Microwave integrated circuits.
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Lecture -19.
Module-5.
Resonator and narrowband filters.

Hello, welcome to week 5 of this NPTEL NOC course, microwave integrated circuits. In the previous weeks or in the week for, we had covered the various microwave devices like the 1 port, 2 port, 3 port and 4 port devices and while discussing 3 port devices, I had mentioned that these 2 port devices also include filters but then filters themselves are a huge topic in themselves, will cover it separately. So, in this lecture we will be covering filters. Now, filters as you know, they are selective in which frequencies they allow to pass through them.

And based on this we can have various types of filters like lowpass filters, high pass filters and bandpass filters and so on. Now, in microwave engineering, because of the distributed nature of the components, it some weekend we can clearly classify the various filters that can be realised into 2 categories. One is what we call narrowband filters and the other we call broadband filters. So, let us in this module we will be just discussing about the resonators and narrowband filters. So, let us see what is narrowband filter and…

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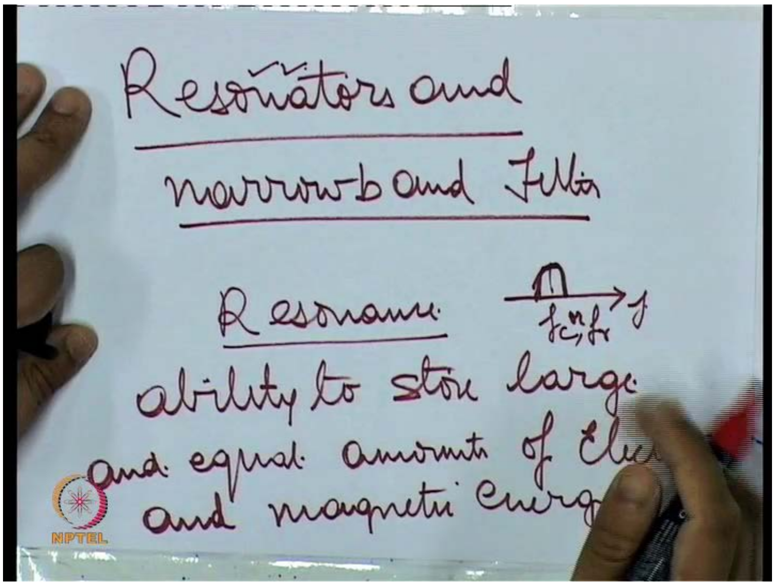

To discuss narrowband filters, it is very essential to know what these resonators are. Narrowband filters are nothing but resonators when properly input output terminated. Now, what is this concept of a resonance? Now in EM Field theory, resonance refers to the ability to store large and equal amounts of electrical and magnetic energy with minimal losses. Now, because the resonance as a phenomena happens over a small band of frequencies, say if this is our frequency scale, resonance happens over a small band of frequencies with a certain centre frequency say FC or FR.

Then what happens is that the property of these resonators, that is the devices which create this resonance is such that they have a centre frequency and a certain range of frequencies are about the Centre frequencies where the frequencies can be passed or stopped.

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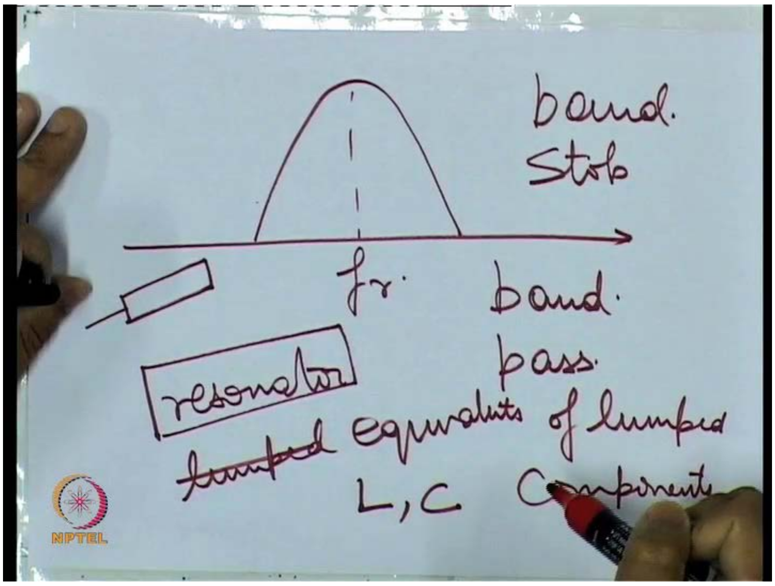

So, essentially, resonators are bandpass components or bandstop components, so what they if I can elaborate what I mean, resonator will have a characteristic like this, centre frequency FR with a range of frequencies where either the attenuation will be large or the attenuation will be less.

