

Design Principles of RF and Microwave Filters and Amplifiers
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Module No # 2
Lecture No # 10
Tutorial an Insertion Loss based Microwave Filter design

Okay so we come to this final lecture on microwave filter. So here will see some tutorial problems, we have seen a long journey we have started from the image impedance concept and how based on image impedance the low frequency filters were designed. Then we have seen that if insertion loss based filter design in image impedances already you are we have introduced the concept to high light the importance but those problems generally you can solve yourself also in the tutorial sheets will give some problems.

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TUTORIAL ON MICROWAVE FILTER

A maximally flat LPF, cut off freq 8 GHz.
 ↓
 Butterworth

min^m attenuation of 20 dB at 11 GHz.
 How many elements are reqd.?

$\omega_c = 2\pi \times 8 \times 10^9$ rad/s

$\omega = \omega_1 = 2\pi \times 11 \times 10^9$ rad/s $\rightarrow P_{LR} = 20$ dB.

$\frac{\omega_1}{\omega_c} = \frac{11}{8}$.

for $\omega \gg \omega_c \rightarrow P_{LR} \approx \left(\frac{\omega_1}{\omega_c}\right)^{2N}$.

$P_{LR} \text{ (dB)} = 20N \log\left(\frac{11}{8}\right)$

$\Rightarrow N = 7.23$

But let us see some insertion loss based design and suppose if we want to have let us say maximally flat. A maximally flat low pass filter is to be designed for cutoff frequency 8 gigahertz, minimum attenuation of twenty db at eleven gigahertz. So how many elements are required elements means how many inductance capacitance etc whichever elements how many required. So what you said I require that minimum attenuation should be twenty db and at what frequency 11 gigahertz.

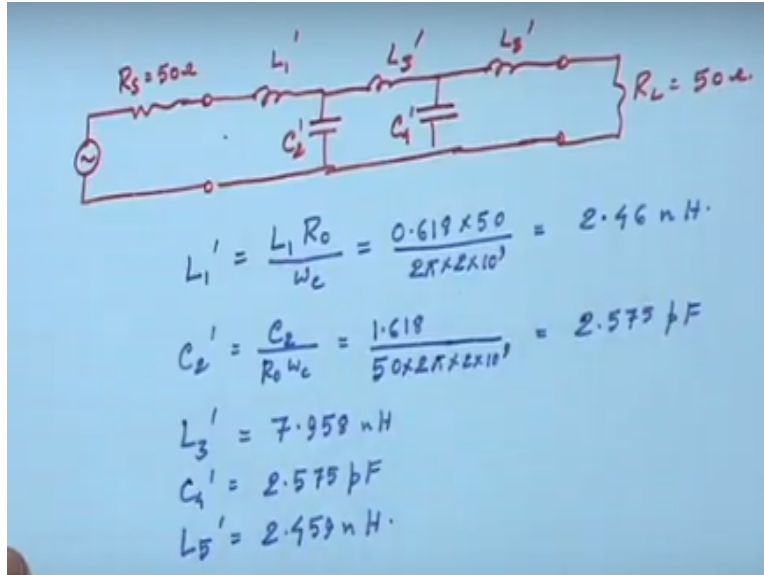
What is your, cutoff frequency is given as 8 gigahertz it is a maximally flat filter a low pass filter. So what I am saying is this is my cutoff this is my PLR, this is my ω_c . But I am specifying at certain other ω let us say 1 am specifying that it should be at least this. So you should achieve this is ω . So let us see that what is said that, what is ω_c is $2\pi \times 8 \times 10^9$ into ten to the power ten hertz sorry 8 gigahertz.

So 10 to the power 9 gigahertz and what we want at $\omega = \omega_c$ which is equal to $2\pi \times 10^9$ into 10 to the power of 9 hertz, not hertz ω cannot be hertz. ω is radian per second, this is also radian per second. I required that PLR should be 20 db basically this ω_c by ω that ratio is nothing but 11 by r . We know that for Butterworth type of polynomial this is a maximally flat means it is actually Butterworth function we can use to synthesis.

