Design Principles of RF and Microwave Filters and Amplifiers

Prof. Amitabha Bhattacharya
Department of Electronics and EC Engineering
Indian Institute of Technology - Kharagpur

Module No # 1
Lecture No # 01
Image Impedance based RF Filter Design

Welcome to this course on design principles of RF and micro filters and amplifiers first week theme is microwave filter design. Today is the first lecture here, we will not enter into the microwave filter design but before that we will today see image impedance based filter design. Basically this is radio frequency filter design at a much lower frequency than microwave filters.

Microwave filters are starting from gigahertz etc., we have already seen in earlier impedance courses that at micro frequencies the wave propagation is not TEM only there are TE, TM etc., waves are all modes are also generated in microwave. So microwave filter design should account for that, but before that already we have seen radio was invented even before that when telephone was invented and telephone kids was developed.

There was a need to design analyze, the filters that can separate one frequency from another think of this airspace. Many radio stations are transmitting radios signals here, now if I want to listen to a particular suppose All India Radio I need to tune my radio receiver for that. So out of various frequency signals we tune to a particular frequency RF signal to do that we required a tuner which is nothing but a LC filter.

In your basic B.Tech courses on electronics engineering, you have seen RC filters, a simple RC circuit, TR circuit or LR circuit or RLC circuit they also are used as filters but all of them are lossy filters because of the presence of the resistance but in a radio frequency transmission reception etc., There we need to maximize power, so we do not use any lossy filters there. So the basic premises of our filter design your RF filters lossless filters. Now you know that if you have a LC circuit is a resonance circuit it as an IQ.

So for a very at a particular frequency which we call very narrow band the filter tunes and then receives the signal which is that case the radio receiver filter. But there are applications where always we do not need such IQ or we need to have a band of frequencies which need to be passed and all other bands to be suppressed. So a narrow band LC filter or a resonance circuit, first order resonance circuit, LC circuit cannot serve that purpose because it just select one frequency suppresses all other frequencies.

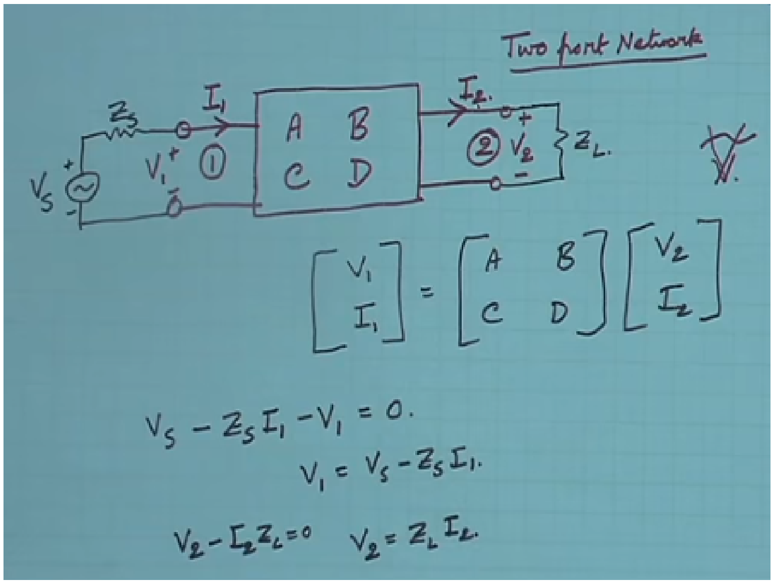
So RF filters by that we mean that there should be band of frequencies which we will specify and accordingly filter will pass that and all other frequencies it will try to suppress ideally all other frequency should be attenuated by infinite amount but no real filter can do that. But it will be attenuated to sufficient amount, so that it does not disturb others.

Now we will see that, since we are talking about lossless filters, the filter elements or the elements of the filter network they need to be reactive there should not be resistance with that. So this reactive networks who has this property that all the band of frequency are passed or transmitted unattenuated and a band of frequencies are rejected completely or stopped that two port network is called filters.

Scientist J A Cambell and O G jobell where the starts to look into analysis of this filters they were engineers in BELL Telephone Laboratories and from that date the RF filters has been designed, developed and used extensively in all application were you need to play with RF frequencies. Now all this filters are symmetric network, composed of symmetrical network section.

All of you familiar with 2 port network, now we will start this analysis, because this is a, in B.Tech course this is included but many times this is not so well understood that why we are, this first lecture refreshing of that the thing is, the lecture topic is image impedance based lossless RF Filter design. Now we will introduce image impedance bit later but I start with a two port reciprocal network, a two port reciprocal network you know that a port have two terminals.

