Design Principles of RF and Microwave Filters and Amplifiers
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Module No. #4
Lecture No. # 17
Broadband Amplifier Design

Welcome to today's lecture, today we are continuing our amplifier design lectures. So today we will see another class of amplifier which are broadband. We have seen that if we do conjugate matching, that match and also S parameter of any transistors they are true for any particular frequency. But many times we know that since our bass band signal is a band of signal it is not a spot frequency.

So we try to design amplifiers for bit broader band and with today's technology etc more and more new applications are coming which are demanding much broadband amplifiers because the bass band signal is also going large and also in RF the band width etc to have high detonate systems the band width is increasing. So RF signal also should be having quiet large band width so one (()) (01:27) amplifier designer is you should know how to design broad band amplifier.
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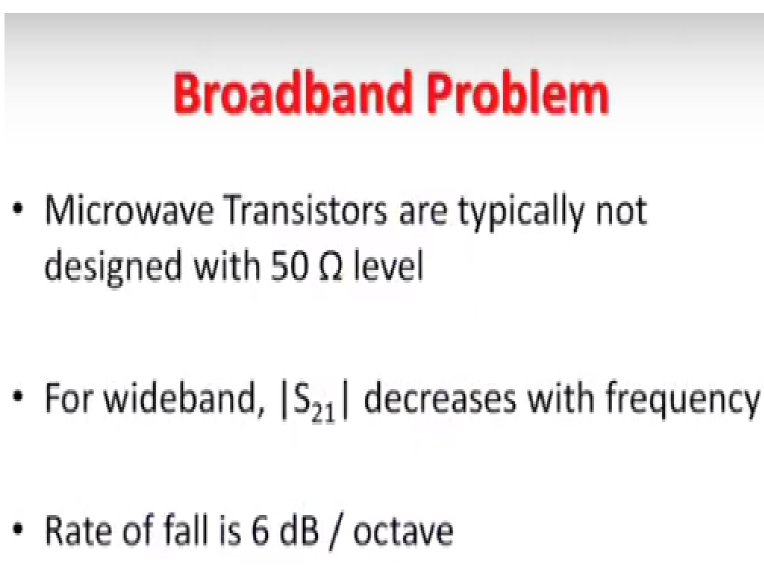

Now broadband problem is you see that microwave transistors typically not designed with 50 om level but source and loads these 2 sides typically 50 ohm that is an electronic industry standard. Generally in lower frequency that was hundred ohm but in now a days it is the industry standard is 50 ohm. So we should have these ultimately any amplifier should be design for 50 ohm.

But unfortunately if we look at the S21 parameter of the transistor itself device itself that as a frequency response which decreases as a frequency typically it is follow up of 6 db per octane. As we go higher and higher in frequency s21 decreases so that problem now we will have to tackle when we attempt a broadband amplifier design.

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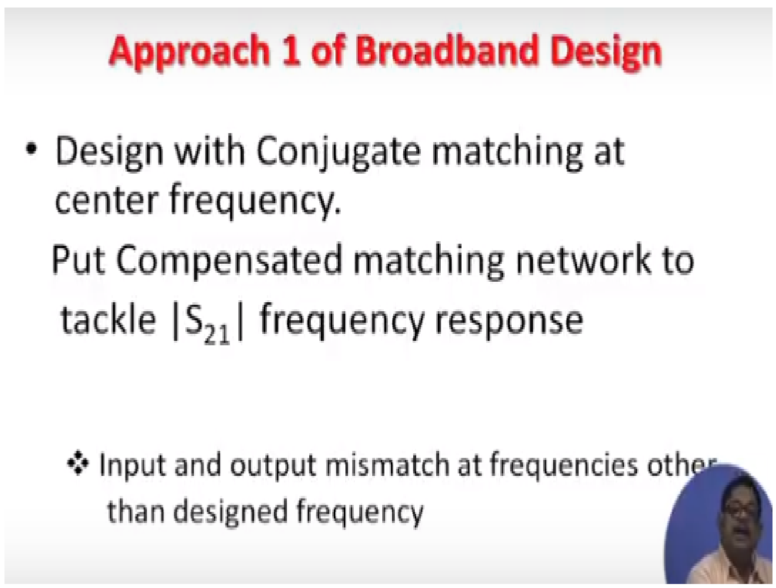

So there are various approaches I am just letting you know what are typically approaches the first approach is design with conjugate matching at a particularly frequency typically that is a Centre frequency of a band in which you are trying to design the amplifier. You know Centre frequency can be the amplitude mean sorry arithmetic mean or it may be geometric mean or it may be a brand is properly defined a Centre of that band.

Now then what you do you know that at other frequency you have designed for a Centre frequency at other frequency either lower are higher than the design frequency the S21 will follow will fall you have a matching network which will compensate for that change in S21. But obviously here due to this matching network the input and output mismatch at frequencies other than designed frequency will come. So will have input and output mismatch and that will also have some you will loss some power in the mismatch thing.

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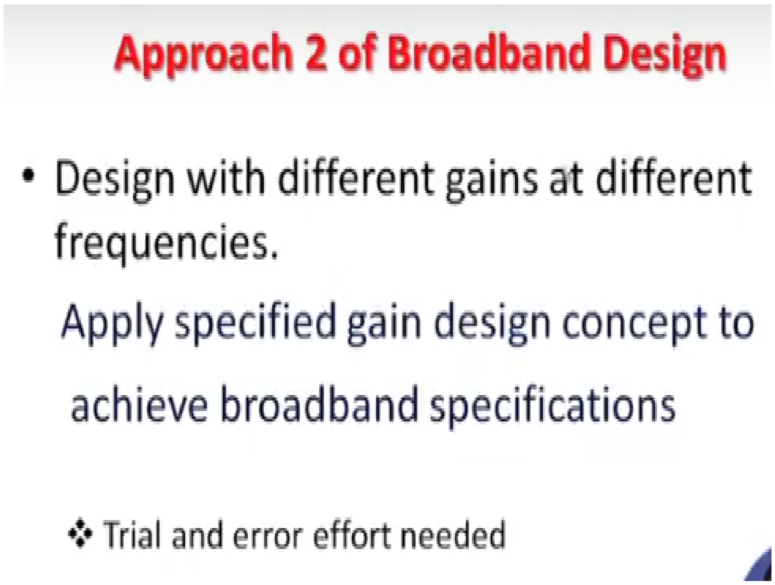

