

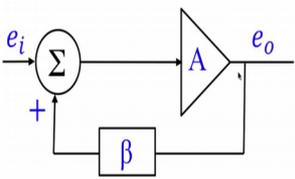
**Microwave Theory and Techniques**  
**Prof. Girish Kumar**  
**Electrical Engineering Department**  
**Indian Institute of Technology, Bombay**

**Module – 9**  
**Lecture – 41**  
**Microwave Oscillators – I**

Hello and welcome to today's lecture on microwave oscillators. In the last few lectures, we have been talking about different types of amplifiers. So, today we are going to talk about microwave oscillators using an active device. Now, active device can be a stable active device, in that particular case we will use that as an amplifier and use positive feedback to design oscillator. And if the device is unstable, in that particular case we will draw input stability circle and choose a point which is most unstable and then we design oscillator.

(Refer Slide Time: 01:00)

### Amplifier with Positive Feedback



$$e_o = A(e_i + \beta e_o)$$
$$e_o(1 - A\beta) = Ae_i$$

$$\frac{e_o}{e_i} = \frac{A}{(1 - A\beta)}$$

If loop gain =  $A\beta = 1$ , then  $\frac{e_o}{e_i} \rightarrow \infty$ .

For  $e_i = 0$ ,  $e_o$  may have finite value. ➔ Oscillation Condition

To start oscillation: Choose  $A\beta > 1$ . Generally  $A\beta \approx 1.1$  to  $1.2$

Microwave Theory and Techniques | Prof. Girish Kumar, IIT Bombay2

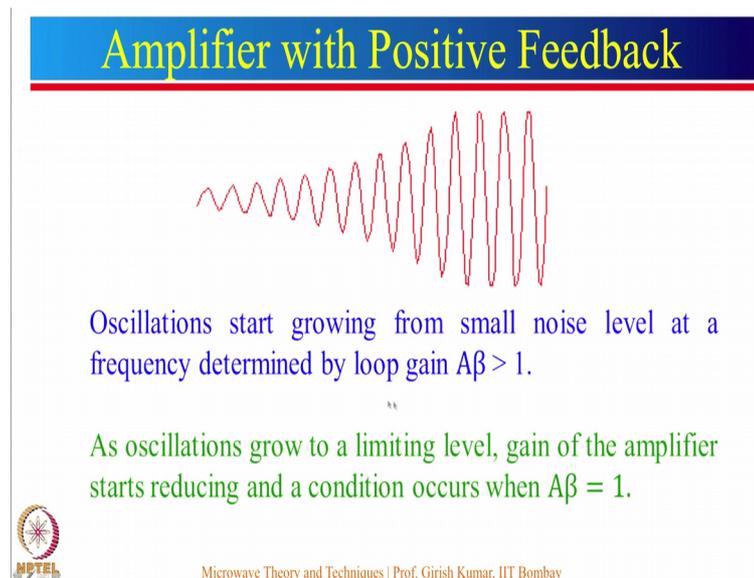
So, let us start today's lecture. Let us first look at what are the oscillation conditions. So, we will start with an amplifier with positive feedback. So, we have an amplifier with a gain equal to A. So, part of this output is fed back to the input side, and here is an input signal. This is only to show you there is an input signal for derivation; in reality for oscillator we do not require this input signal. So, let us see how we can write the equation. So,  $e_i$  can be written as amplified output which is multiplied by whatever

is the input. So, what is input equal to input is equal to  $e_i$  plus beta times  $e_o$ . So, this is a times  $e_i$  plus beta times  $e_o$ . We can simplify this as  $e_o$  multiplied by this term will come to this side  $1 - A\beta$  which is equal to  $A$  times  $e_i$ .

