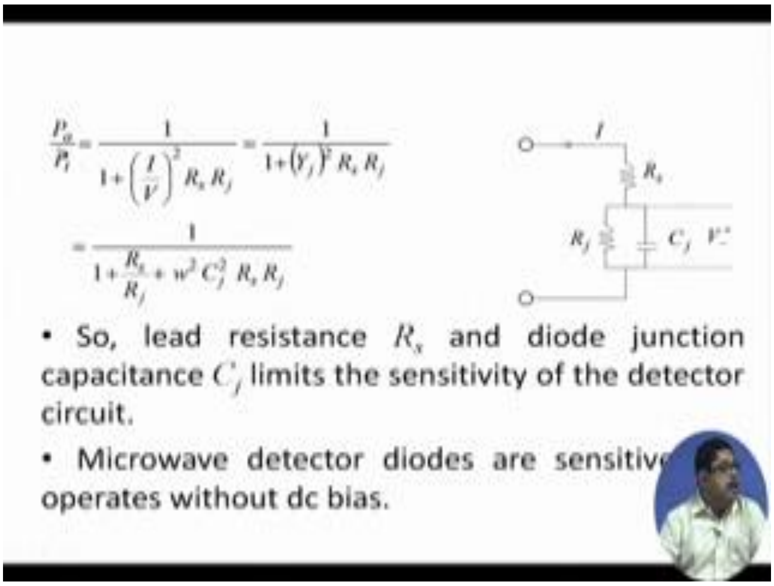

Now I by v we can put there the admittance in the junction y j. So, if we do that and that y j is nothing, but it is the parallel combination of r j and c j. So, we can put that value and then finally, it becomes you see a function, lead resistance r s that affects the power that you can finally, get, so that is why you should try to make the lead resistance. You see our idea is to make this ratio as high as possible, so that our detection sensitivity increases, so you should make r s small, so that we get this ratio high. So, lead resistance should be as small as possible, and also diode junction capacitance that should be made small, so that this ratio becomes high.

Now, microwave detector diodes are quite sensitive, and you need not bias it, because whatever it is normally in the (Refer Time: 15:31) region. So, no extra biasing is needed, then they are quite sensitive, give a good amount of current you can get, detection sensitivity is good, because lead resistance etcetera they are made to minimum, capacitance made to minimum; obviously due to the metal contact.

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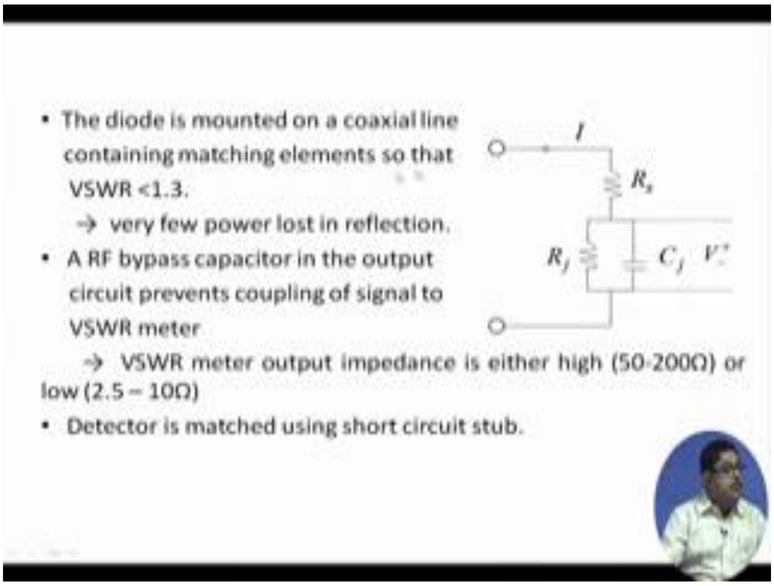

The diode is mounted on a coaxial line containing magically matching elements. So, that VSWR is kept at less than 1.3. You know VSWR 1.3 means very low reflection coefficient, because of this matching. So, it is almost good. Today we have seen that 2 3 etcetera VSWR is not good. If VSWR is less than 1.5; that is a good well matched circuit we say. So, very few power lost in reflection, a RF bypass capacitor in the output circuit prevents coupling of signal to VSWR meter. So, VSWR meter output impedance, you can select it either as high or low and detector is matched using a short circuit stub, that plunger that we are showing. This probe, so this when it makes this thing the stub that also balances, so it makes you the penetration dip also by the stub there is also a stub there by that stub you can always match the short circuit stub.