Now depending on if the attenuation is large, it acts as a bandstop and if the attenuation is large, then the resonator will act like bandpass. Then you might ask why are we directly going to bandpass or bandstop, from traditional filter theory, we should 1st discussed about lowpass and high pass filters. The reason we go to this bandpass concept or this narrowband concept whether it is bandstop or bandpass, that is a narrow band of frequencies which will be either allowed or which will be either past or attenuated is because of the special properties of these microwave microwave component.

It is easier to realise a resonator than say lumped equivalence of or the equivalence of lumped components like L and C.

So, because of the more difficulty associated with realising equivalent versions of equivalent distributed versions of L and C, it is more convenient to actually build the resonator using microwave components. Now, this we have already discussed, for example, here is a open Stub, you saw that in the previous module we had discussed that the same stub can act as **as** a inductor or as a capacitor depending on the length or the frequency.

If the length is constant, and if we keep varying the frequency, then this open stub will act as a inductor for some frequencies or as a capacitor for some frequencies. So, we see that, and in fact it will act as 0 impedance, that also solved, there might be no impedance or reactance itself might be 0 for certain frequencies. So, because of all these factors, it is actually as we shall see, it is actually easier to design a resonator as compared to equivalence of lumped components in microwave engineering. Now, so, that is the basic concept that, that this why we have this concept of narrowband filters because resonators are easier to build than L and C.

Having said that, we do have a need for say broadband filters where we have to design the responses of the passband and the stop band, so for that cases, we do have some methods to realise the equivalence of lumped components.

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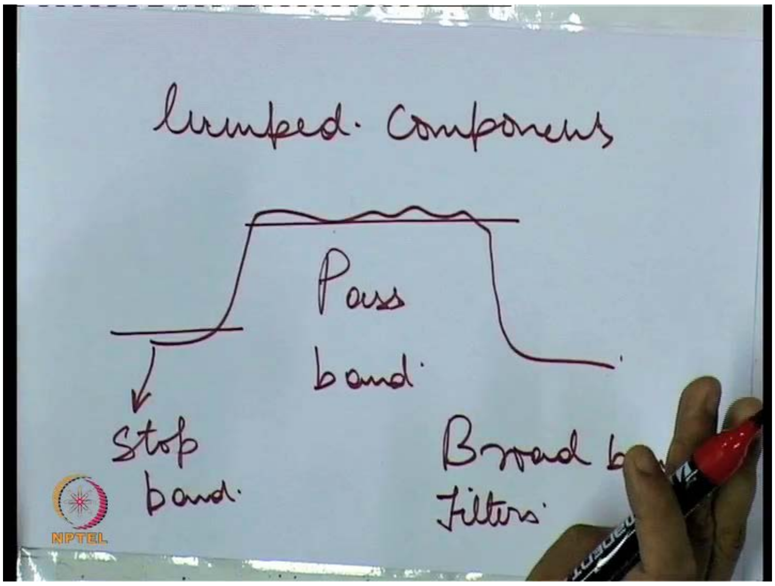

So, for example if you want a design, rather than the centre frequency, you want a certain minimum attenuation in the stop band and certain maximum attenuation in the passband, that is your attenuation cannot exceed that value. So, in that case you have to kind of it is like a traditional filter design of the stop band attenuation, passband attenuation.

There we have to design the response and there we have to rely on the traditional design philosophies except that we also need to convert those lumped elements to their distributed equivalence and that we shall see while we discuss this high pass while we discuss the broadband filters. So, those topics will be covered in the in some models, in some later models broadband filters. There the design philosophy is somewhat different from these narrowband filters.

So as to summarise for narrowband filters, resonators are the fundamental entity, whereas for broadband filters, we 1st design using the traditional filter design techniques using lumped elements and then we have to find the mechanism to convert these lumped elements to their broadband to their distributed equivalent. So, then the next topic that we shall be discussing is about resonance. We all know what a resonator looks like, for example a simple resonator circuit would be like this.

