Design Principles of RF and Microwave Filters and Amplifiers
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Module No # 3
Lecture No # 15
Amplifier Design for Specified Gain

Welcome to this lecture now in previous lecture we have seen the amplifier design with conjugate matching. We could not see an example that how the input and output matching network are designed.

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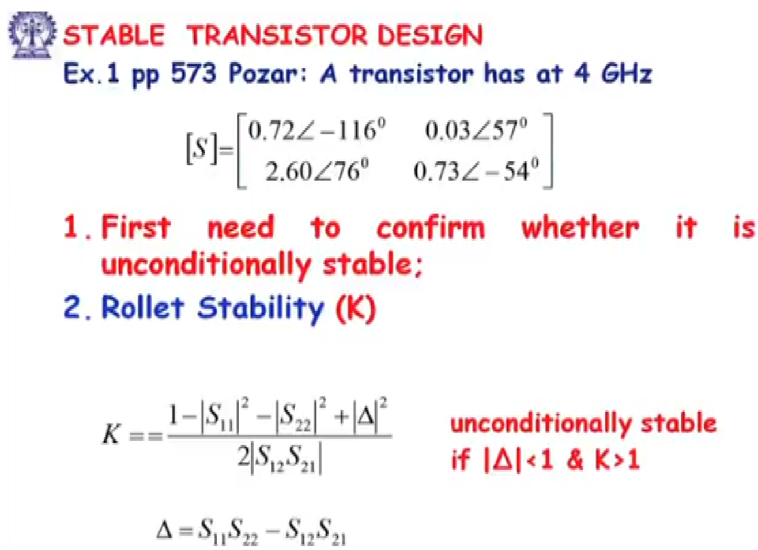

So an example we will see that so see this problem from pozar's book. Again one of our reference in my edition it is at page at 573 a transistor at 4 gigahertz it is S parameters are given please remember that S parameter is a frequency dependent quantity. So manufacture specify at various frequencies the S parameters so at 4 gigahertz we are testing it at other frequencies it will also change.

Also S parameters are bias dependent quantity so if we change the DC biases he S parameters values will also change. So this is the problem S parameter is given now you design for conjugate matching.

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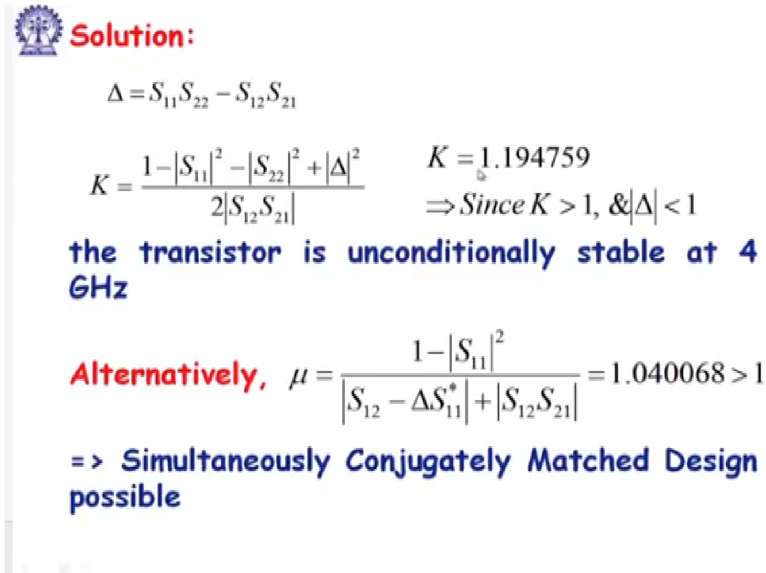

Now first obviously we need to confirm whether it is stable or not so we enforce rollest stability criteria and find out that K is greater than 1 also delta is less than 1 so transistor unconditionally stable also it passes the Mu test that it should be. So conjugate match design possible, we know conjugate match means gamma S = gamma N star and gamma L = gamma L star we have to do this simultaneously. And then we will get the gain of obtained gain maximum.