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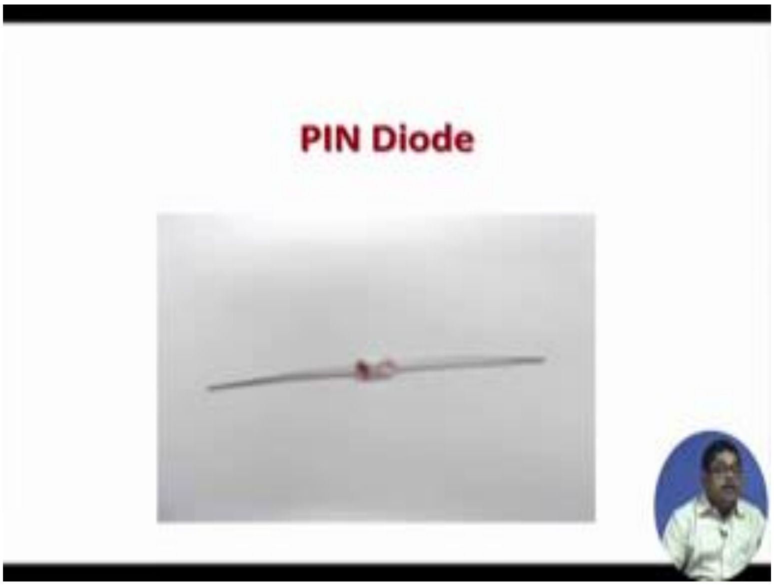

Now, the next diode that we see is PIN diode do not write p small I small n, these are all capital. p is the p type semiconductor, I is intrinsic, there is an intrinsic line on non diode (Refer Time: 17:39) player and then there is a n type semiconductor.

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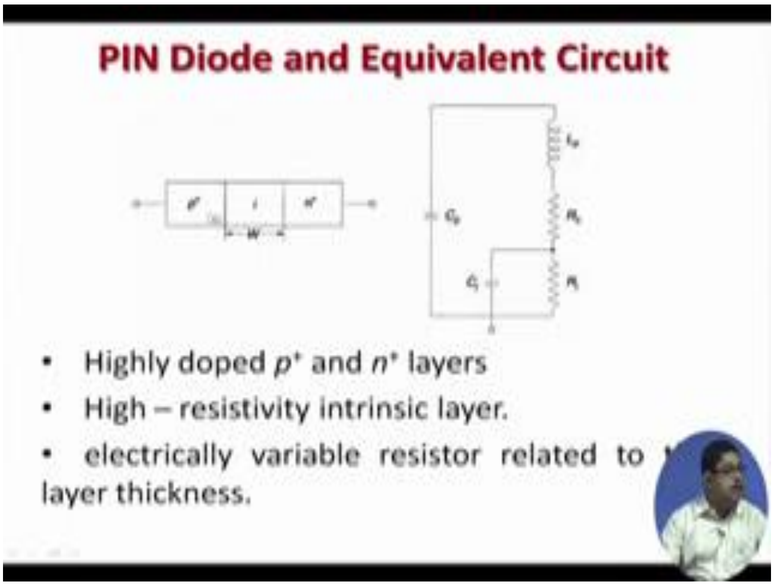

So, this is a PIN diode. PIN diode equivalent circuit as I said p n, but actually they are heavily doped, so they are called p plus and n plus. For every material there is a limit before if the doping is more than that, we call it p plus and n plus, and there is a intrinsic semiconductor, intrinsic layer of width w. So, this intrinsic semiconductor, this is a highly resistive intrinsic layer, because no doping is there. So, electrically variable resistor related to the high layer thickness; that means, this poses are basically acts as a resistance. So, if you make it is thicker depending on the resistance you can change that?