Now, we take the ratio  $e_o$  divided by  $e_i$  is equal to  $A$  divided by  $1 - A\beta$ . So, what will happen, if  $A\beta$  is equal to 1, then  $1 - 1$  will become 0,  $A$  divided by 0 will be infinity. So, loop gain here in this particular case is nothing but a multiplied by beta. So, if loop gain is equal to  $A\beta$  is equal to 1 in that case  $e_o$  divided by  $e_i$  becomes infinity. So, now, just think about, if  $e_i$  is equal to 0 then  $e_o$  may have 1, 2 or 3 any value, for example, if it is 1 divided by 0 it is still infinity, 2 divided by 0 it is still equal to infinity; that means, for  $e_i$  equal to 0  $e_o$  may have finite value which will be determined by the amplifier and the feedback network we will see that later on.

So, the oscillation condition is nothing but loop gain should be equal to 1. However, to start the oscillation choose  $A\beta$  greater than 1. Now, the question is how much greater a beta should be?  $A\beta$  can be 1.001 also a beta can be 10 also. So, what is the appropriate value, so I generally recommend choose  $A\beta$  equal to 1.1 to 1.2. The reason will be obvious from the next slide.

(Refer Slide Time: 03:32)



### Amplifier with Positive Feedback

Oscillations start growing from small noise level at a frequency determined by loop gain  $A\beta > 1$ .

As oscillations grow to a limiting level, gain of the amplifier starts reducing and a condition occurs when  $A\beta = 1$ .

 NPTEL

Microwave Theory and Techniques | Prof. Girish Kumar, IIT Bombay

3

So, here is the response of the amplifier with positive feedback network. So, let us say there is some noise, we discuss about different types of noise, when we talked about low noise amplifier. We talked about thermal noise, we talked about shot noise. And we had

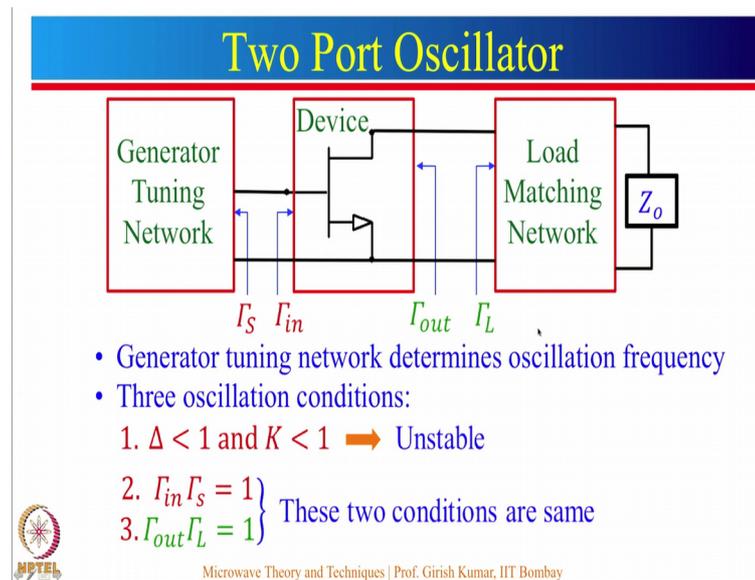
seen that, because of those noises the noise voltage or noise current could be of the order of microvolt or nanoampere. So, what happens, now if loop gain is let us say equal to 2, so if the loop gain is equal to 2, let us say that 1 microvolt signal, now through the loop gain will become, now 2 microvolt, 2 will become 4, 4 will become 8, then 16 and so on.

A condition comes when the voltage levels will get built up from, let us say microvolt level 2, let us say 1 volt, then 2 volt, then 4 volt, 8 volt, but now we have to stop here it cannot become 8 volt suppose, if the power supply is equal to 5. So, from 4, it may try to go to 8 volt, but because the power supply is limited to let us say 5 volt, so then the top as well as the bottom will be chopped out that is something like we have cut down the head and the leg, we are left with the just central body and that will have a clipping over here as well as clipping over here. But when we are designing an oscillator, we would like to have a sinusoidal waveform, if not 100 percent pure, relatively pure sinusoidal waveform.