So for ω greater than ω_c we know that PLR sorry PLR can be approximated as ω by ω_c whole to the power $2n$ that means one term I can neglect. So, if I put it in db PLR db that will be 20 in $\log \omega$ by ω_c by ω_c . So 11 by 8 , so you solve for this it is given as 20 so 20 is equal put it as 20 . So that gives you any 7.23 now N needs to be integer now obviously it says at least 20 db so if I take N is equal to 7 it wont be at least 20 db.

So I know that since it is increasing here so since at least 20 db required i should take N should be equal to 8 . So there should be 8 order here, this is a simple one but you see this approximation of the function at higher value that will help us to find out what is the order of the filter. Next one let us say that again another problem that specification as maximally flat filter low pass filter, ω_c 2 gigahertz, load impedance 50 ohm and at least 15 db insertion loss at 3 gigahertz.

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You see cut off frequency 2 gigahertz far away I want may be at 3 gigahertz there is some interfering signal or into another signal source is there. So there I want to put it at least you should have a high insertion loss of 15 db there. Now again the first thing is like before also this is first we can find the num order N by previous method that PLR should be $1 + \omega C$ whole to the power 2. So that is 10 to the power 15 db so solving that N we are getting 4.22.

So we will take N to be greater than equal to 5 now let us take 5 and from 5 you find the prototype from Butterworth filter see the table for N is equal to 5 prototype values will be $G = 0.618$, $G_2 = 1.618$, G_3 is from the table directly you need not when that this will be given in a problem got or as an engineer you can always refer a tables and find out what are the values $G_6 = 1.0$.

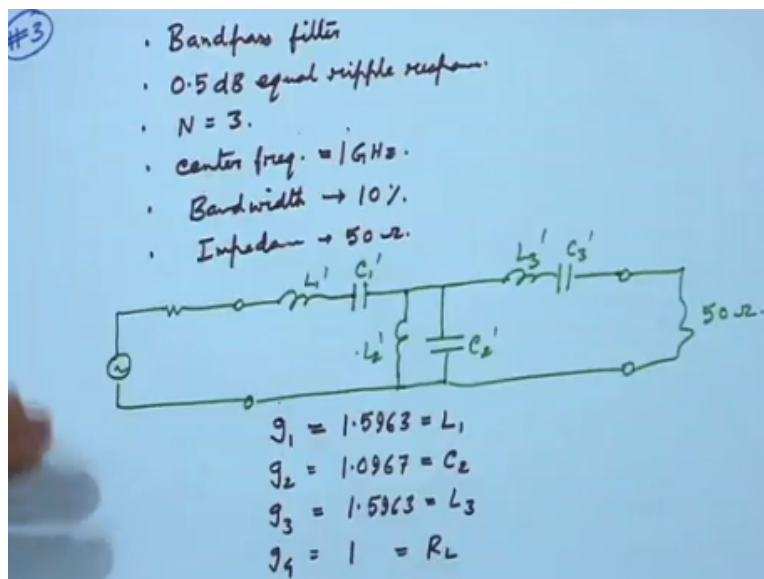
Now you scale up you know that from these values the first value. So I can draw that this will be the circuit I have the source then the source impedance that has been said to be 50 ohm this is a Butterworth filter. So in our prototype assumed as 1 that means G_0 is always 1. But here it is 50 so you need to scale with 50 at appropriate time that means our unknown value multiplier will be 50. And then we know the first element we can choose as L_1 .

So let me call L1 since it will be scaled both in impedance in frequency type is same. So no type change so I am calling it L1 dash, then this will be C2 dashed, this will be L3 dashed, this will be C4 dashed, then this will be L5 dashed, then I need to stop and the load impedance will be again $R_L = 50 \text{ ohm}$. So what will be my value for L1 dashed if you see your notes this will L1 R0 omega C and what is L1? L1 is nothing but your G1 this is 0.618.

So 0.618 into 50 by omega C which is $2 \text{ pie into } 2 \text{ into } 10 \text{ to the power } 10$. So this will give you a value of 2.46 nano henry, then C dashed will be C2 by R0 omega C now C2 you can see that it will be 1.618 from the table 1.618 by 50 into 2 Pie into 2 into 10 to the power 9 = 2.575 picofarad. Similarly, I think now you can go on you own L3 dashed you can get the value 7.958 nano henry. C4 dashed will be 2.575 picofarad and L5 dashed is equal to 2.459 nano henry.