(Refer Slide Time: 06:49)



So let us say this is my port 1 and this is my port 2, another 2 terminals I call it port 1, port 2 I have some network here electronic network. So I described, you know that any two port network, electronic network can be described by several parameters either J parameters or Y parameter or H parameter or G parameter etc., Also you know that there is a parameter called ABCD parameter, which I take here why because this filter, finally I will arrive at filter, so this 2 port network will be filtered.

Now this is always in cascade it is connected in the input site to something, it is connected to output site with something. So it is in cascade so we need to find out how the RF signal transmits here through this network so ABCD is transmission parameter. All of you are familiar with this definition etc., so I will use ABCD parameters for describing this 2 port network. Also this model you see this is not a low frequency model here this voltages current etc

They are TM mode but the transmission line is distributed, it is based on distributed line parameters. So voltage current etc are actually there are voltage waves. So there is always at the depending upon the load and the level of impedance of this network there is a possibility of reflection of waves. So keeping that in mind we know that if they are reflection then actually the model is a distributed line model where voltage incident waves and reflected waves both are present.

So voltages currents they are complex in nature in this type of circuits, this is called as RF circuits. So our port voltages, port 1 voltages, port 2 voltages, port 1 current, port 2 current. They will be also **(()) (09:33)** quantities they have both magnitude and phase, so they are complex voltages and complex current. So I start that let this port 1 as a voltage given by B1 generally we say that complex voltage. We prefer to represent by V with the Tilda at the top that is complex voltage.

But here since all the quantities are complex voltages I do not use these thing I do not put the tilda, I say B1 but you should understand that is this actually a complex voltage. If you want you can have your own notation B1 with the Tilda on top. So at port 1 the voltage is B1 complex voltage and the current entering port 1 is I1 again a complex current. Similarly at port 2 I have the terminal voltage as B2 as shown and I have current which is leaving this port I2 complex current.

Please note this direction of current, generally in all other 2 port parameters Z, Y, H, G etc the I2 is the current entering the port I1 is current entering the port 1 I2 is current entering the port 2. But in transmission parameters, since actually the wave transmits like this I2 is directed away from the port, now this obviously, I will connect with the source. This is the network this ABCD parameter this port parameters completely describes the network.

I need not know what is inside if I know ABCD, I know how the network will behave when I excide with a particular voltage and current. Now I connect with this a voltage source, complex voltage source obviously an SC Source. We are not talking of DC voltages it is an RF circuit. So, I call that generator as BS and SC source with assume polarity like this and internal impedance is ZS.

So voltage source with internal impedance ZS is connected to port 1 to excide this network and there will be some other thing, electronic blocks, electronic 2port blocks but for this we assume that is acting as load impedance all this load impedance and source impedance they are complex in nature generalized impedance okay. So once I have this you all know that i can describe this

V1 I1 and V2 I2 with the help of an ABCD matrix so I can write B1 by I1 is equal to ABCD V2 I2.

Now with this loaded condition, that means with the source voltage and generator and load. I can write that VS if I apply Kirchoff's law around this loop I get VS – ZS I1 – B1 depending upon the polarity i have shown is equal to zero so I get V1 = VS - ZS I1 at the port 2. I can write V2 – I2 ZL = 0 that gives me V2 = I ZL i2 so I have in V1 and V2 I have incorporated the generator BS voltage, ZS internal impedance of the source and load impedance ZL.

Now we can proceed and write the ABCD parameters actually our objective is we will design this RF filters. They are made with reciprocal components generally, you know that we do not use magnetic materials like pheroids etc to design a filter so this because they become bulky and lossy etc., So we are assuming reciprocal 2 port network so with this 2 port network I will add a condition that this is a reciprocal network.

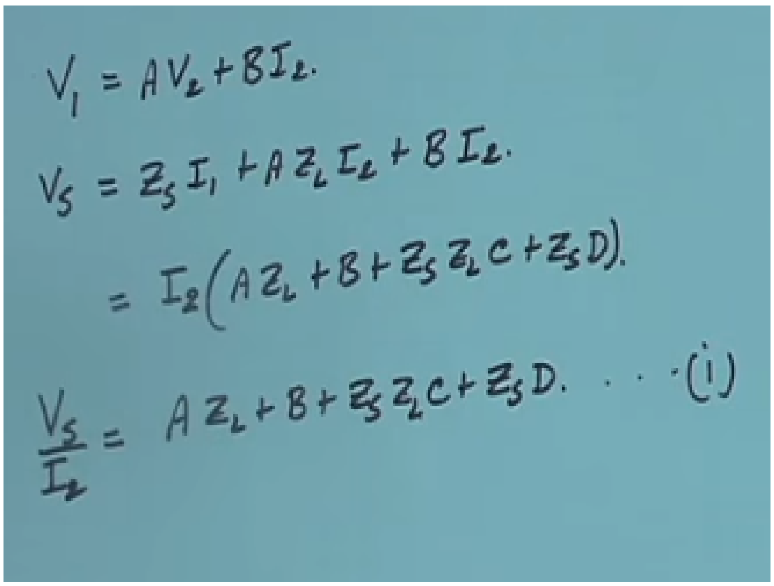
Now I will see that what this reciprocity demands from this network, that means ABCD what is the condition that is imposed if I use reciprocity, so for that what I will do you see what is reciprocity? That if I have a multiport network and one port if I excide if I give some excitation and at some other port if I find the response then everything network remain unchanged.