So, this is where I recommend, if you take loop gain as let us say 1.1 or 1.2, then what will happen, now 1 microvolt will become let us say 1.1 microvolt, then it will become 1.21 microvolt, now as it keeps on building up. So, let us say then 1 volt will become now 1.1 volt and so on further increase it. So, now, what happens as the signal amplitude keeps on increasing amplifier gain also starts reducing. Why, if you recall amplifier gain is not always a 100 percent linear, it actually speaking has a curved path that means, amplifier gain starts reducing as the input signal strength increases.

So, a condition comes, when  $A\beta$  will become 1, why, because  $A$  has now reduced  $\beta$  remains same. So, then the question comes why not we choose 1.01. The reason why I do not recommend 1.01, because the components which we have used to design an oscillator and feedback network, which gives rise to an oscillator may have tolerances; typical tolerance of inductor or capacitor can be about 5 to 10 percent. Hence it is always recommended that do not take 1.01 or 2 or 3, take 1.1 to 1.2. So, if you take 1.1 to 1.2, then what happens you are taking care of component tolerances. And also by taking that number you will ensure that there is a not clipping at the top and the bottom level.

(Refer Slide Time: 06:53)



So, now, let us see how we can design an oscillator using a device. You had seen this particular configuration, when we talked about amplifier design except for 1 difference and that is over here. See in the case of amplifier there was an input and there was an input impedance matching network, but now for oscillator we do not need any input. So, hence we have given the term over here which is a generator tuning network this part is similar to that of amplifier design.

So, let us see now what happened the generator tuning network is designed such a way that it determines oscillation frequency. Now, there are three oscillation conditions first condition that is delta should be less than 1 and K should be less than 1 in that particular case device is unstable. Now, you may say what will happen, if the device is stable; that means, if K is greater than 1 in that particular case I tell you we will use the positive feedback to design an oscillator.

Now, let us just look at the two other conditions. The condition number two is gamma in multiplied by gamma s is equal to 1. Let us see where it is, so gamma s is from this side gamma in is looking from this side. So, we can say that this loop gain is nothing but equal to gamma in multiplied by gamma s. So, if the product is equal to 1 that will be the condition for the oscillation.

Now, what about this third condition? So, let me tell you condition number two and condition number three they are exactly same, but let us see where it is. So, this is

gamma out looking from the output side of the device gamma l is looking at the input side from the load matching networks. So, if you see loop gain is nothing but gamma out multiplied by gamma l. So, this should be equal to 1 as I just mentioned these two conditions are same. So, let us see the derivation we will start with one of the equation and we will get the second equation from that.

(Refer Slide Time: 08:58)

### Two Port Oscillator (contd.)

Derivation of Condition 3 from Condition 2:

Condition 2:  $\Gamma_{in}\Gamma_S = 1 \implies \frac{S_{11} - \Delta\Gamma_L}{1 - S_{22}\Gamma_L}\Gamma_S = 1$

$$S_{11}\Gamma_S - \Delta\Gamma_L\Gamma_S = 1 - S_{22}\Gamma_L \implies \Gamma_L(S_{22} - \Delta\Gamma_S) = 1 - S_{11}\Gamma_S$$

$\Gamma_L \frac{S_{22} - \Delta\Gamma_S}{1 - S_{11}\Gamma_S} = 1 \implies \Gamma_L\Gamma_{out} = 1$  Same as Condition 3

Since  $|\Gamma_S|$  and  $|\Gamma_L|$  are  $< 1 \implies |\Gamma_{in}|$  and  $|\Gamma_{out}|$  are  $> 1$

This implies  $R_{in}$  and  $R_{out}$  are negative.


