Design Principles of RF and Microwave Filters and Amplifiers
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Module No # 1
Lecture No # 05
m-Derived Prototype Filter Design

Welcome to this fifth lecture of this lecture series, now in the last lecture we have seen how to design constant K filter section using image parameter method today. We will point out 2 major drawback of this design we look the graph yesterday we have drawn these graphs that the characteristic impedance of the section for, if we take a T section the characteristic impedance falls from a constant value K at zero frequency to 0 at cut off frequency.

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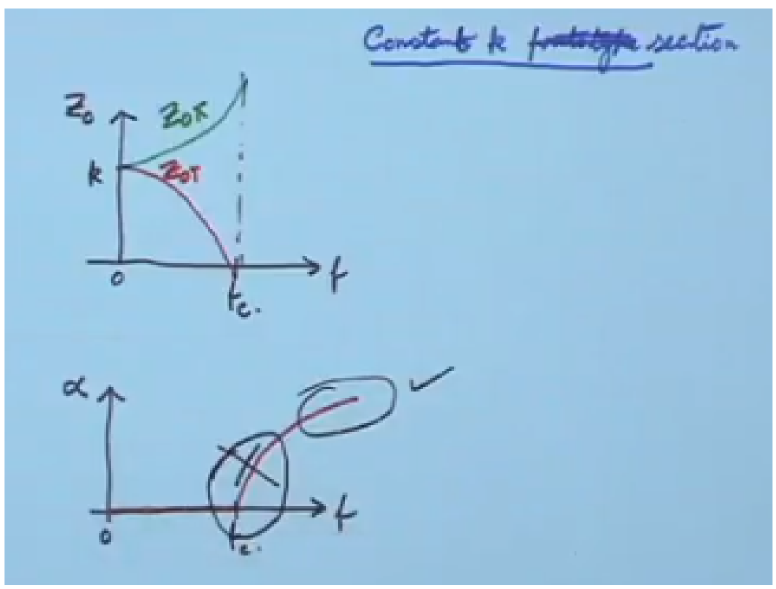

So characteristic impedance is changing so it is a problem for matching the filter section impedance matching. Similarly this is the graph for the PIE section characteristic impedance and you see here also from constant K it goes to very high value so it is very difficult to match this. So if we cannot match there will be reflection and some power will be lost so even if we are using a lossless filter due to impedance mismatch between source and load side there will be some problem.

And that needs to be rectified also if we look at the attenuation constant graph. We see that ok in the passband from that means frequency from 0 to FC the filter is ok this is low pass filter the it is ok there is no attenuation. But once it crosses the pass band the stop band there is attenuation that is also desirable. But you see that near this cut off frequency near this zone the attenuation value is not much.

So if I have another channel very near to this cut off frequency or another radio signal then the attenuation won't be much. Once it is separated by reasonable distance then it goes to high value and it is also desirable that when omega is very high the attenuation is infinite that means this portion that is ok but this portion in some application may not be acceptable because we want that stop band there should be a good amount of attenuation.

But near the stop bandage for this constant K section the attenuation is not much that is why this is also another problem. So these 2 problem motivated people to design a better filter section that design is called m-derived filter section. So what is m-derived filter almost same as our constant k filter I start with PIE I start with T section so this is same as T section it is a symmetrical section reciprocal element, lossless element all these are reactances.

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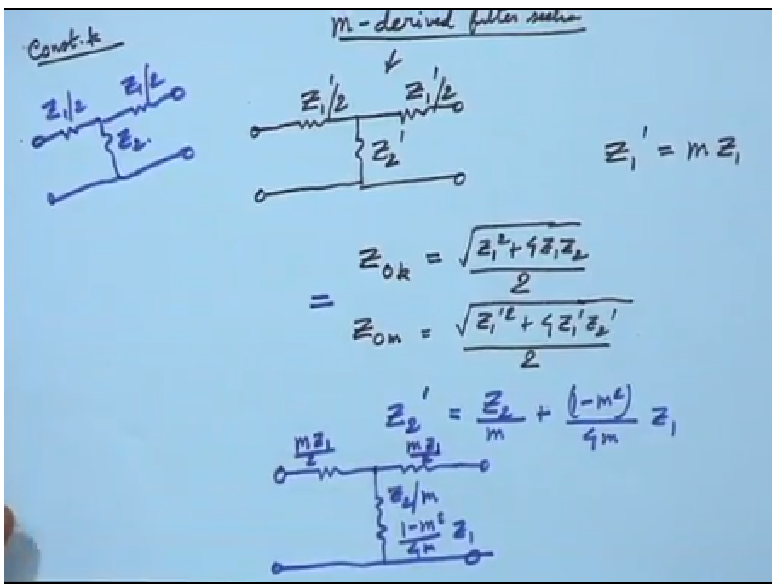