And so this is the example of a prototype filter design but we also scaled up prototype was first from the table. We could have found the prototype but we have scaled up in impedance and frequency. Now we will see a type change, type of thing so our third problem is this. That design a band pass filter having a .5 db = ripple response it is given that you take $N = 3$.

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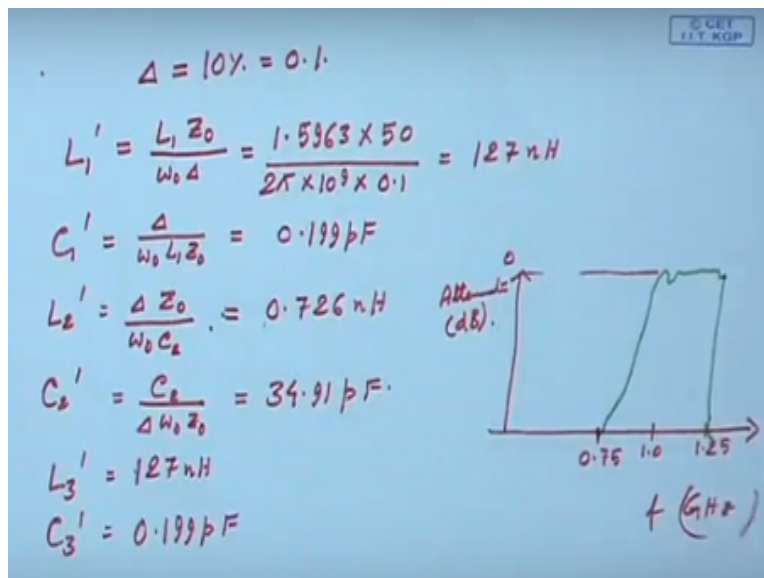


The center frequency that means our ω_0 is 1 gigahertz bandwidth percentage bandwidth is 10 percent and impedance level is 50 ohm. So we can you see $n = 3$ said so basically we will have how many the 4 things from table G0 always this one. So what value this okay so I can take the

circuit is like this. First element if I take L1 dash second because this is band pass so I know any L1 is basically L1 C1 dashed. Then L2 is L2 dashed C2 dashed then L3 test C3 dashed and that 3 = 3 finally it will be terminated by 50 ohm.

Now where from my get all this L1C1 values from the it is equal repel so Chebyshev so I see Chebyshev is equal to 3 I get $G_1 = 1.5963$ that is L1. L1 of the prototype G_2 that is $1.0967 = C_2$, $G_3 = 1.5963$ again from the table L3 and G_4 remember it is Chebyshev with N0. So no problem G_4 will be 1 and that is nothing but your RL. Now you can easily find out L1 dash C1 dash from L1. What is this that delta value, delta they say 10 percent that means 0.1.

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So what is my L1 dashed L1 dashed is L1 Z0 by omega 0 delta, so it is L1 I have seen 1.5963 into fifty divided by 2 pie 10 the power 9 into .1 that comes 127 nano henry. LC1 dashed again it will depend on L1 the formula is delta by omega 0 L1 Z0 so that you can put and it will be 0.199 picofarad. L2 dashed again is delta Z0 by omega ZC2 and that will be 0.726 nano henry and C2 dashed will be C2 by delta omega 0 Z0 and that will be 34.91 picofarad.