Microwave Theory and Techniques | Prof. Girish Kumar, IIT Bombay
5

Derivation of condition 3 from condition 2. So, we will start with condition two which is gamma in gamma S is equal to 1. So, we know the expression for gamma in is given by this particular term over here gamma S comes as it is which is equal to 1. So, now, you simplify this particular expression. So, we can write this as S 1 1 gamma S minus delta gamma l gamma S which is equal to now this will go to this side, which is 1 minus S 2 2 gamma l. Now, we simplify this particular thing we can write in this particular fashion and after one or two steps, we can actually obtain the condition gamma l gamma out equal to 1 which is same as condition three ok

So; that means, if this particular condition is satisfied this condition will automatically get satisfied, for given source and load impedances gamma S and gamma l will always be less than 1. Recall Smith chart, on the Smith chart, we can locate all the real and imaginary values of the impedances. And for the Smith chart, we know that gammas are always less than 1. And if gamma S is less than 1, what will happen to gamma in; that means, gamma in will be greater than 1. Similarly, if gamma l is less than 1; that means,

gamma out will be greater than 1 and either of these two conditions what they imply, they imply that R in and R out are negative.

(Refer Slide Time: 10:38)

## Negative Resistance

Example: If  $R_{out} = Z_{out} = -10 \Omega$ , then

$$\Gamma_{out} = \frac{Z_{out} - Z_0}{Z_{out} + Z_0} = \frac{-10 - 50}{-10 + 50} = 1.5 \angle 180^\circ$$

$|\Gamma_{out}| > 1$

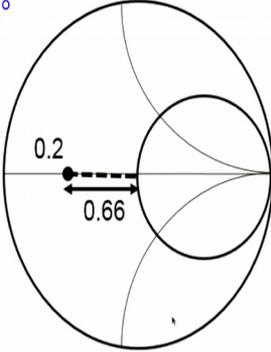
To find negative  $R_{out}$  from  $\Gamma_{out}$

Plot  $\frac{1}{\Gamma_{out}^*}$  on Smith Chart

$$\frac{1}{1.5 \angle -180^\circ} = 0.66 \angle 180^\circ$$

Read value of R and make it negative

$\Gamma_{out} = -0.2 \Rightarrow Z_{out} = -10 \Omega$



Let us take a simple example So, how do we define negative resistance. Let us say, if R out which is equal to Z out is equal to minus 10 ohm I am just taking a negative value of a resistor. So, for this particular case, we can find out the value of gamma out as Z out minus Z 0 divided by Z out plus Z 0. So, we have chosen this as minus 10, so minus 10 minus 50 divided by minus 10 plus 50, so this will become minus 60 divided by plus 40 which is equal to 1.5 angle 180 degree.

So, we can say that magnitude of gamma out is nothing but greater than 1. In fact, you can take any value of Z out which has a negative R value and it does not matter what is the reactance value gamma out will always be greater than 1. So, here we can see that, if Z out is given we can find out the value of gamma out, if gamma out is given how do we find out Z out well, we can use Smith chart to find the value of Z out.

However, as you might recall Smith chart always represents gamma less than 1. So, how we can use Smith chart when gamma out is greater than 1, well there is a technique to do that. So, let us see what is that technique. So, to find negative R out from gamma out what do you do you plot 1 by gamma out conjugate on Smith chart. So, we know that gamma out is greater than 1. So, if this is greater than 1, 1 divided by gamma out will always be less than 1, so that can be placed on the Smith chart why complex conjugate

over here. So, when we take 1 by gamma out conjugate that angle of this particular term will be exactly same as that of gamma out.

So, let us plot this particular term on the Smith chart. So, 1 divided by 1.5 angle 108 degree will become, now 0.66 angle 180 degree. So, we know that this is 0 axis this is angle 0 this is angle 180 degree. So, we go around go to 180 degree locate this point 0.66 from the center. So, that will be 0.66, if you read the corresponding value that comes out to be 0.2. Now, read this value of R as negative. So, make R out equal to negative why we are doing that actually speaking we are plotted 1 by gamma out. So, this value corresponds to 1 by gamma out to obtain the value corresponding to gamma out greater than 1 this is what we do.