So I call now the new series impedance as Z1 dash by 2 so I am using a dash or primed quantities to represent this and this I call Z2 dashed so this is empty right now. What was our constant K? that was Z1 by 2 , Z1 by 2z2. This was constant K today we are saying it is Z1 dashed now is M-derived so how this m terms come the actually we let Z1 dashed = MZ1that means we just M is a parameter we multiply Z1 dashed with this parameter.

And then we want to keep the characteristic impedance for same with contact K. So what was the characteristic impedance of constant K. If I am calling that Z0 this time I am using a subscript k to remind you that this is constant that was root over Z1 square + 4 Z1 Z2 by 2 and the new m-derived filter characteristic impedance will be Z1 dashed square + 4 Z1 dashed Z2 dashed by 2 now we do not want to disturb this characteristics impedance.

So we equate this 2, so we say that this 2 are equal, once we say that then we can find out Z2 from here because Z1 dashed we have expressed in terms of MZ1. So by solving I get Z2 dashed = Z2 by M + 1 – M square by 4MZ1. So if you remember that Z1 and Z2 they are the impedances of the series of the shunt term of the constant K section.

And if you remember that always should have interaction they should be of opposite nature that means if one is chosen as L and another is C and depending on whether I choose L in the series are (()) (07:18) see in the shunt term I get a low pass or high pass action etc. So now you see that this equation says that Z2 dashed it will be now 2 elements one is a scaled version of Z2 and in series with is scaled version of Z1.

Ok so the new m-derived version of section I can derive as you. So this will be Z2 by m and this will be 1 – m square by 4mZ1. So it is a series circuit in the shunt term. So this is the new design so we have seen the propagation characteristic impedance now we have already known that filter has 2 fundamental characteristics. One is characteristic impedance another is propagation constant let us see what happens the propagation constant in this case.

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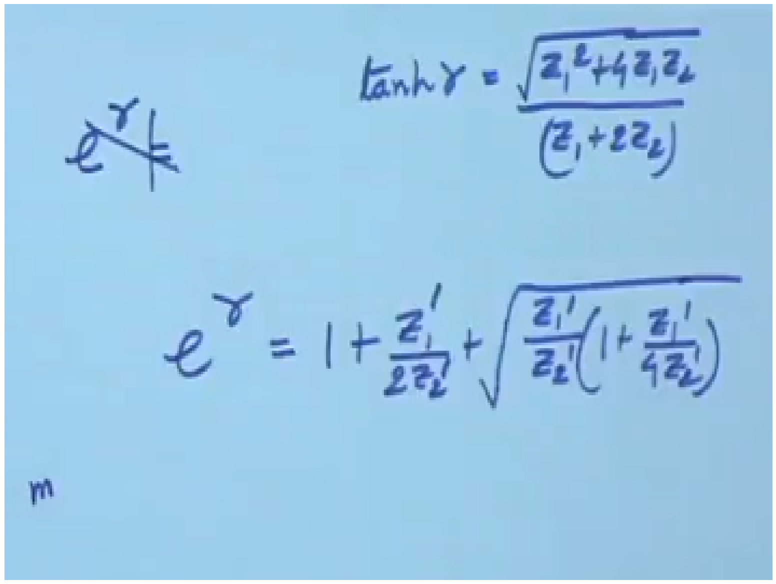

So this propagation constant if you remember that yesterday we have derived this TAN hyperbolic gamma = root over Z1 square by 4Z1 Z2 by Z1+2Z2. So from here we will have to find our e to the power gamma it is easy to do because this TAN hyperbolic gamma = SIN hyperbolic gamma by COS hyperbolic gamma and you know SIN hyperbolic gamma is e to the power gamma – e to the power gamma by 2 + COS hyperbolic gamma is e to the power gamma + e to the power – gamma divided by 2.