So this is one of the design so by knowing conjugate matching and impedance matching you can attempt this people many time do this but let us see another approach. Another approach is you instead of conjugate matching you design with different gains at different frequencies and for that you apply whatever we have discussed in specified gain concept that draw the specified gain or any constant gain circle at that frequency and try to have the matching circuits for that.

And so if you want to do it for over a band basically over a all possible frequency you cannot do you select typical various frequencies in that band and they are you do that design and finally with trial and error have some balance. But some trial and error effort is needed but people also do it we will also see a example of these in the examples.

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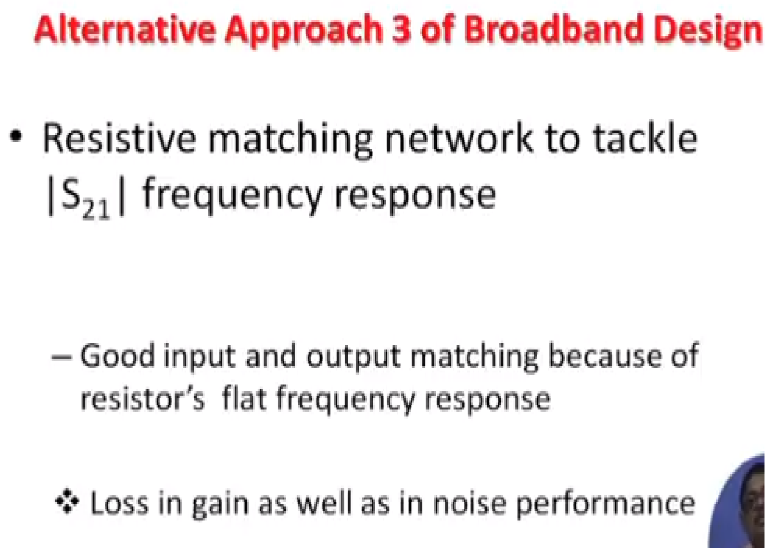

Then approach 3 you can also have resistive matching network to tackle S21 frequency response its good because you see that in output and input matching as the register as the flat frequency response you will have more or less a frequency response good. But obviously since you are using resistive elements you will have some loss in gain also due to resistance you will have more noise so some noise figure will also shoot up.

Now this is also another approach we also have seen many types that in resistive loading we have stabilized transistor. Similarly here we are doing broadband with resistive matching network. Fourth alternative here negative feedback you can use you know any negative feedback that will be make your input and output matching better because any negative feedback that flattance the frequency response S21 frequency response that with feedback that will be bit at flatten.

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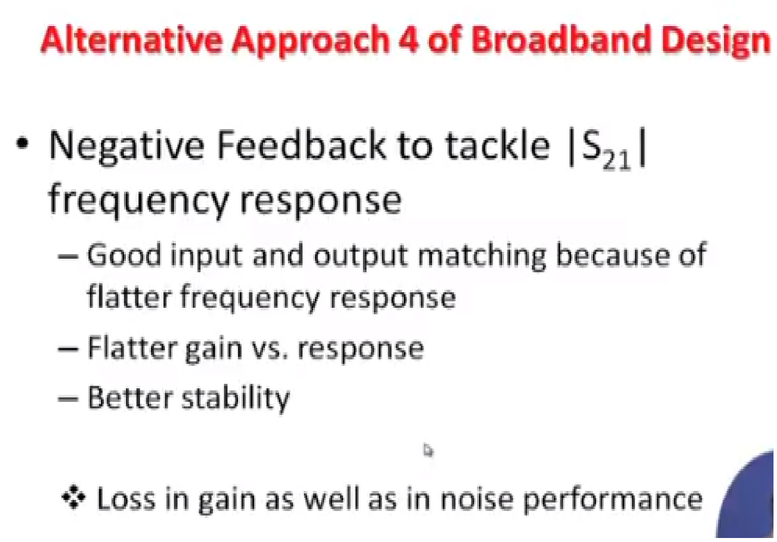

So you will get flatter gain versus frequency response better stability obviously negative feedback makes the any amplifier circuit stable. But here also you will get because of negative feedback your gain as well as noise performance will be gain.

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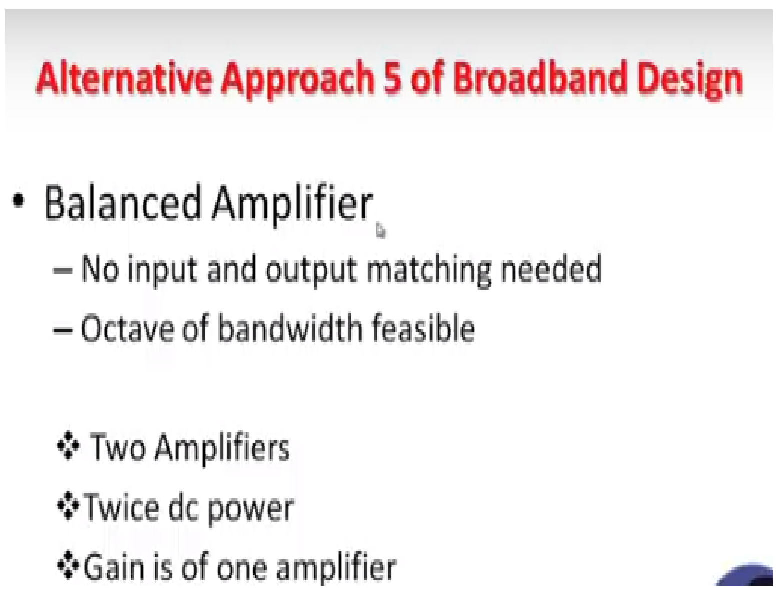

But these is a new very elegant concept this is the fifth approach, here you can use balance amplifier and the beauty of this is apart from all other previous four here there is no input and output matching needed. Obviously there will be mismatches but we will see that we can avoid that, there are no input and output circuit needed we can have balanced amplifier. And we can get typically an octave broadband width that means with if suppose if I have a design frequency of 5 gigahertz.