So, from here, we can find out the value of Z out, how do we do that multiply this with 50. So, 50 multiplied by 0.2 will be 10. So, this is the value of Z out which is equal to minus 10 ohm. So, you can see that this is how we started with minus 10 ohm, we got this value of gamma out, then we started from this value of gamma out we got this 1. Now, the same thing you can also do for complex value of Z out also. We will take an example later on then this will be more clear. Now, when gamma out is greater than 1, that means, now output impedance of the device has negative resistance.

(Refer Slide Time: 14:15)

### Derivation for One Port Oscillator

When  $\Gamma_{out} > 1$ , output impedance of the device has negative resistance.

Two port oscillator circuit reduces to single port oscillator.

For Loop Gain = 1:

$$\Gamma_{out}\Gamma_L = 1 \Rightarrow \frac{R_{out} + jX_{out} - Z_0}{R_{out} + jX_{out} + Z_0} \cdot \frac{R_L + jX_L - Z_0}{R_L + jX_L + Z_0} = 1$$

$$(R_{out} + jX_{out} - Z_0)(R_L + jX_L - Z_0) = (R_{out} + jX_{out} + Z_0)(R_L + jX_L + Z_0)$$

Real Part:  $(R_{out} - Z_0)(R_L - Z_0) - X_{out}X_L = (R_{out} + Z_0)(R_L + Z_0) - X_{out}X_L$

$$R_{out}R_L - (R_L + R_{out})Z_0 + Z_0^2 = R_{out}R_L + (R_L + R_{out})Z_0 + Z_0^2$$

So,  $-(R_L + R_{out}) = (R_L + R_{out}) \Rightarrow R_L + R_{out} = 0$

Similarly Imaginary Part:  $X_L + X_{out} = 0$

So, let us say we have a generator tuning network. After that we have an active device and the output impedance or you can say gamma out is greater than 1 so; that means,

looking from this particular device, we can actually say that  $\gamma_{out}$  can, now be represented as  $R_{out}$  in series with  $X_{out}$ , but  $R_{out}$  now has a negative value. So, we can actually convert a two port network problem into a single port problem. So, the single port problem here is nothing but replacement of the earlier portion into just the corresponding value of the impedance which is  $R_{out}$  in series with  $X_{out}$ .

So, for this particular case, now  $\gamma_{out}$  will be greater than 1 and for oscillator design  $\gamma_{in}$  is less than 1. And what we want we want the loop gain should be equal to 1 ok. So, two port oscillator circuits, now reduces to single port oscillator. So, let us see how we can find the condition for single port oscillation. So, for oscillation loop gain should be equal to 1; that means,  $\gamma_{out}$  multiplied by  $\gamma_{in}$  should be equal to 1 let us substitute the value of  $\gamma_{out}$  and  $\gamma_{in}$  in terms of its impedances. So, we can say that  $Z_{out}$  is equal to  $R_{out} + j X_{out}$  well  $X_{out}$  can be plus or minus. Similarly, for  $\gamma_{in}$  we can write corresponding term. Now, all we do it is multiplied the numerator term over here. So, that is right over here these denominator terms will go to this side and that will come and that will come on the right hand side.

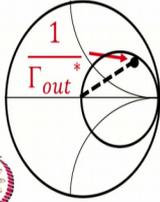
Now, the next step would be is to separate real part and imaginary part. So, if we separate the real part after a few simplifications, you will find the condition that  $R_L + R_{out}$  should be equal to 0, so that means,  $R_L$  should be equal to minus  $R_{out}$  now please recall  $R_{out}$  has a negative value. So, if this has a negative value,  $R_L$  will have positive value. Similarly, if we equate imaginary parts, then we get the condition  $X_L + X_{out}$  equal to 0, so that means,  $X_L$  is now equal to minus of  $X_{out}$ . So, if  $X_{out}$  is inductive then this will be capacitive; if this is capacitive, this will become inductor.