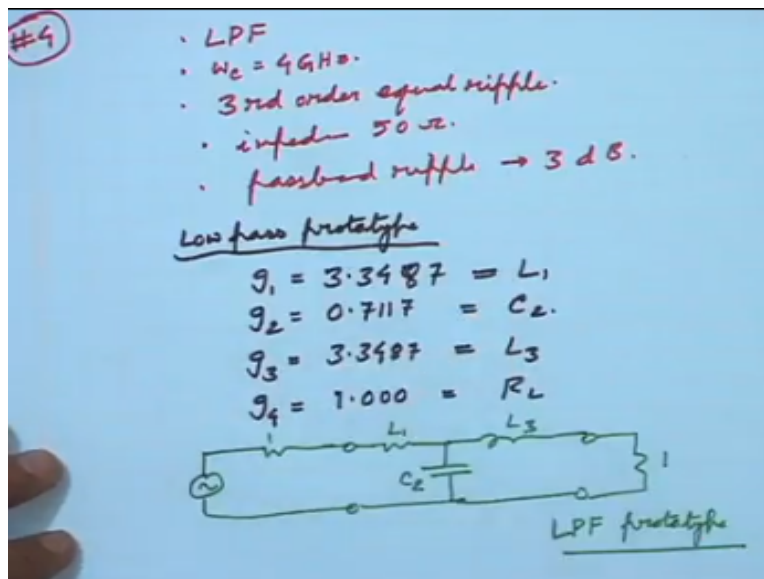
Similarly L3 dashed it will be same as this 127 nanohenry and C3 dash will be 01.99 picofarad. So if you can plot his you can with this you can plot this attenuation. Obviously that require some computer programming this attenuation curve goes like this. This is 0.75 this is in gigahertz

frequency 0.75, 1.0, 1.25 roughly the curve is some ripples, when it comes to 1.25 and generally this ripple is around 0 db approximately.

So this type of graph so this is a band pass to see now let us see a another problem that suppose that was I think four let us say band pass filter design we have seen now implementation wise you see that design let us say a low pass filter cut off frequency 4 gigahertz third order equal ripple that means Chebyshev with $N = 3$, then impedance is 50 om and pass band ripple is 3 db.

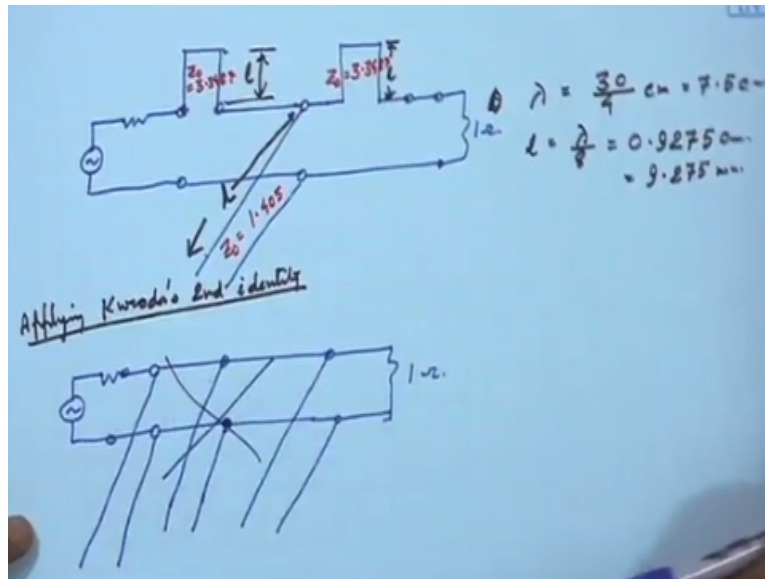
So easily third order so we can find out low pass prototype so here from table we can see from Chebyshev third order again you see the final one RL should be 1 so G_1 is 3.3487 and that we can call L_1 . First one will take L_1 series element then then G_2 is 0.7117 let us call that C_2 , G_3 from the table is 3.3487 and that we call L_3 and G_4 again I said Chebyshev with N card third order so this is 1 and 0 this is RL.

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Let me draw the circuit, but this is one prototype this is my L_1 , this is my C_2 and this is my L_3 . Then I have this as 1 good this is prototype, LPF prototype. Now from this these are all lumped elements I know the values but I need to do Richard transformation so I need to put those Richard transformation value. If you do that then Richard transformation will look like this you see your notes that this first one is L_1 .

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So that is a series stub I will have a series stub, this is a series stub and that is L_1 so I have to short it. So what will be the value you see that time we said that this L will be the characteristic impedance the length of the stub will be unit length λ by 8. So that we are calling that this characteristic impedance is that this is Z_0 is equal to 3.3487 and this length is L .