Typically I can say that I will have a bandwidth of 5 gigahertz that means I can have from 2.5 gigahertz to 7.5 gigahertz typically 5 gigahertz bandwidth is a huge bandwidth. Generally we require 500 megahertz 1 gigahertz bandwidth but now a days applications or coming particularly ultra-white band systems are coming for which this types of bandwidth will be needed one day balanced amplifier will be able to do that.

In balanced amplifier will see in details this balanced amplifier it uses two amplifiers. Instead of that means 2 active devices instead of one transistor we have 2 transistors. And so obviously the dc power requirement is twice that mean you know dc power actually uses for biasing. So that bias dc power is not of any value for wireless transmission so there you are wasting some power.

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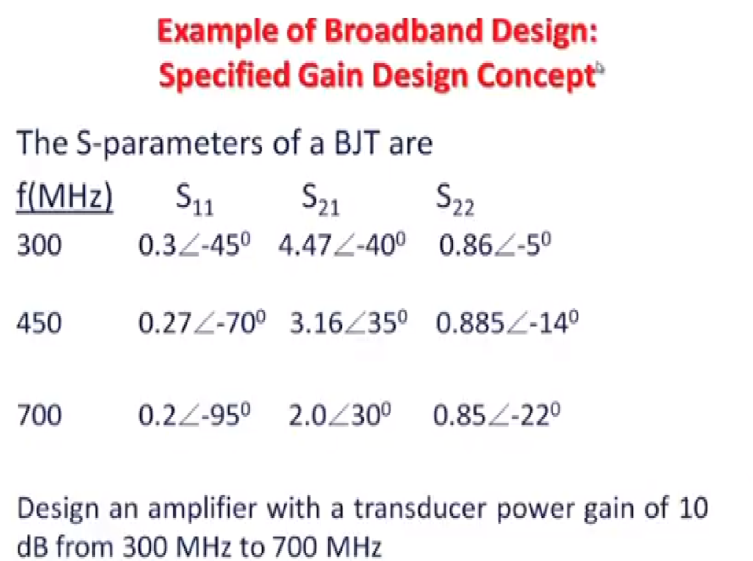

And also though you are using 2 devices 2 transistor devices the gain should have been more but actually gain is of one amplifier only that will show so this are disadvantage etc but still it is for broad banding it is a very good choice. Now before going here, let us see example of a broadband design from the specified game designed concept. That means as I said in alternative 2 I think this one that applied specified game design concept to achieve broadband specification design with different gain and different frequencies.

These examples will see now that broadband design first then we will go to balanced amplifier. Suppose the S parameters of BJT are given in three hundred megahertz this is the S parameter you see we are assuming unilateral that is why s parameters are not specified. Similarly four fifty megahertz and seven hundred now this is ask that design an amplifier with a transducer power gain of 10 db from three hundred to seven hundred.

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Is it Feasible ?

$$|S_{21}|^2 = \begin{matrix} 13\ dB\ \ at\ \ 300\ MHz \\ 10\ dB\ \ at\ \ 450\ MHz \\ 6\ dB\ \ at\ \ 700\ MHz \end{matrix}$$

- Matching network needs to provide attenuation of 3 dB at 300 MHz
  gain of 0 dB at 450 MHz
  gain of 4 dB at 700 MHz
- Is it possible ?

So now first let us see whether it is feasible or not so, we see S21 square already given at different values so if you calculate it turns out that at three hundred megahertz I have thirteen db at four fifty megahertz I have 10 db and seven hundred megahertz 6 db. That means I have this I am suppose to get 10 db gain in three hundred megahertz lower frequency 3 db extra.

So I should have a matching network which should give me basically an attenuation of 3 db similarly at four fifty megahertz is ok at 6 db we should squeeze from matching networks input and output both together another 4 db. So matching networks need to provide attenuation, 3 db at three hundred megahertz gain of 0 db, at four fifty megahertz and gain of 4 db, at seven hundred megahertz. Now is it possible let us see.

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Input Matching or Output Matching ?

$$G_{s,\max} = \frac{1}{1-|S_{11}|^2} = \begin{matrix} 0.409\ dB\ \ at\ \ 300\ MHz \\ 0.329\ dB\ \ at\ \ 450\ MHz \\ 0.177\ dB\ \ at\ \ 700\ MHz \end{matrix}$$

- Little advantage by input matching

$$G_{L,\max} = \frac{1}{1-|S_{22}|^2} = 5.6\ dB\ over\ the\ band$$

output matching can give 4 dB gain

→ Hence feasible

Now we know that how much gain I can get from the source side I can that is in the lecture on specified gain etc we have seen that maximum gain I can get from the input side is given by these. So that from the S11 tabulated values I can see that I can squeeze out from the input side . 409 or this and this.

Little advantage you see not much I am getting from input matching. But output side let us see so from the output side I can get gain a of 5.6 db over the band. So output matching can give me that 4 db that I require a seven hundred megahertz so it is feasible. If this was outside the range of this, suppose this value if I did not get 5.6 but suppose I got it 2 db then I said that no with this transistor I cannot have that broad band thing.