(Refer Slide Time: 16:57)

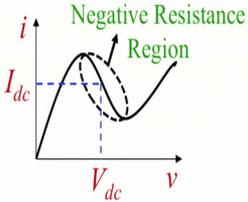
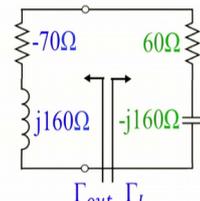
## One Port Oscillator (contd.)

**To start oscillations:** Loop gain  $\Gamma_{out}\Gamma_L > 1$ ,  $|R_{out}| \geq 1.2R_L$

**One Port Oscillator Design:**  
 A Gunn diode has  $\Gamma_{out} = 1.24\angle 30^\circ$  at 10GHz.  
 Plot  $\frac{1}{\Gamma_{out}} = 0.81\angle -30^\circ$  on Smith chart  
 $Z_{out} = 50(-1.4 + j3.2) = -70 + j160\Omega$



**To start oscillations, choose:**  
 $R_L = 60\Omega$  and  $X_C = -X_L$   
 $-\frac{j}{\omega C} = -j160 \Rightarrow C = 0.1\text{pF}$

Microwave Theory and Techniques | Prof. Girish Kumar, IIT Bombay

However, to start the oscillation loop gain should be greater than 1; that means, gamma out multiplied by gamma L should be greater than 1. And this will only happen, if R out magnitude is greater than 1.2 R L, why we are defining like this, the reason for that is remember R out has a negative value and this is a positive value. The magnitude of R L should be chosen less than the magnitude of R out. So, that the net resistance is negative and if the net resistance is negative then only loop gain will be greater than one.

Let us take an example. So, we will take a one port oscillator design here we have taken an example of a Gunn diode. So, Gunn diode has I V characteristics given by this particular form over here. So, you can see that as current increases voltage increases in this particular region, but if you see in this particular region voltage increases, but current decreases. So, this region is known as negative resistance region. So, what do we do to design an oscillator, we bias this Gunn diode in this particular region.

So, diode is biased with this dc voltage V d c corresponding to this DC current I d c, if you bias the diode in this particular region in that case what will happen gamma out of Gunn diode will be greater than 1, because it has a negative resistance region we have just seen that, if the resistance is negative in that particular case, gamma out will be greater than 1. So, this problem is given. So, for this biasing condition gamma out has a value equal to 1.24 angle 30 degree and this is at 10 gigahertz.

Now, what we need to do we need to design the oscillator circuit. So, the first thing what we should do it is we should find out the corresponding value of  $R_{out}$  and  $X_{out}$ . To do that we plot  $1/\Gamma_{out}$  on the Smith chart. So, this will be now 1 divided by 1.24 which is 0.81 complex conjugate of this will be minus 30 degree. When it comes to the numerator side it will become angle 30 degree. So, you can see that this angle is exactly same as that of angle of  $\Gamma_{out}$ .

So, now, we have to locate this particular point on the Smith chart. So, 0.81 angle 30 degree, so draw a line at an angle of 30 degree locate 0.81 on this particular Smith chart this will be  $1/\Gamma_{out}$ . So, read the corresponding value of the  $Z_{out}$  from here, so what will be  $Z_{out}$  that will be 50 multiplied by whatever is the resistance value take negative of that. So, the normalized value of resistance is 1.4, you can actually see this will correspond to the circled over here. So, it will become minus 1.4. And you can see that this will correspond to somewhere here, so the, so the reactive part is positive which is plus  $j 3.2$ . So, we multiply this it comes out to be minus 70 plus  $j 160$  ohm. So, for this particular Gunn diode this is the  $\Gamma_{out}$ . So, we can see here this is minus 70 this is plus  $j 160$  ohm.