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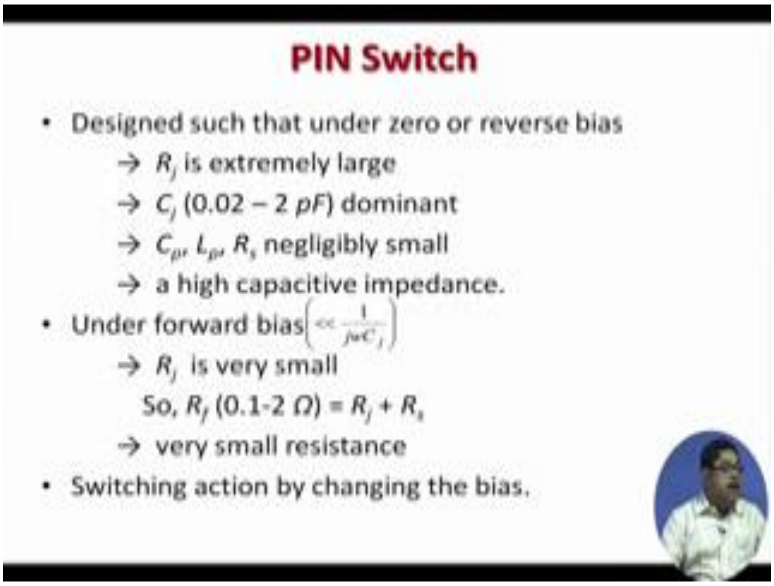

Now, again the same thing we will see that diode will be represented by this c j and r j, then there is a lead resistance (Refer Time: 18:43), and also throughout there is a, because there is a total gap there, so there is a c p here. Designs are such as under zero are reverse bias r j is extremely large. So, when the either zero bias or reverse bias r j is large that is any diode, and c j that becomes dominant, it is value is typically 0.02 to 2 pico ferret; c p, l p, r s negligibly small.

So, basically the diode gives you, this r j is quite high under reverse bias, so you get a high capacitive impedance similarly under forward bias; that is when the frequency is less than this. So, r j that is quite small and RF is typically forward resistance; that is 0.1 to 2 ohm, and from the circuit you can easily see that it is r j. Sorry r j plus r s very small resistance. So; that means, basically this diode is under reverse bias, it gives you a high capacitive impedance, so it is as if open, and when it is forward bias, then it is a very small resistance, so almost a short, switching action by changing the bias.

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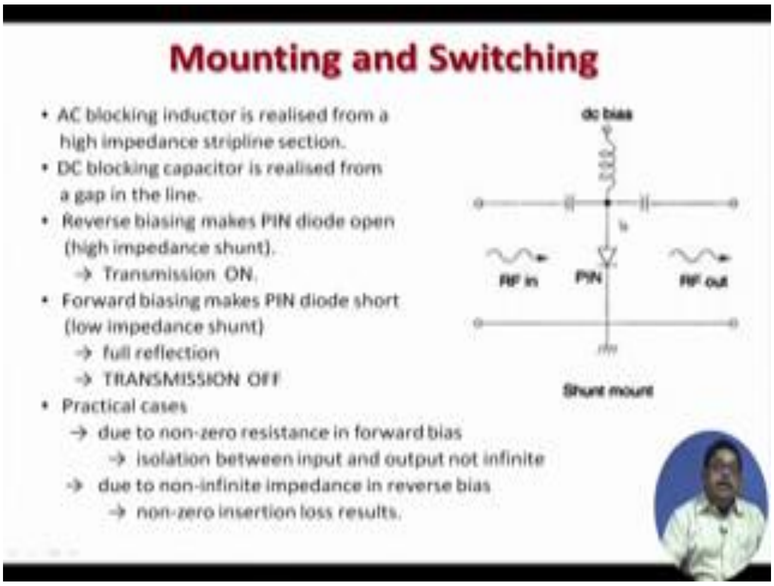

So, it has two states. So, either you have a open circuit or a short circuit in the switching, in the forward bias short circuit, in the reverse bias you get a open circuit. And there are various ways of mounting; the popular ones are the shunt mount. So, PIN diode is this is the line RF transmission line. So, RF is coming, now you put the PIN here. You can also put the PIN in the series direction, but then the other circuit elements will be different. This is a good choice in our laboratories etcetera we make a PIN diodes like this. Now also there is a inductor here and capacitors here. So, a c blocking inductor generally it is realized from a high impedance stripline section, yesterday we have seen stripline section, so that inductor is fabricated from that. Fabricating inductor is a good engineering thing. It is quite difficult to do at various as a (Refer Time: 21:10) element to fabricate inductance, inducting size etcetera becomes correlative, but if you use transmission lines like striplines etcetera, you can get a good inductance. So, also that is very planar circuit, so easily you can put it there. So, this is for putting the d c bias, so that it blocks a c s, this inductance and you get the d c there.