So if you that and then some component or dividend as a break manipulation, you get the value e to the power gamma. So e to the power gamma will turn out to be simple mathematics 1 + Z1 by 2 Z2 + root over Z1 by Z2 1+ Z1 by 4Z2 this is the expression we always we get. Now we are looking for m-derived section put prime quantities here e to the power Z1 dashed okay.

So this is the expression for e to the power gamma now from these since we know the values of Z1 and Z2 dashed. We can find out for the particular type loss pass or high pass that what happens to gamma and once we have this expression for gamma we can enforce the stop band and pass band specification and from that we can find out what is the stop band pass band etc., So let us do that for m-derived low pass filter.

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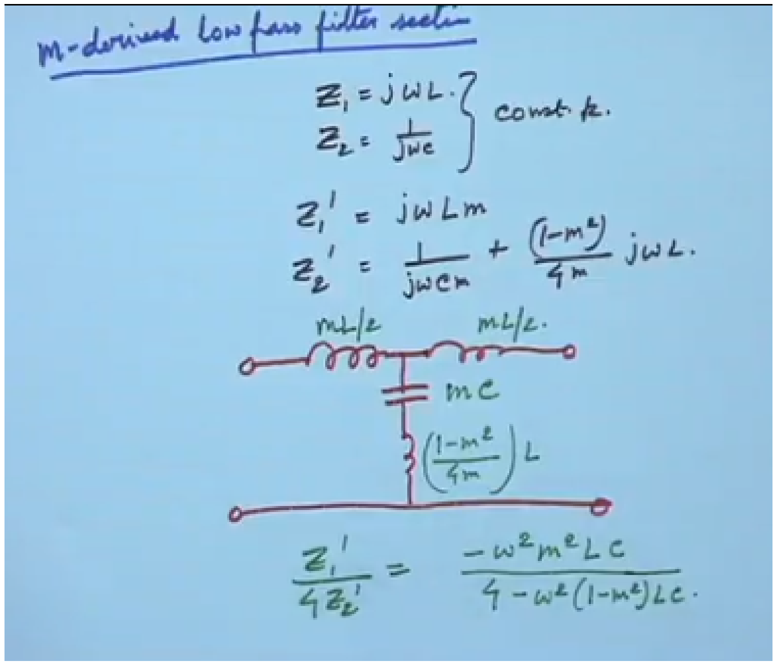

So you know we need to choose Z1 in constant K we choose Z1 = j omega L Z2 = J omega C this is constant K so Z1 dashed for m-derived section will choose as J omega LM and Z2 dashed as 1by j omega CM + I – m square by 4m j omega L. Okay so now I can draw the in the component level this will look this like that I have so this will be ML by 2 and this will also be ML by 2 this will be M into C and this will be 1 – M square by 4M into L.

Okay so this is a m-derived section so find out as I said what is the propagation factor now if we look at the propagation factor expression there is a this important factor Z1 dashed by 4Z2 dashed. If I know that I can find out a lot because these factor always you see at Z1 dashed by Z2 dashed, Z1 dashed by 2Z2 dashed.

So if I can find this then I can have various I can easily find out the propagation factor so let me find out what is this value Z1 dashed by 4 Z2dashed you will be able to do this because Z1 dashed expression is given Z2dashed expression is given Z2dashed expression is given if you do this it turns out to be like this good.

So now once we have this term we can enforce pass band we know that always for this image parameter method this pass band is like this pass band is when -1 less than Z1 dash by 4 Z2 dash less than zero. So this if we manipulate we get that 4 – 1 – M square omega square LC by M square LC greater than omega square greater than zero.