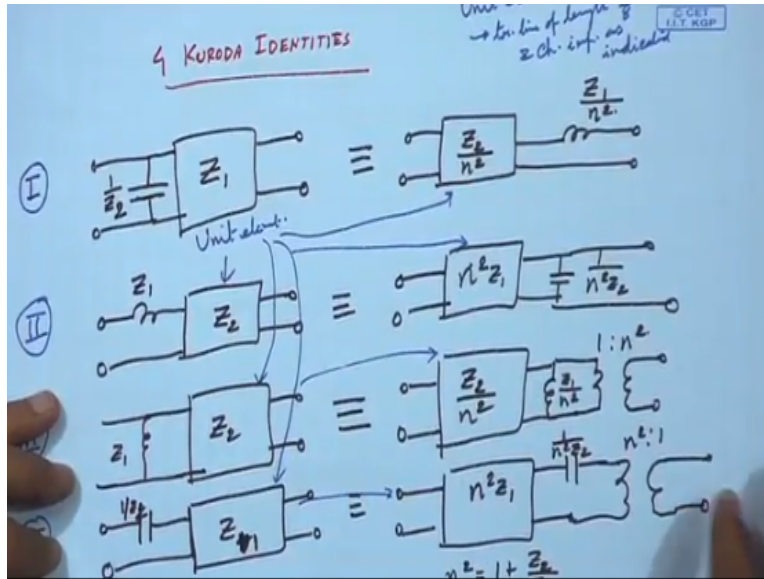
Then we will go the C_2 will have to put C_2 is Shunt so will have to put a shunt stub with open circuit and this L again will be that same λ by 8 at the cut of frequency that means λ by 8 at 4 gigahertz. So what is the value of L , is 4 gigahertz $\lambda = 30$ by 4 centimeter, that is 7.5 centimeter. So $L = \lambda$ by 8 is 0.9275 probably if am correct centimeter or you can say 9.275 millimeter.

So all these lengths are this and what is the characteristic impedance of this C_2 that this is G_2 value is 0.7117 will have to take inverse of that so that will become Z_0 is 1.045. After C_2 I have a series stub so will have a series stub and then will have a short head it is a impedance inductance so and then from there this is a resistance 1 ohm. So what is this value again let me say that this is L and Z_0 is 3.348, so now this is this is after Richard transformation.

Now if it is implemented okay but if we think that okay why do not have uniform type of shunt things because making shunt stubs are easier than making series stubs. So if we want to do that

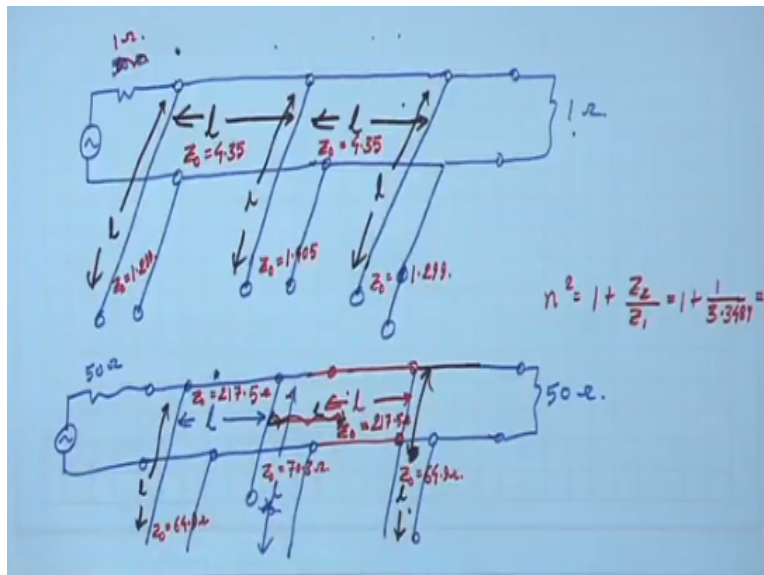
you see that series stub was where in Koroda's identity yes so see kuroda's identity so series stub I want to make shunt stub so kuroda's second identity I will use so using kuroda's second identity.

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So let me write applying kuroda's second identity this new circuit becomes very systematic procedure this thing so instead of this I will make a shunt stub then again already there was this one. So then so what we have done that here we have put because after the stub if you can see the second identity that you put a unit element and then a but your stub so that means sorry here actually.