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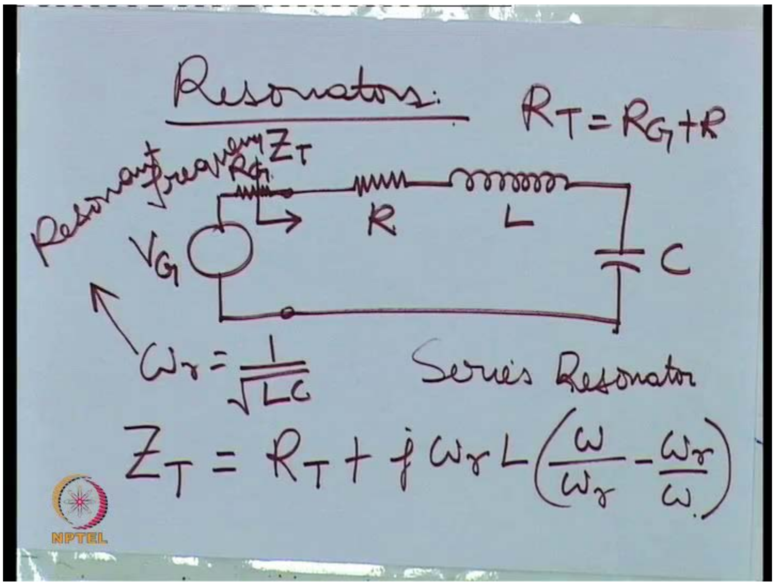

This is what we called as the series resonator. And a shunt resonator will be one where these R, L and C are in shunt. Now we can show that that the total input impedance ZT of this resonator is given by RT + J Omega RL omega upon omega R - omega R upon omega where omega R equal to 1 upon square root of LC is called the resonant frequency. RT suppose we also have a source resistance RG, then RT is equal to RG + R. So, this is the equivalent circuit diagram and the input impedance of a series resonator.

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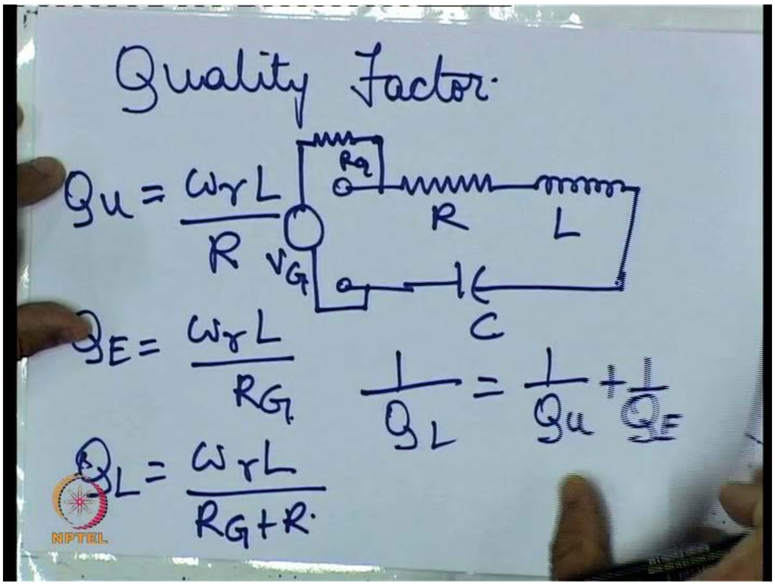

Now here, we define certain term called qualitative factor. For an unloaded or for a series resonator like this, some quality factors something called a QU is defined as the unloaded quality factor and its value is given like this. QE is the quality that with respect to some external, for example as I showed, if we have a generator VG with some RG connected, then this is the quality factor. And QL is the total quality factor that is including the internal and external resistances. It can be shown that this relation is valid.