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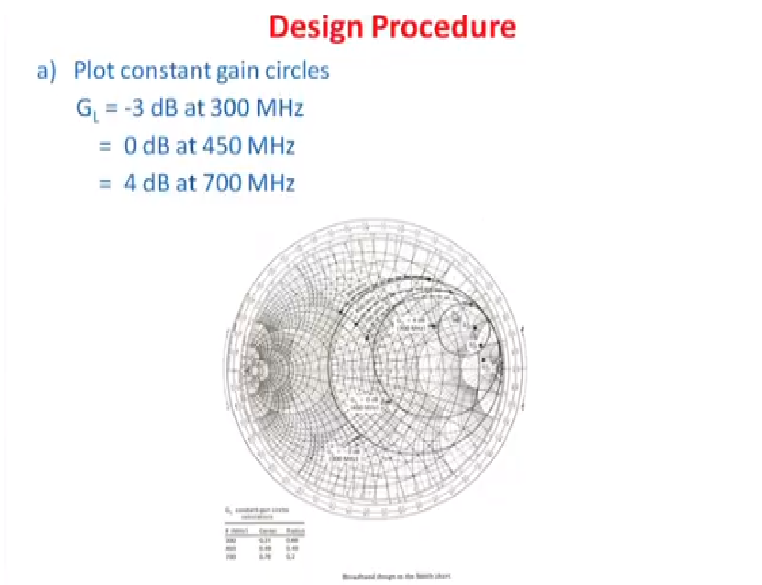

But here we are getting so let us proceed hence it is feasible designed proceed you constant gain circles GL = - 3 db at three hundred megahertz. So we are doing it for output side load side because in input side we can have anything and that will give us something so GL I require 3 db at three hundred 0, db at four fifty, 4 db at seven hundred we have plotted this circles seven hundred megahertz this are the circles now.

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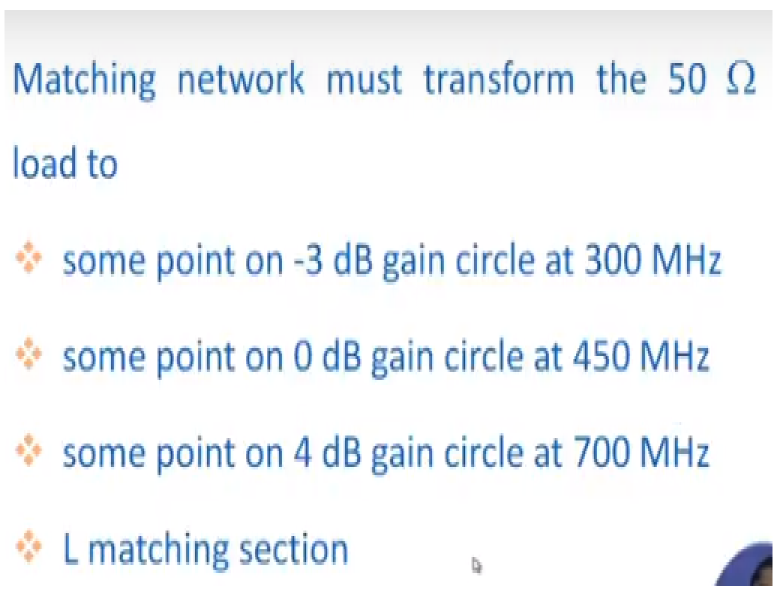

Matching network must transform the 50 ohm load to some point on -3 db gain circle at three hundred megahertz, some point on 0 db gain circle at four fifty megahertz, some point on 4 db gain circle at seven hundred megahertz. Let us see since it is a megahertz we need not go for distributed matching we have L matching you can also go for distributed you know how to do that let us in this example.

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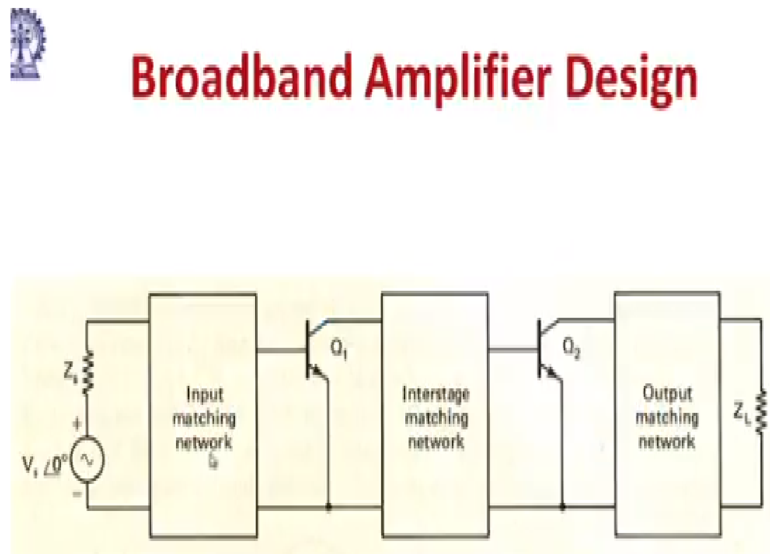

We have chosen an there will be intern input matching output matching lump teleman matching so designs are possible one design is like this.