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Let me redraw because the element should be drawn first so first will have to make one unit element and then that element will having anything then we will have our original L1. Then again we will put another unit element and then will push that so you see this is 50 ohm these are now I will say L length all are L lengths L is Lambda by 8. So there are three search and this is also length L unit length this is also unit length L.

So all lengths are L only they differ by their characteristic impedance so that first one Z0 you see that what happens to N square. N square is $1 + Z2$ by $Z1$ and you see our $Z1$ our $Z1$ is 3.3487. so $1 + Z2$ is 1 and $Z3.3487$ that gives the ratio as 1.299. So with this the first one will have a characteristic impedance of 1.299 then this one if you that the Z0 for is unit element that will be with that ratio 4.35 then this one $Z0 = 1.405$ and this one is $Z0 = 4.35$ and this one is $Z0 = 1.299$.

This is the original capacitor, so that you see that is why this is difference but these towards same. Now you can have the this instead of this one ohm I have impedance level as fifty ohm so fifty this was 1 ohm, now I need to scale up to fifty ohm. So all these values I will scale up and I will write this is fifty ohm then we will have this stub length again L and Z0 Is this 64.9 ohm just scale up by 50 into this.

Then I will have again this is of length L a length L and this is $Z0 = 70.3$ ohm 1.4 into 50 ohm then you go another, here there was one L and this L has a Z0 of 217.435. So 217 by 5 ohm then here again this is L and again the Z0 is 7.3 L will be from here but here to here there will be another line and there the length is L $Z0 = 217.5$ ohm another unit cell then we have that the from here another stub.

So that again is Length L this length L and this stub will have $Z0 = 64.9$ ohm and then we will have this fifty ohm line okay. So you see I have now see these stub and also per unit cell 2 unit cells stub but they are not stub they are transmission lines these towards these three are three open circuited stub this is for the first inductance, this is for the capacitance, this is for the inductance L3 and this are unit cells. So now with length sizes are manageable I have separated them now these unit cells are called redundant sections.

They are matched so that is why they are because they are impedances are both sides they are matched to one that is why they do not disturb the operation of the filter. But what they do they become separates the two so that two stub elements there is enough separation between them. So that any in the discontinuity any high even as a modes that gives generated that can be tackle there.

Particularly at higher level frequencies if any in discontinuity those points there is any other modes generated that comes because this we are implementing by transmission lines but in other microwave filters we need to do it by wave guides etc there that type of problem may come. So this completed the microwave filter design hope from the very basic point of filters just from RC filter we have started. Then we have seen need to have LC filters for radio frequencies because RC filters are lossy.

So went into lossless LC filters, there we have seen how to design from image impedance concept. Then we came to the concept of characteristic impedance we said that our network will be symmetric, will have instead of two impedance many impedances one characteristic impedance, that characteristic impedance will try to control but we saw that there are lot of problems of impedance matching etc, that can be tackled.

But another viewpoint is if we tackle the insertion loss if we specify the insertion loss of the whole filter then we can synthesis any desired insertion loss characteristics and by that we have seen first we need to do a low pass prototype filter design, and once we have low pass filter design we can scale it up either in impedance or in frequency or in type we can change the type, and we can have any desired type of filters with any desire it. Then we have seen that if we want to implement it as high frequency of microwave type of filter then we need to implement not to lumped the circuit elements but distributed circuit elements.

So how to do that we have seen thru Richard's transformation you can do that distributed transmission line implementation and then to have some realizable gaps or to convert one stub to another how to do that so for that we have introduced 4 Kurodo's identity. Any identity you need to choose for you particular application and you apply the method is straightforward it can also

be implemented on a computer and you can do that whole things in you think that type of simulators etc are available.

You can use that but once you know the basic principle design then you use that then it becomes meaningful otherwise you won't be understanding what is happening? what is the principle microwave principles formula this is there so we hope that with this you have got a thorough knowledge of microwave filter both it is design and implementation also you will be able to analyze any filter design from this view point.

After this we will switch over to another very important microwave circuit thing that is amplifier it will be an active based device design this is filter was passive but microwave amplifiers there will active device base we will see that in the rest of this lecture series. Thank You