Similarly, d c blocking capacitor you put the capacitors which do not allow the d c to go into the transmission line. This is basically realized by putting a gap in the line. So, in the transmission line you put a gap, that gives you fabricate this d c blocking capacitor. Now as I said, when I reverse bias this is basically I can it is an open circuit, high impedance across shunt. So, r f, if we know, if RF signals is an open circuit, then it is transmission goes, because the whole signal, it receives a high impedance path. So, it goes on seeing a thing a RF signal goes out, just like an open circuit. Forward biasing, when the thing is forward biased PIN diode is short; in a short the full reflection takes place. So, transmission there is nothing that goes here, hold the RF energy that gets reflected from here. So, that means.

Now, please remember that when, in the other case when high impedance is there. So, at this point what will be the total voltage wave, because reflection coefficient of open is plus 1? So, that time the total voltage that becomes twice of the maximum voltage, so the whole circuitry in the path, they should be able to withstand that twice voltage there, because if you put open like this. So, all these places they will get a voltage; that is twice of the thing. So, transmission is off in the forward biasing case, this is quite easy to understand. Now; obviously, in practical cases we do not forward bias, does not mean that purely it is a known short circuit. So, some non zero resistance is there; that is why we can say that isolation between input and output is not infinite, but still it is a good isolation that provide. Similarly, due to non-infinite impedance, because ideally at reverse bias you should have infinite impedance, but that is not true, non-zero insertion some loss is there in the.

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Now, you see this is the PIN diode modulator, so there is a GUNN oscillator, we will see GUNN diode later. So, based on that there is a gun diode oscillator, the GUNN oscillator, and then we put a isolator here, because this as I said that there is in the case of reflection, when the PIN diode is there then the full signal that comes back, and in terms of reflection the voltage will come, twice the voltage. Now that voltage if it is comes to the GUNN diode, it may destroy the GUNN diode that is why. Always you know that the diode any oscillator circuit or any source that has a very small resistance. So, if a high voltage comes there, then there will be large current it will flow through the source, and source may get destroyed, because it is resistance is very small. So that is why put an isolator, so that the reflected power from here that cannot come to the source, but while going it goes, then we put the PIN modulator, that PIN modulator, then put that 1 kilo hertz. The PIN modulator is biased, the biasing PIN modulator that the power supply here.

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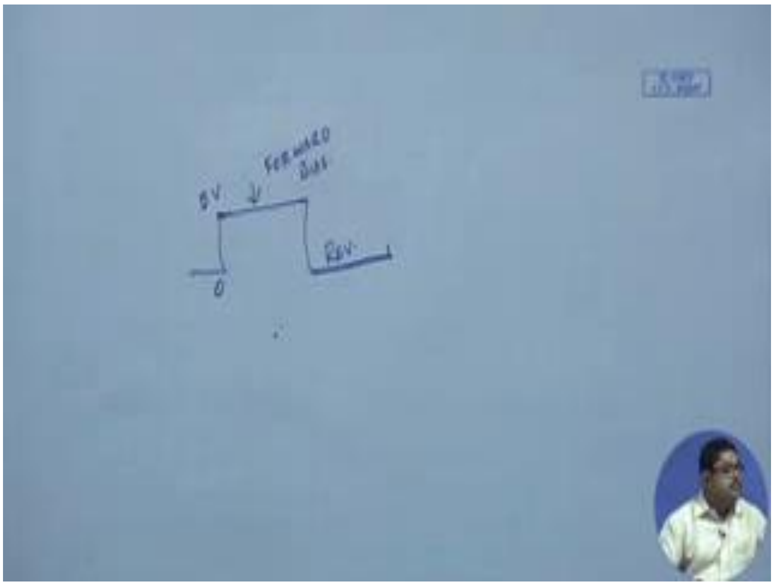

This is the modulating voltage, so we have a 1 kilo hertz square wave signal, they show here. We have a 1 kilo hertz square wave signal. So, this is the d c bias this gives. So, this is the ON, and when it is not getting this is zero. So, this is some 5 volt something is given. So, this is the forward bias, this is the reverse bias. So, in the reverse bias the transmission goes on in forward bias the transmission is cut out.