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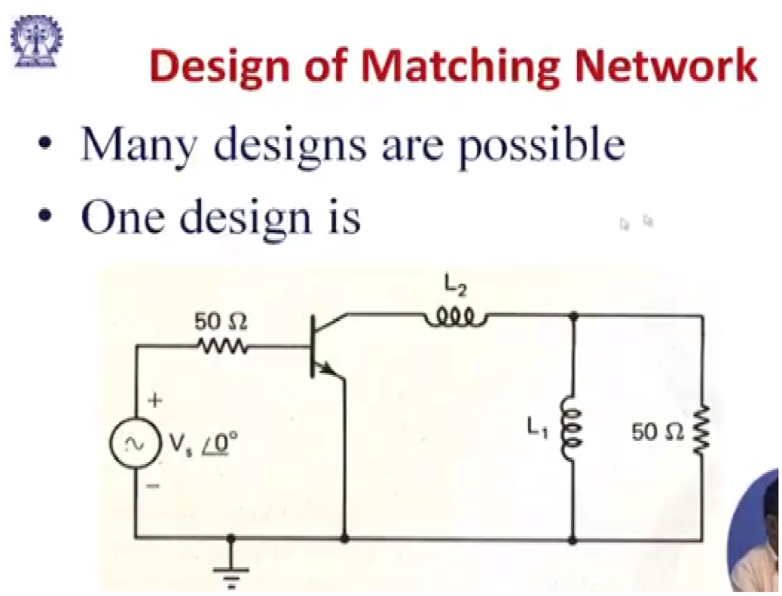
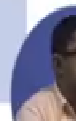


So constant gain circle this are the calculations you can note down then you know that here actually I have the load now from this s22 value that means this is the delta L. **(Refer Slide Time: 13:01)**

Calculations for constant gain circle

f(MHz)	Centre di	Radius R_i
300	0.31	0.68
450	0.49	0.49
700	0.76	0.2



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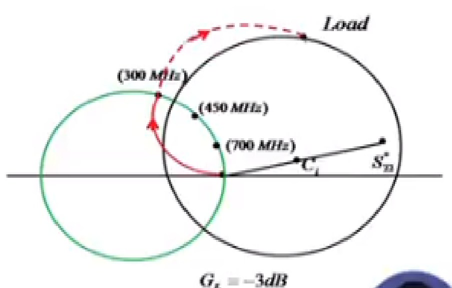
Choice of L_1 at 300 MHz



$$\frac{50}{jwL_1} = -j1.2$$

$$L_1 = 22.1\ nH$$

I need to know transform and then go to that 1+ GB circle at three hundred megahertz, at four fifty megahertz I will heat it here at seven hundred megahertz I will heat it here and then accordingly I will choose L1 and L2. So, choice of L1 at three hundred megahertz let us say that this is giving that choice this is the smith chart part.

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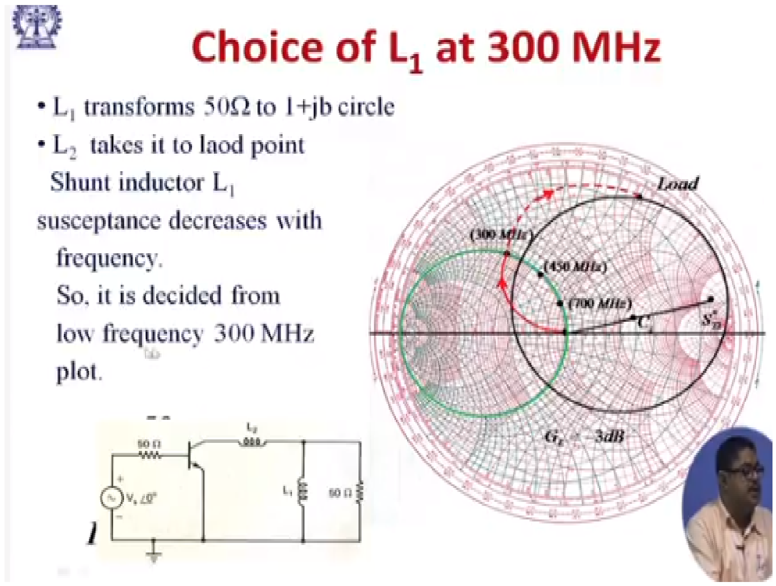

So three hundred megahertz we are from the load I am moving here first am converting then moving here so am hitting it here L1 transform 50 m to this L2 takes it to load point so shunt inductor will he L1 susceptance decreases with so it is decided from low frequency three megahertz three hundred megahertz plot so from trial and error we can do this.

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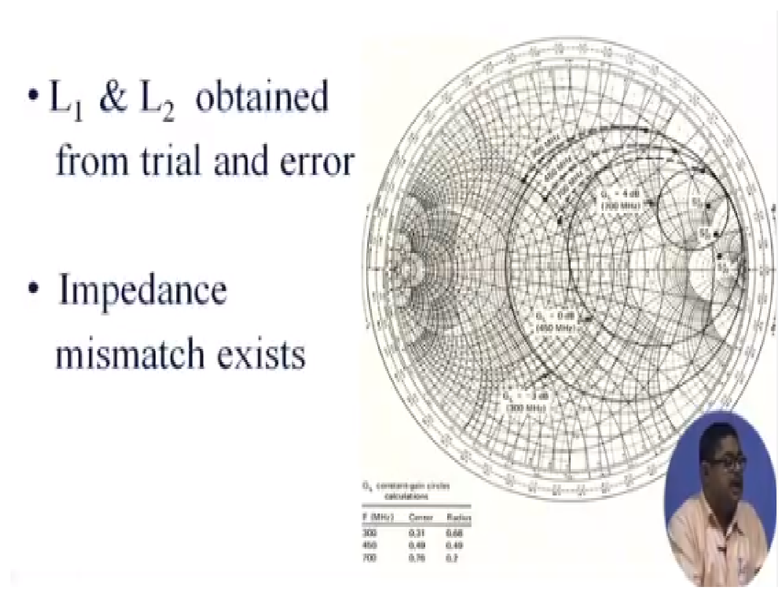