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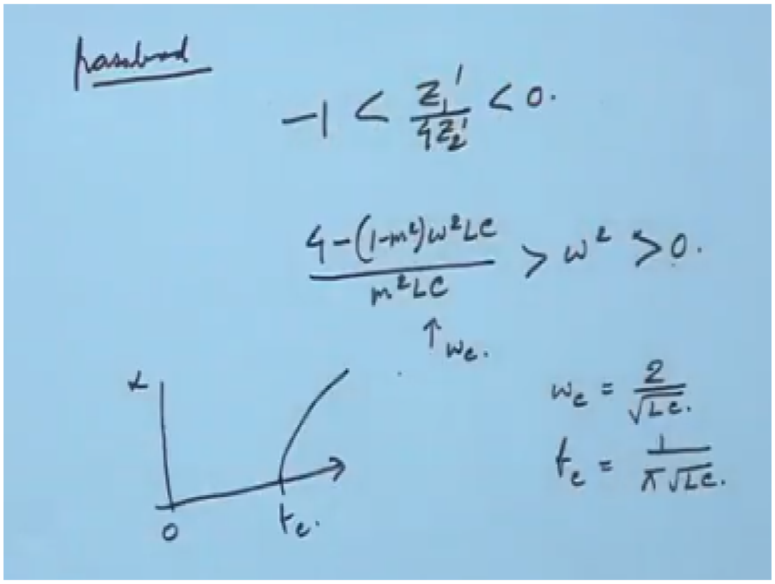

So as we do that you can put this part that means the pass band is extending from 0 omega, omega = 0 2 omega = this value we can say as omega C and then we can solve for that and that will turn out to be omega C is 2 by root over LC or FC root cutoff frequencies 1 by PIE root over LC. So you see that for M-derive section also the cutoff frequency same so the pass band extends from 0 to FC that means 0.

So alpha will be something like this so there is no change in the low pass filtered structure. So then, what is the stop band is as before you know that again since I have this quantity so I can enforce that if this quantity is either it is greater than 0 or it is less than -1 I have pass band. So from that I can say that the stop band according to our yesterdays nomenclature stop band one will come out to be when F is less than 0.

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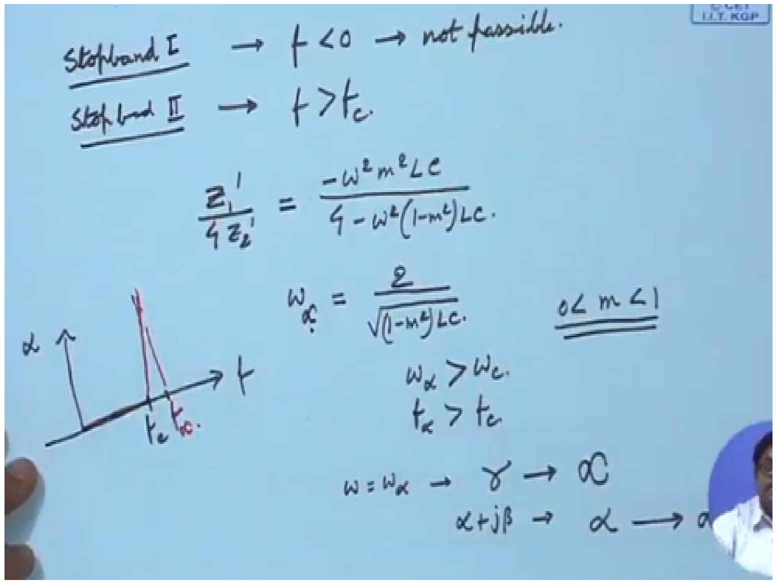

But we cannot have less than 0 so it is not possible so we did not bother about this stop band and the stop band 2 that will be greater than FC obvious that is why I have done like this knowing that these FC will be like this. Now then what we have gained in m-derived section the cutoff frequency is same etc the we have enforced the characteristic impedance to be same as constant K section.

So then what we have gained to see that look at Z1 dashed by 4 Z2dashed expression carefully I derived that again here that get Z1 dashed by 4Z2dashed this is omega square m square LC by 4 – omega square, 1 – m Square LC now look at the dominator. There is a chance that denominator may go to 0 and if that goes to 0 this whole thing will become infinity so that is a crucial point it was not present in constant K let us solve this.