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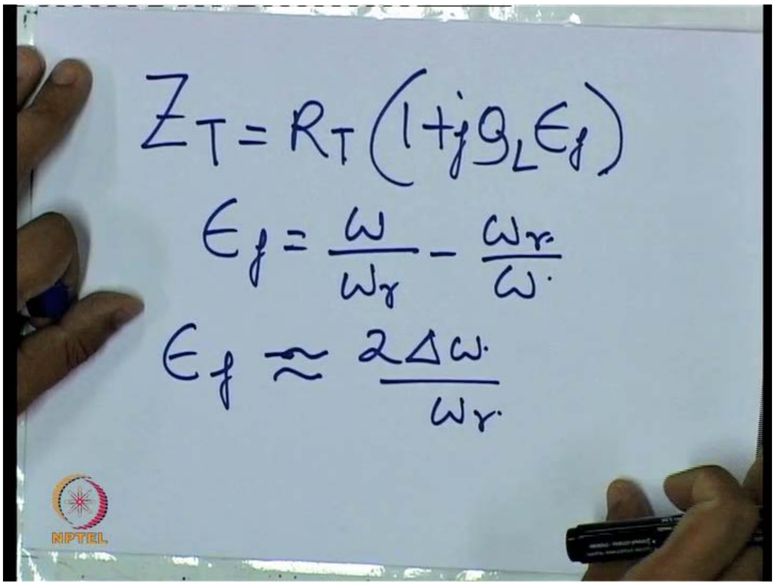

Another way of writing the input impedance of a series resonator is like this, in terms of the quality factors that we just defined where this epsilon f is equal to omega upon, not the details about the derivation is given in the adjoining, in the accompanying the PPT files with this course, you can go through it. Now this epsilon F itself can be simplified to this value, once again the derivation how you are doing it is given in the accompanying PPT files. Now, if you want to find out the total power dissipated in the system, that is both in the external as well as internal resistances.

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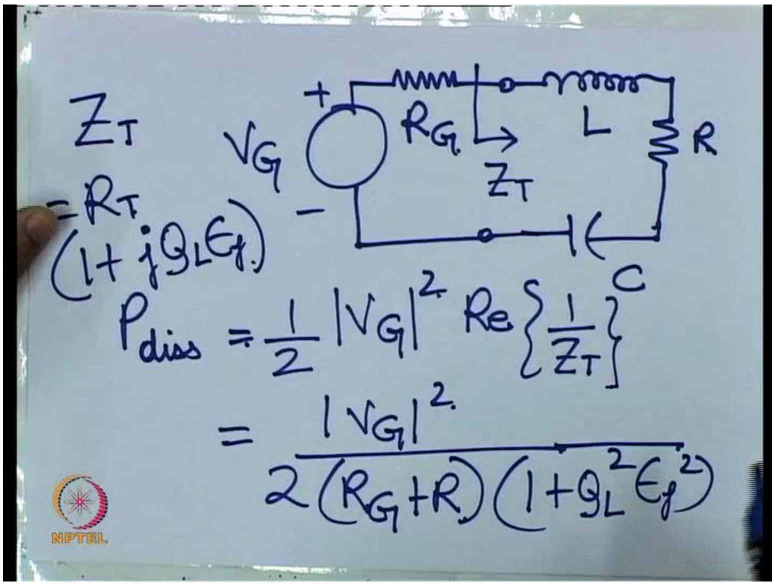

So once again we draw our circuit. The total power dissipated is given by… and this comes out to. So, ZT is this input impedance. So, this ZT can also be written as like this. Now the, there is a particular frequency or particular value of this epsilon F, and epsilon F as we saw is a measure of the deviation of the frequency from the resonant frequency omega R. For a particular value of epsilon S, the power dissipated will be half that will be half the maximum power dissipated and the maximum power is this distributed at resonance.

Now, one more thing I would like you to understand is that for series resonance, at resonance, the input impedance is low, for shunt impedance, we shall see that input impedance is high at resonance. Yah another thing about the series resonator is that, whether for series or shunt resonator is that the power distributed, there is a certain frequency where the power dissipated is half the maximum value and the maximum value occurs at the resonant frequency.

And that value happens when QL multiplied by epsilon F is equal to either +1 or -1. So, there we will have 2 different omegas for which half power is dissipated, that is also obvious from this equation. That is when QL epsilon F is either +1 or -1, the power dissipated will be half that when Epsilon F is 0.