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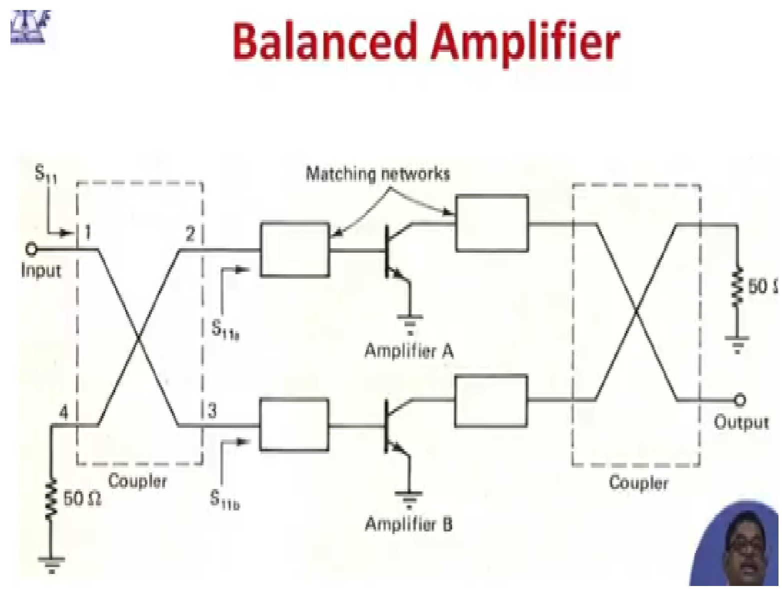

Now let us see the balanced amplifier design now what is the balanced amplifier you see here I have 1 amplifier here let me call it amplifier A this is amplifier B. Now there are two amplifier using generally we will see that we will try to make this two from the same lot so that I have identical things. Now here you see there is dashed one there is a coupler here basically a 3 db hybrid already in our basic building blocks NPTEL lectures we have seen what is the 3 db hybrid is, 3 db hybrid can be acted as an (()) (15:03) subtractor etc., as an also we have seen lot of application of 3 db.

So we are using a coupler here 3 db coupler here before done amplifier also after the amplifier the input we are giving here the four port of coupler we are terminating by match load. Similarly this output couplers the port 3 we are doing it terminating with match load there we are putting it with.

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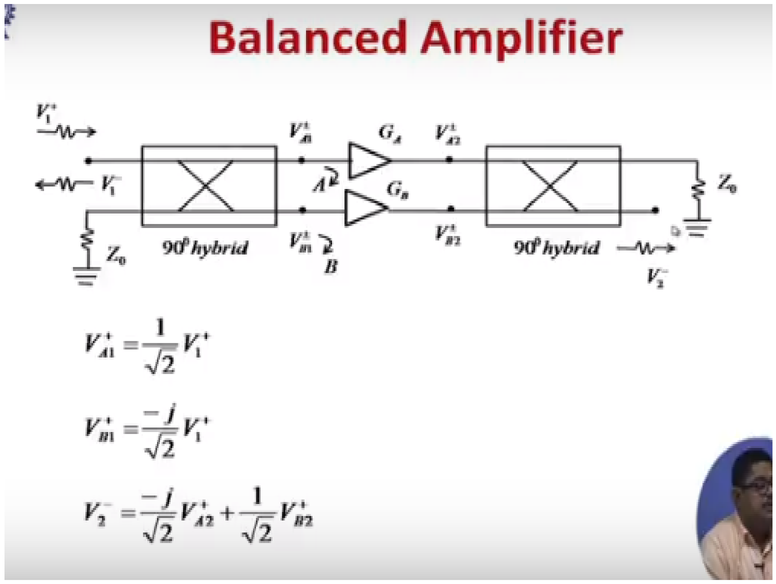

Now this is the diagram this is direction of coupler 90 degree hybrid, I have 2 transistors there gain is Ga Gb am applying V1 + in the input to the input coupler port. Obviously the V1 – goes out here but you know that I will get signals both here and here this is the through port this is the couple port. So I will get signals and then again through this amplifier this whatever signal is coming in this through port that will go here.

Similarly, from here whatever is coming at that will come here then again am putting it to the coupler so this signal will get coupled here this one will go here so this one I will get it here. Similarly, from here whatever reflection is coming that will come here and again will come here I will submit to minus here. Now let us quantitively see, what is Va1 we know this is voltage so I will have 1 by root 2 this is from you hybrid thing you refresh.

That I will get in the through port I will get Va1 = 1 by 3 this 3 db that's why am getting this 1 by root 2 in the voltage in power it is half so V1+. Then Vb 1 + this also how much this V1 then due to 90 degree hybrid I will get a –j and then V1+then V2-. What is V2- it is we know that this Va2 there will be a 90 degree change here and whatever this that is same 1 by root 2 here.

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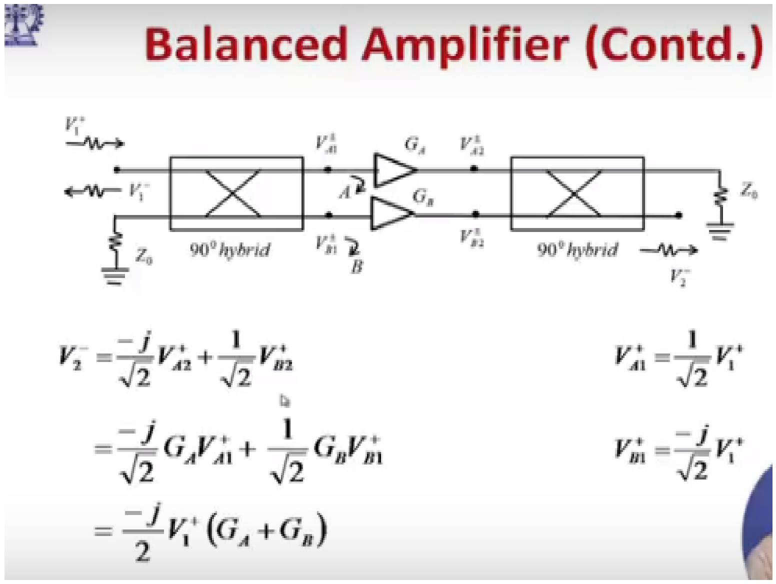

So now then Va1 + what will be this Vb1+ 1 by root 2b1 Vb1 is this so you see that if I put it V2- is what –j this -1 by root 2 this already remember this put those values of A21. So A2 you can put it here and finally see this is Ga+ Gb so V2 – I have in terms of V1+immediately I can.