Let us say that when frequency what if happens let us call that omega infinity, because this will go to infinity there. So what is omega infinity if we solve we get that omega infinity = 2 by root over 1 – m square LC. So what is my omega C for constant K 2 by root over LC omega infinities 2 by 1 – M square LC okay.

You see this is omega C, so if I enforce that M is a parameter that I will choose I will keep it within 0 to 1 it is in my hand designer fan if keep it like this then omega infinity is greater than omega C or F infinity is greater than omega C that means if infinity is in the stop band 2. So in this band there is a this thing but what happens to the alpha there let us see the e to the power gamma expression that will indicate what happens there.

So you see that e to the power gamma expression now here this term is going to infinity now obviously at that point this term will also high so you see this is infinity then this is also infinity so the whole thing is infinity. So can I say that at that point gamma at omega = omega infinity my gamma goes to infinity so gamma is very high.

Now what is gamma is alpha + J beta we have proved that we are at stop band 2, so at stop band 2 what is the we know that beta is a constant = 2M – PIE so let us say PIE. So beta is constant and but alpha + J that is very high so that means we have alpha also is going to infinity there. So that was the thing we were looking for when I said that the problem of this constant K section is near FC I do not sufficient alpha.

But I see here that I can place a pole very near to FC, because that I can control by choosing this parameter M because where is FC this is where is F infinity with respect to FC that is in my hand because I can play with this M value and I can put anywhere and then I can modify that ok the attenuation constant graph alpha this is FC.

Suppose I put so obviously here that it will come like this but when I have a choice that if I put suppose F infinity here then I can force the curve like this assume (()) (22:00). So I can give a very high attenuation just when I enter the stop band which was desirable because many application says that do not disturb your neighbor channel so there I can put sufficiently high attenuation. So how we are able to do these F infinity.

You look at this structure of M derive section basically I have a series circuit this series circuit if it goes to resonance that gives that high attenuation. So it becomes a resonance circuit let us check whether we are physically it is correct or not. So we know that if we have a series like this what will be the resonant frequency F resonant for that will be FR is equal to what that 1 by 2 PIE root over MC into 1 - M square by 4 M into L this M goes and so I get 1 by 2 PIE root over 1 - M square LC which is nothing but my F omega.

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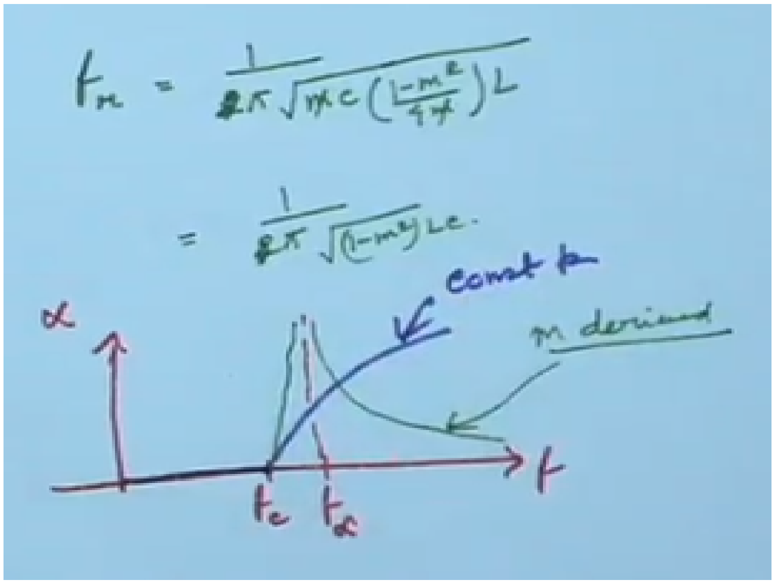

F omega is this by PIE this so that shows me that F physically that is the case since I have this series resonance circuit. I can make it resonated F infinity and by that I can put very high attenuated in the stop band. But the price I pay for that is unfortunately these thing that after F infinity the curve is like this. So alpha gain falls so I also want that at very high values or all further values attenuation should be high.

But you see attenuation is falling due to this M derive section. So I can solve 1 problem but then in constant K this was not a problem in constant K it going exponentially. So in constant K where is the constant K, so in constant k it was rising so at very high frequencies it was high. But due to my paying I could solve the problem here but I have created another problem here.