Now, to start oscillation we choose  $R_L$  equal to 60 ohm you can see that this particular value approximately satisfies this particular equation magnitude of  $R_{out}$  will be 70, this is 60 multiplied by 1.2 is approximately 72. So, condition of  $R_{out}$  greater than  $R_L$  is still satisfied. So, this is reasonably good value to choose what about  $X_e$ . So, as I had just mentioned, if this is inductance this should be capacitance, the reactance of this capacitance should be negative of the reactance of this particular inductor. So,  $X_c$  should be equal to minus  $X_L$ . So, we can say that  $Z_C$  is nothing but minus  $j$  by  $\omega C$ , which is now minus of  $Z$  of this particular value, which is minus  $j 160$

So, from here we can find the value of  $C$  which is equal to 0.1 Picofarad. Now, I just want to mention that this design is not fully complete at this particular point over here. The reason for that is invariably when we design an oscillator, we always say that the load will be equal to 50 ohm. So, here the values obtained are 60 minus  $j 160$  ohm this part I leave it for you people. So, we have a 50 ohm load design the output impedance matching network. So, that  $Z_L$  is equal to 60 minus  $j 160$  ohm.

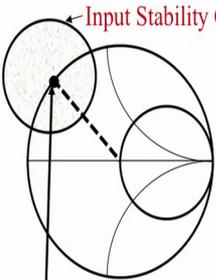
Now, let us look at what are the design steps for designing a two port oscillator. So, in fact, if you ask many people and even if you see many books, they always say oscillator design is very difficult, you want to design an oscillator, it becomes an amplifier. Similarly, sometimes people also say you want to design an amplifier, it become an oscillator that is why I am giving you very simple design steps for designing a two port oscillator.

(Refer Slide Time: 22:59)

## Two Port Oscillator Design Steps

**Design Steps for Two Port Oscillator:**

1. For given S-parameters, find K
2. If  $\Delta < 1$  and  $K < 1 \rightarrow$  unstable
3. Draw input (source) stability circle.
4. Choose  $\Gamma_S$  ( $Z_S$ ) within unstable region
5. Find  $\Gamma_{out} = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1-S_{11}\Gamma_S}$
6.  $|\Gamma_{out}|$  will be  $>1 \rightarrow$  Find  $R_{out}$  and  $X_{out}$
7. Find  $R_L$  and  $X_L$  and design impedance matching network.



Input Stability Circle

Choose  $Z_S$  on the periphery (most unstable point inside the stability circle)

$Z_S$  can be realized by an inductor or shorted stub.



Microwave Theory and Techniques | Prof. Girish Kumar, IIT Bombay

9

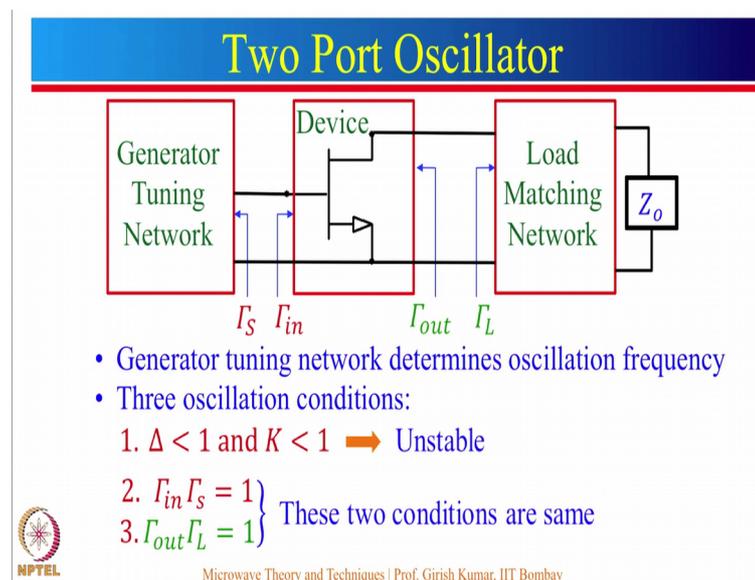
Follow these steps you will see that there is no problem at all you will be able to design an oscillator if you simply follow these steps. So, now, for given S parameters what you do, first you find the value of K. Now, if delta is less than 1 and K is less than 1; that means, it is unstable proceed, if K is greater than 1 that means, this device is stable for that I will tell you in the next lecture how to design an oscillator, but today we will assume that the device is unstable that means, delta is less than 1 and K is less than 1. So, in that particular case, what do you do you draw input stability circle or we can also say source stability circle.