If I just change excitation to response port in earlier case and see the response in the original excitation port. I will get the same response that is called reciprocity all of you know, so I will do that but you that characterization of network is always in terms of impedances voltage current etc., they can be anything but impedance of the network is the fundamental quantity characterization network. So here I will do that, suppose at this port 1 exciting with VS at port 2 the response i am getting in terms of I2.

So what is the, this transfer impedance is VS by I2, then I will find this quantity first then what I will do I will excide the port 2 with the same voltage VS and keeping this obviously this ZS should be kept there. I will excide with VS and I will find what is the current that time this I1 current that will be the response. I will find that ratio and what is the transfer impedance for that means when it will be transferred from port 2 to port 1 what is the impedance?

Now if the whole network is reciprocal this two should be equal the transfer impedance incase 1 and incase 2 should be equal so from that I will try to find out what is the relationship between ABCD so that this network is reciprocal. So towards that first, I keep this in same circuit diagram first let us analyze what is transfer impedance in this case

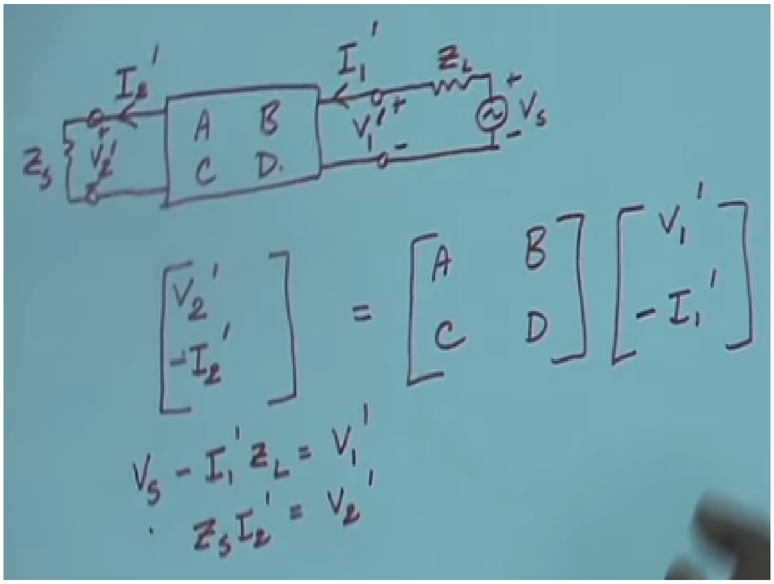
(Refer Slide Time: 17:37)



So as you all know that I can write V1 = AV2+BI2 and V1 already here you see I have related V1 to the excitation voltage VS. So I will put that and then I will get VS = ZS I1 +AZL I2+BI2 finally by manipulating you get this becomes I2 into AZL+B+ZS ZL C+ZS D. So I have got my transfer impedance VS by I2 = AZL + B + ZS ZL C+ZS D. So you the transfer impedance dependence all ABCD parameters of the 2 port network also it depends on my internal resistance of the source excitation and the load impedance.

I leave this here let us consider these as equation no.1 then I change the scenario that means I exchange the excitation and response. So I have the same old ABCD network, I am not exciting at port 1 I will excite at port 2 but all other condition at to be kept same. So my VS the same excitation that I gave in earlier case i am connecting here but the internal resistance I will have to consider now as ZL because I cannot change as impedance of this full loaded network.

(Refer Slide Time: 19:23)



So VS is the only voltage source ideal voltage source its internal impedance taken care of ZS it will come in the input side or port 1 side. So the this now I will call generally we call port 1 as the excitation port. So now I can call these port as B1 this is port 1 but to avoid confusion i will call that as V1 dashed, so this is my V1 dashed port voltage here. In this new scenario because base is connected here, so I have to call it V1 but am call it as V1 dashed.