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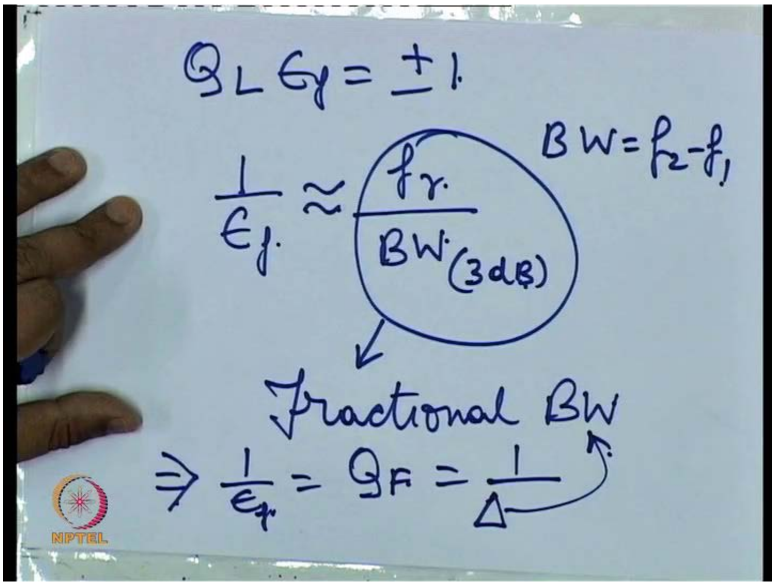

And further using the equation that I just derived, that is QL epsilon F is equal to + -1, we can obtain a relationship for 1 upon epsilon F is equal to FR into bandwidth which we call the 3 dB. The bandwidth is equal to F2 - F1 which are the 2 frequencies corresponding to this condition, now this term is also known as fractional bandwidth.

This is the absolute bandwidth, bandwidth upon resonant frequency is called the fractional bandwidth, in other words, one by epsilon S which is equal to QS is equal to 1 upon the Delta, Delta represent the fractional bandwidth. Again you know the details of these derivations are given in the PPT files, you can go through them.

So, now one other definition which of the Q factor that is frequently used is in terms of the reactive because in microwave circuits, it is not always so simple to find out whether a circuit is inductive or capacitive.

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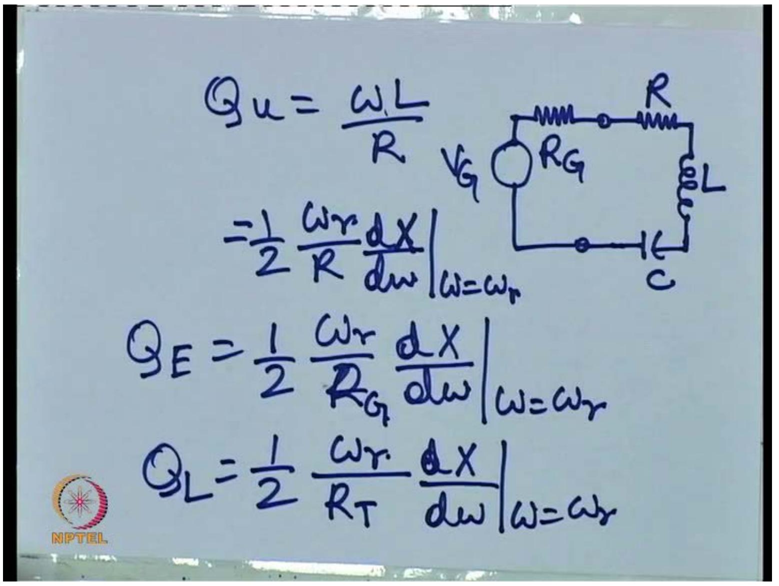

In the 1st case we have defined say QU is equal to omega L upon R. Here we are assuming that we have knowledge about L but suppose we do not have knowledge. Once again if we do our series resonator circuit. When QU without any loading is given by this. The other way of defining this, another formula is like this. Now, using this formula, what happens is we we do not need to know whether the circuit is inductive or capacitive. If we know the X and its dependence on omega, we can directly find out the QU.

Similarly say is we to find out QU, then just this denominator R changes to RG, so this will be equal to half omega R upon 2 DX Upon D omega upon sorry RG omega equal to omega R and QL will be equal to half of omega R upon RT. Now, proceeding similarly, we can also derive the same relations for shunt RLC resonators.

I am not going to do derivations but it can be found as I said in the accompanying PPT files and we will see that for a shunt resonator, we talk in terms of admittances, susceptance and conductances instead of impedance, resistance and reactance. And the relations for a shunt RLC resonator, will have very similar as I said but except that admittances are used in place of impedance and so on and we can go through it.