So this is a problem that so it intro once again the attenuation constant of M derive section that there will be FC there will be F infinity now I can put it shows that I come here then it goes to very high value and then it falls like this, this is a M derive section alpha attenuation constant. So what is the remedy, remedy is we need to put in cascade this these a constant K filter section, let us see that is the constant K filter that we have seen that time that it is thing something like this.

So here you see this is a very sharp increase I wont have any problem this 2 in the cascade when I put alpha will be almost like this and here also it is a very sharp decrease so it will be dominated here also like this but then here you see that this constant K section this is constant K this is M derived. So, if I combine then I get something which is called composite filter.

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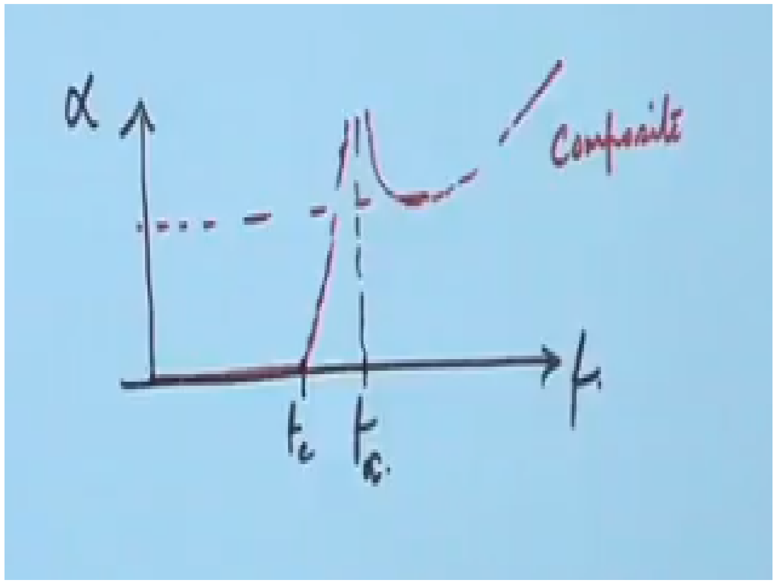

So I get a attenuation constant frequency that let me mark FC, let me mark F infinity it is these then it and it goes almost like this then it comes and then goes like this so this is called composite of M derived in cascade with a constant K. So there you can see that I will have to be careful about these part, that these alpha should accept this part for the application that means nearby neighbor or next to that channel there is a low attenuation but if this is sufficiently high this level for that application.

I can go with it I am dash dash that is henceforward it will be higher and higher attenuation. So these you see that I have started with 2 problems that means this alpha was not very high here. So that at least with its composite design I have solve this problem but these problem is still unfinished. Because we have enforces M derived section to be have same Z0 variation with constant K.

So, characteristic impedance problem I have not solve M derived section has not solve the problem but what people do then to match the section there are some extra matching section at the load end and the source end they put so that makes this whole filter think a bit bulky and all. So that is the problem with image parameter method but something is done and throughout this development for last sixty seventy years people have used that in telephony in radio, radio reception etc this filters were designed from this image parameter method.

But as we sure that this problem can be solved if instead of all these problems that means we try to find out. Okay if we choose these how would happen if we can say that from a specification I will specify what is my stop band attenuation, I will specify what is my stop band phase sorry pass band phase I will specify what is my pass band attenuation that should be 0.

So all these if I space always 0 is not required because in application I require that okay to a sufficiently low attenuation so I will specify that and that If we can find out that what type of filter components that means what LC values how they are interconnected there if I can find that means are basically a synthesis type of thing that I will specify some attenuation characteristic and from that you find out which section which components can achieve that so that is called insertion loss based filter design.

All high frequency filters microwave filters are based on that so that will take up in the next lecture but these up to this this image parameters based filter design that give us insight about what happens in a filter. What is the characteristic impedance thing how it is very important for matching the filter and also how to specify pass band stop band of a filter from the propagation constant point of you. So that is the basic foundation on which we will see how insertion loss base filter design can be attempted come to the next class.