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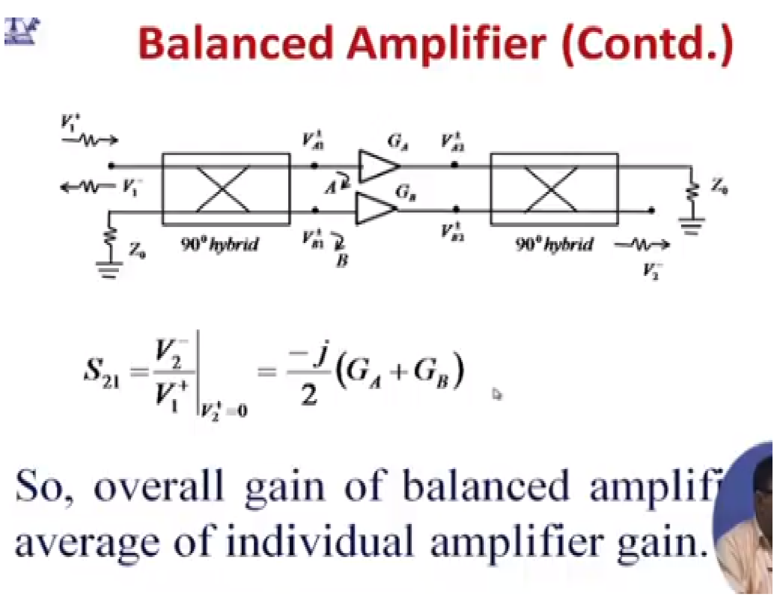

write the S21 parameter S21 of the whole thing will be V2 – V1+ when V2+ is 0 we have made V2+0 because you we have match terminated it so this value is GA + GB. So you S21 is this now if you we have identical transistors let us assume GA + GB, so it its simply S21 is GA by 2 with a phase change of ninety degree. So, overall gain of amplifier is average of individual amplifier gain. So that is why we said that though we have 2 amplifier but actually we are getting gain of 1.

But where is the beauty again you see that V1- if we see that how much we are reflecting V1- is 1 by root 2 Va1- V1- means and then Vb1- Vb1 what is being reflected here that it is coming here with a ninety degree phase ship that is why j by root 2 then you know that V by A1+ Va1- is nothing but Gamma A into Va1+ and Vb1- is nothing but gamma B into Vb1+ so if we put that then we get V1- = V1+ into this is nothing but gamma A and gamma B take common so it is Gamma N – Gamma B.

If this 2 are identical then V1- = 0 so you see that though there are reflecting signal from individual one but with this balanced one am getting V1- by V1+ is this. So, what will be my S11, S11 will be gamma A - Gamma B by 2, So S11 is half gamma A - gamma B. Now if we have balance if gamma A and gamma B are same we are getting no reflection. So no need of matching circuited sector it is always matched here.

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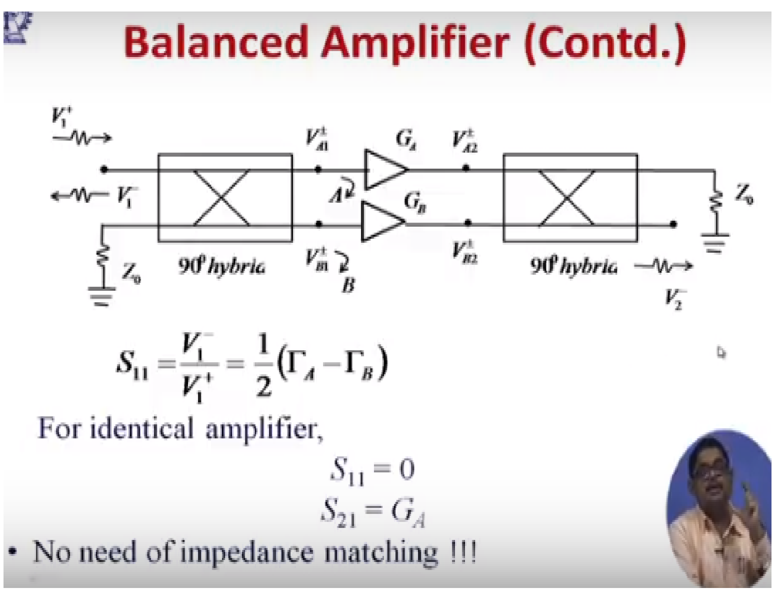

For identical amplifier S11 = 0, S21 = GA. We have already seen that previously, so no need of impedance matching. It is a elegant concept this balanced amplifier, only thing you are required to have 2 transistors for this now issues with balance amplifier. If one amplifier fails, what will happen, nothing will happen, your overall gain will drop.

You see that if suppose amplifier B fails so what you get is half of this is S21 that means your in db scale your are getting a in voltage gain that it is falling by 6 db, overall gain drops by 6 db. Some power also we are losing in coupler, because those coupler are we are putting passive devices we know coupler has some loss. So some power is lost in coupler also noise figure of overall thing FA+FB by 2.

So noise figure also will change if the two noise performance of 2 transistor are never similar so there will be some noise increase also so bandwidth of balanced amplifier you see that in at every frequency this is true but the coupler they have a bandwidth. Basically balanced amplifier bandwidth will be limited by the coupler bandwidth now coupler typically have 1 octave of bandwidth that is why we see that balanced amplifier can do broadband design, broadband amplification for octave bandwidth.