Since they are the dual of these relations, I do not want to spend my time on that. Rather, I would now like to show some actual, some of the actual resonators, microwave resonator is that are used.

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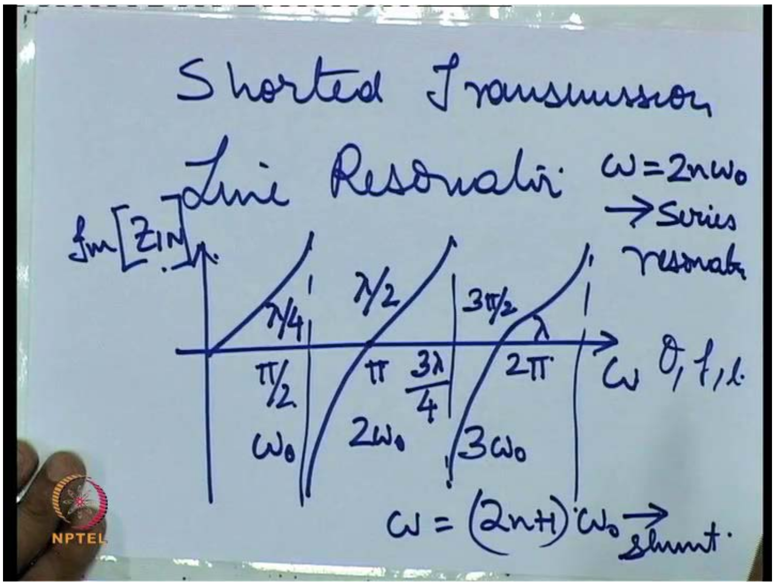

So, let us see the characteristic of a shorted transmission line. For a shorted line resonator, the imaginary part of the reactance, if we plot the reactance vs the frequency, then we get a curve like this which is a Tan function and this is periodic in frequency theta and L.

If we plot the values of theta or if you plot in terms of the length. Now, what we see is that for the shorted line resonator there are some particular values or certain frequencies omega 0 where the value becomes 0 and certain frequencies say here where the input impedance becomes infinite. So, we saw that for a series resonator, our input impedance should be low. So say for frequencies 2 N omega 0, this resonator, the shorted line resonator acts as a series resonator.

And say for omega equal to 2 N +1 omega 0, the shorted line resonator acts as a shunt resonator. Okay, so, the same shorted line can act as both as a shorted as a series resonator as well as a shunt resonator for different frequencies.

Now, coming this also gives a reason why address it, narrowband filters might actually be easier to implement than say broadband filters using lumped elements, the reason is that as we saw that certain microwave components like this shorted stub or open stub are actually easier to implement and hence and because these have a bandpass or bad stock characteristics, so they are actually easier to implement, these particular narrowband filters than say a broadband filter which has to be 1st designed using the lumped element equivalent and then of course lumped elements have to be converted into their distributed equivalent. Now, can we improve the performance of this shorted or open stub, can we do that?

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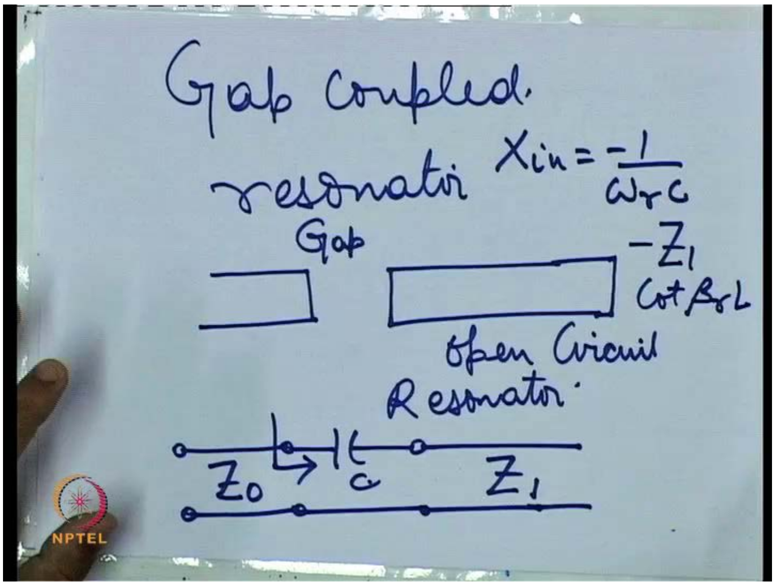

So, one way to do that is what we call a gap couple resonator. So, gap coupled resonator has a construction like this, this is our feed line, that is the mainline which connects our work resonator to the rest of the circuit, there is a gap and say we have an open circuit resonator. The equivalent circuit is like this. Now X in, that is the input reactance of this gap coupled resonator is equal to. Now, Beta R corresponds to the frequency omega R that is the frequency where this structure consisting of the gap and the open circuit resonator acts like either a series or shunt resonator.