So, this is the Smith chart. So, when you draw the stability circle, we know that stability circle will be cutting the Smith chart somewhere. So, if you see this particular portion, this is the portion where the device is unstable. So, now, we can choose any point in this particular unstable region and that point can be used to design an oscillator; however, please do not choose this point or this point or this particular point over here, because

they are at the borderline of the stability. So, because of the device tolerances or even, because of the power supply fluctuations, it is possible that this point may become this point over here and then the device will become stable

So, I recommend that choose a point which is the most unstable point in this particular region. So, you can actually see that this particular point is deep inside the input stability circle. So, this is the most unstable point within this particular region over here. So, please always choose this particular point and also there is an advantage this particular point can be very easily realized by an inductor or shorted stub. So, I just want to show you the circuit which, which we started

(Refer Slide Time: 25:19)



So, what really happens over here. So, this is the point where I mentioned about gamma S. So, this entire generator tuning network is simply replaced by an inductor. So, all you do it is just put an inductor over here or you can use shorted stub line also. So, what happens, if this particular stability circle is somewhere over here, then in that particular case you can say that the most unstable point will be somewhere here and that can be realized by simply a capacitor.

So, what will happen if the stability circle is somewhere here that means, that even a short circuit will make this device unstable. So, you do not even have to put inductor or capacitor simply short circuit the input side that will satisfy the instability criteria. So, once you have chosen the value of gamma S or  $Z_s$ , which is this particular point, then

the next step is you find out the value of  $\Gamma_{out}$ .  $\Gamma_{out}$  is given by this particular expression and you had seen this particular expression when we were discussing about amplifier design.

Now, you can see that  $S_{22}$  is known,  $S_{11}$  is known,  $S_{12}$ ,  $S_{21}$  all these S parameters are known,  $\Gamma_S$  has not been chosen corresponding to this particular point. So, we can now find out the value of  $\Gamma_{out}$ . Now, please check  $\Gamma_{out}$  magnitude has to be greater than 1. If it is not greater than 1 that means, you have done calculation mistake ok. So, it has to be greater than 1, it will always be greater than 1, if you have chosen the initial steps properly. So, once we know  $\Gamma_{out}$  is greater than 1, find out the value of  $R_{out}$  and  $X_{out}$ , then choose the value of  $R_L$  and  $X_L$  as I did in the previous case. And after that design impedance matching network to complete a oscillator design.

So, in the next lecture, we will look at oscillator design. We will look at several different examples. So, just to summarize today we talked about what are the different oscillation conditions. So, we actually saw that loop gain should be equal to 1 for oscillation condition. However, loop gain should be greater than 1. And I recommend you choose loop gain as maybe 1.1 to 1.2 to start the oscillation, so that there will be less clipping in the output sinusoidal waveform. Then we looked at the single port oscillator condition, and we had seen that  $R_{out}$  should be equal to minus  $R_L$ ,  $X_{out}$  should be equal to minus  $X_L$  however, for loop gain greater than 1, you have to choose  $R_{out}$  as approximately equal to 1.2 times  $R_L$ .

And then we looked at two port oscillator design for which you draw the stability circle for only input side, please you do not have to draw the output stability circle at this particular point. And then follow these seven steps, and you will have oscillator ready for you. So, in the next lecture, we will see more examples. Till then please study I do want to mention here that when you want to see the next video please see this video just before that and refresh your memory.

So, thank you very much, we will see you next time. Bye.