If you can improve coupler bandwidth you can get more bandwidth because conceptually balancer amplifier at all possible frequencies it will have the same thing in which it has a gain. obviously amplifier the next to have a gain circuit that means it is much before if it is maximum usable frequency where gain become 1 so it is much less than that so once that then any frequency you can have this gain thing.

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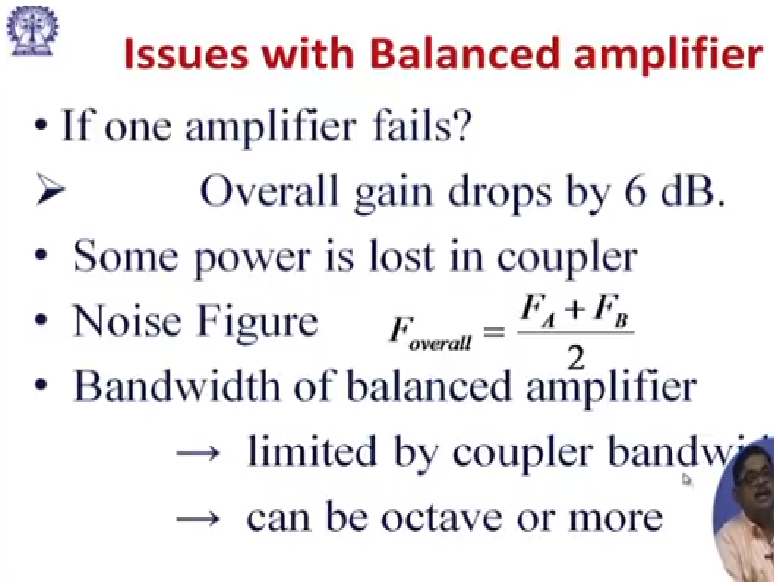

Now advantage is output power twice of individual amplifier power as you have already seen before that output power is you see that V2- am getting some from here, some from here. So, obviously output power is twice now also you have seen that redundancy built in I degrade my performance if one fails. But the whole thing is usable because still amplification goes on easy to cascade also because you have coupler on both sides.

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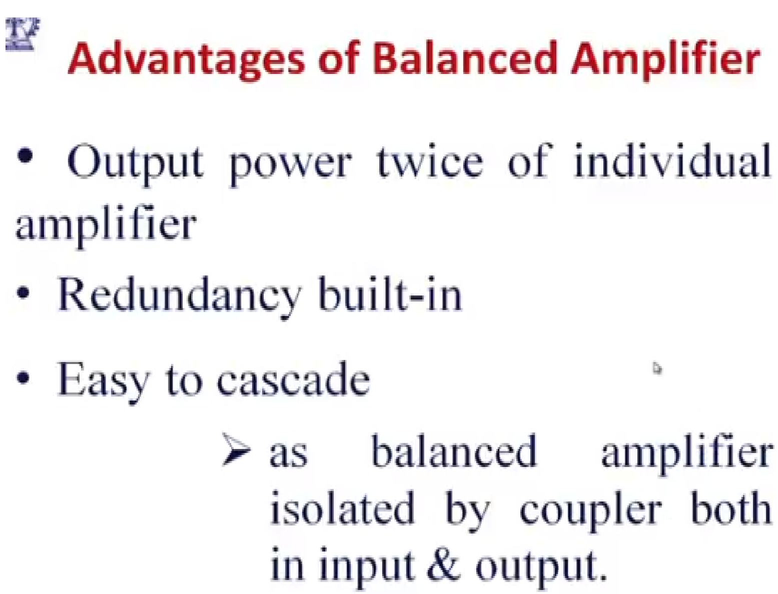

So you have good isolations we know directions of coupler have good isolation as balanced amplifier isolated by coupler both in input and output. You get good cascading property also now disadvantage as I said that 2 amplifier , but gain is of single stage wastage of DC power, size also is larger because coupler are passive thing becomes bulky.

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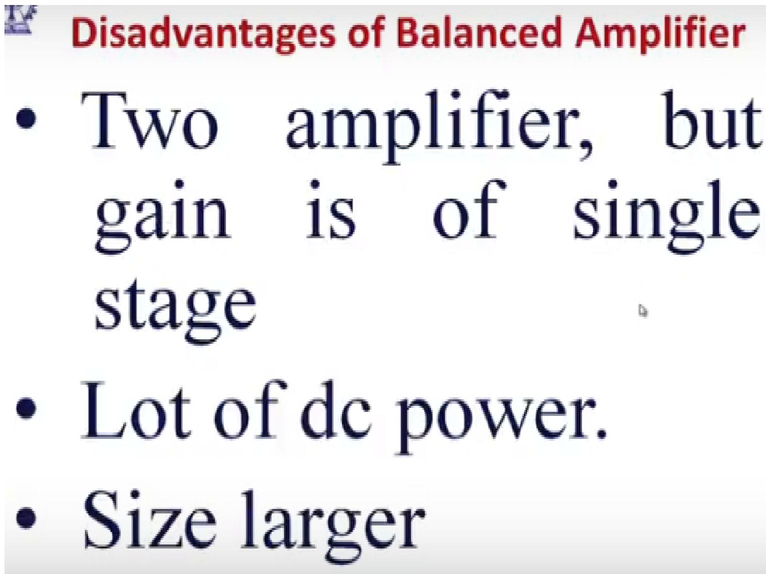

Completes the broadband amplifier design part so you see that with balanced amplifier you can have if you can afford the direction of coupler thing. So here also this we did not say when we discussed direction of couplers this is an another example. But directional coupler changing the whole ball game and making the whole amplifier is matched for all frequencies.

Though internally it is not matched but with the balanced thing finally the overall S11 the overall reflection that you are getting that is becoming almost very low. So also gain wise you are not losing much, but you are not gaining much you are keeping that gain so it is good design for broadband amplification. Thank you