Now, how do we find out that value of omega? To do that, let us let us see the construction, let us see the graph or how the reactance varies with this frequency, the reactance that I just drew.

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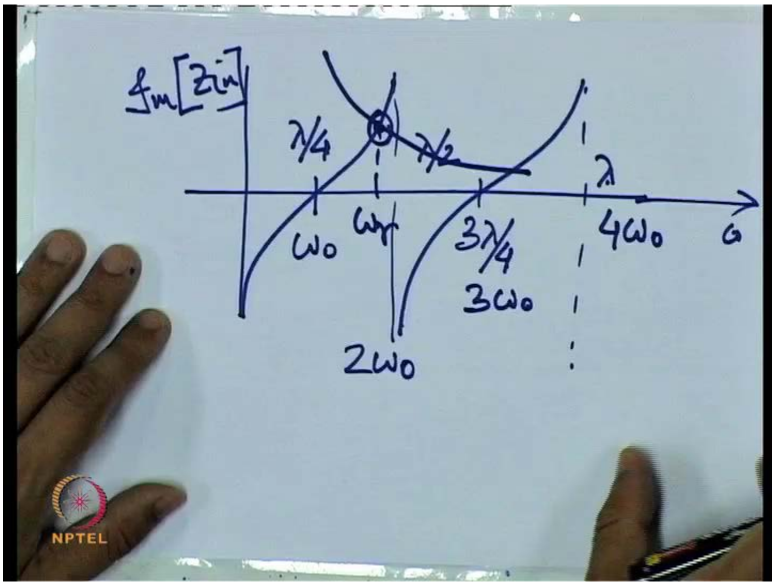

Now for and open circuit stub, the imaginary value of Z in or the reactance, input reactance vs omega curve looks something like this. Also in terms of omega 0, it can be written like this. And that capacitive reactance varies like this, so the intersection of the 2 gives the frequency where it will resonate.

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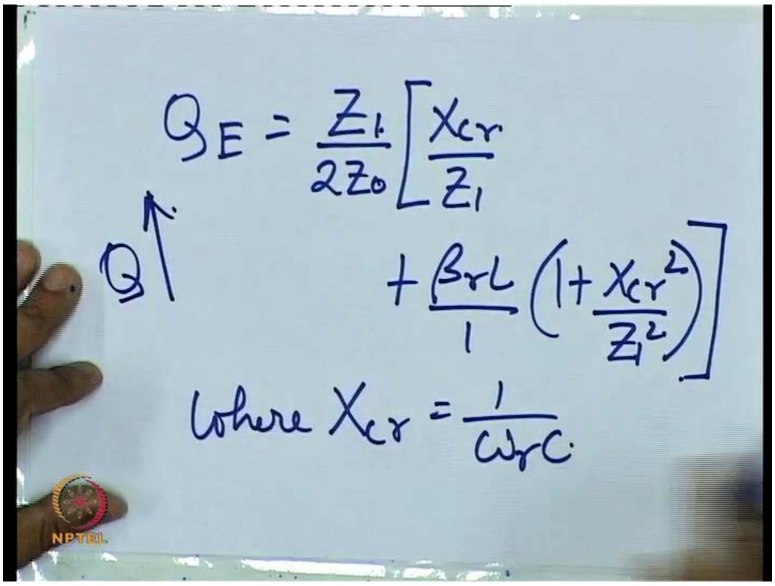

In fact the QE, suppose this resonator is connected to external impedance Z0, then the QE value for this gap coupled resonator, it can be found to be like this. The advantage of this is that we can get very high Qs, the Q factor that can be obtained is very high using this gap coupled resonator.

So, in summary, we saw how resonators can be easily built using some standard microwave components like shorted lines or open stub lines and how we can improve the Q factor of these lines using a gap. In the next module, we will see how using these resonators we can actually build the narrowband filters. Thank you.