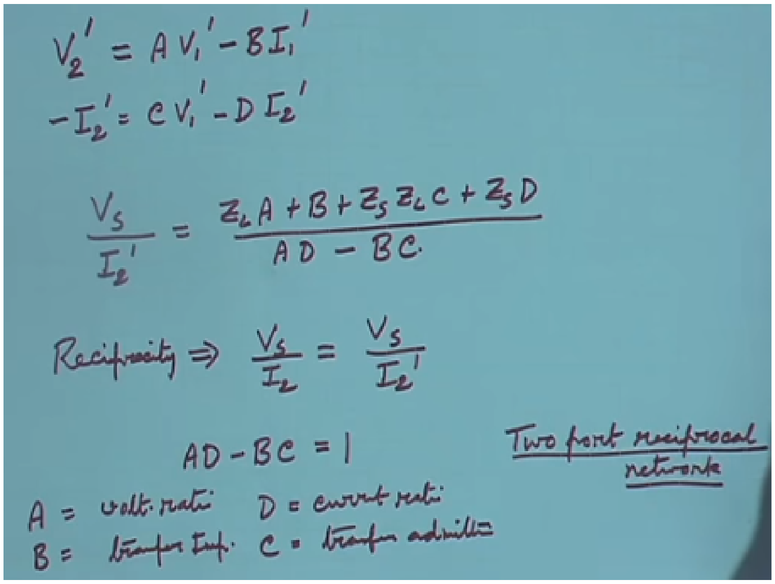
Also the current will enter, so always from excitation port current enters so I1 here I1 dashed am calling ABCD is unchanged because I have not changed this network anything but this outside condition have change. So that current that will come out of it I will have to call this as I2 dashed in transmission parameters the current enters to the excitation port leaves the response port so I2 to dashed is like this and then I will have to keep that internal impedance in the first case it should be same here otherwise that is proceed your own role.

So ZS is here and I will call this port voltage as V2 dashed okay. So now just ABCD parameter is unchanged so can I say that in terms of ABCD parameter I can represent V1 dashed I1 dashed V2 dashed I2 dashed how I will write V2 dashed, then you see compare to the previous case it as changed. So I minus I2 dashed because direction changed last time it was oppositely deducted is equal to ABCD V1 dashed and again I1 dashed.

Previous case and this case the voltages V1, V1 dashed, V2, V2 dashed they are assume polarity are same but currents are opposite polarity compare to the earlier case. Since I will compare this 2 cases so compare to the earlier reference now my I1 dashed I2 dashed are negative. Now I can include the excitation part as I have done before, so I can write by applying KBL here VS – I 1 dashed ZL = V1 dashed and ZL into I2 dashed = V2 dashed.

Okay, and we can as usual write the ABCD parameters from this equation I can write V2 dashed = A, B1 dashed – B, I1 dashed and – I2 dashed = C V1 dashed – D I 1 dashed I will do thatV 2 dashed = A B1 dashed - B I 1 dashed and – I2 dashed = C V1 dashed – D I 2 dashed. Once I have the excitation this 2 coefficients this 2 equations I can now find the transfer impedance what will be the transfer impedance?

(Refer Slide Time: 23:40)



My transfer impedance is VS by I2 dashed so by simple manipulation you get ZL A + B + ZS Zl C + ZS D By AD – BC. So I have earlier got VS by I 1dashed now I got VS by I2 dashed they should be equal reciprocity implies VS by I2 in the first case should be equal to VS by I2 dashed in the second case. So if you do that you will get the relation AD – BC = 1. All of you know this that for a reciprocal network ABCD parameters have this relation.

But for us forth it as particular bearing and an important bearing that you see for a 2 port reciprocal network I do not need 4 parameters to represent the network since ABCD are connected like this. I see parameters are sufficient out of this ABCD parameters 3 parameters are sufficient to characterize completely a network minimum 3 parameters will suffice the rest I can find from this the fourth one I can find from these.

So, 3 parameters needed to represent a reciprocal to port network. Now here you see ABCD is not suitable for me, when I will go to filter design why because what is A? If you see the definition of A from here you can see that it is a voltage ratio. So A is a voltage ratio, D is a current ratio, B is a transfer impedance and C is a transfer admittance.

But as I said that, I require to specify that what will be my pass band of frequencies. What will be my stop band of frequencies, so I cannot impose by on this voltage ratio current ratio transfer impedance, transfer admittance I cannot enforce that so I need to search parameters which will characterize the network, but which will also take the specification of filter from me.

So, first will say that instead of this voltage ration, current ratio can we have some impedance description of this network. That will lead us to the concept of image impedance, so we will see the concept of image impedance. I do not know whether you heard this term this image impedance is an important concept in developing filter theory or many other applications, electronic network applications this image impedance will take up in the next lecture and we will see that how this image impedance will solve this problem.

Will try to find out what are the parameters that will characterize my network and on which we can pass band stop band those description or specification Thank you