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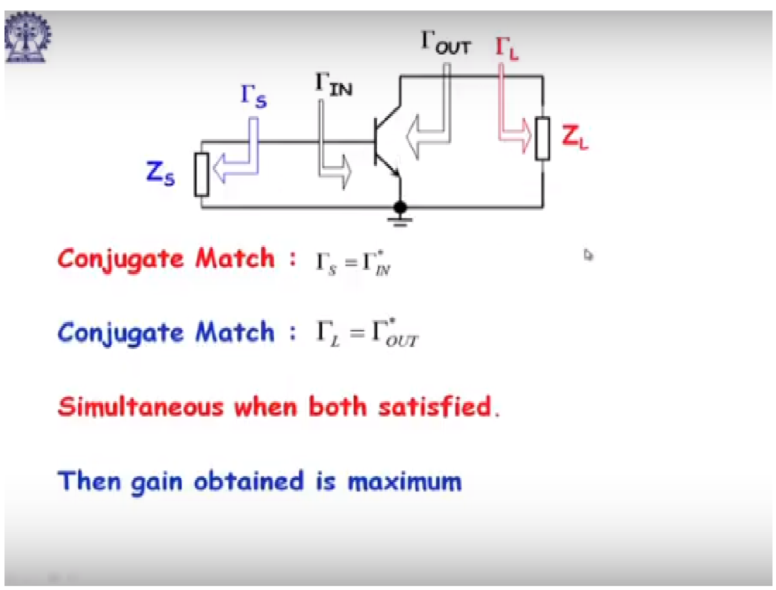

This are the gamma L, gamma out, gamma in, gamma S that we have discussed also the corresponding power criteria's we have seen.

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$$S_{11} = 0.72\angle -116^0 \qquad S_{12} = 0.03\angle 57^0$$

$$S_{21} = 2.60\angle 76^0 \qquad S_{22} = 0.73\angle -54^0$$

$$\Delta = S_{11}S_{22} - S_{12}S_{21} = 0.487527\angle -162.29^0$$

$$B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 = 0.747817$$

$$B_2 = 1 - |S_{11}|^2 + |S_{22}|^2 - |\Delta|^2 = 0.776817$$

$$C_1 = S_{11} - \Delta S_{22}^* = 0.370415\angle -123.41^0$$

$$C_2 = S_{22} - \Delta S_{11}^* = 0.385047\angle -61.0261^0$$

$$\Gamma_{ML} = \frac{B_2\sqrt{B_2^2 - 4|C_2|^2}}{2C_2} = 0.8762912\angle 61.0261^0$$

$$\Gamma_{MS} = \frac{B_1\sqrt{B_1^2 - 4|C_1|^2}}{2C_1} = 0.8717592\angle 123.41^0$$

So we see the design S1 again we are written the actual values of S1 delta turns out to be this. Now as we have seen in the previous case that we will have to find out the gamma L and gamma S.

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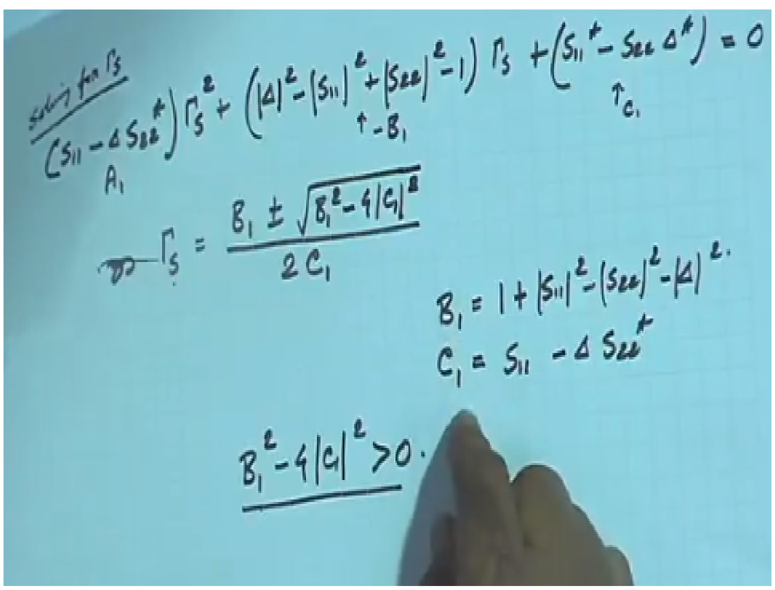

This the solutions so with B1 gamma S values so we will need to calculate B1 C1 for finding gamma S and B2 C2 for finding gamma S and also seen rollets test is passed. So we know that this will be satisfied to gamma S and gamma L they can be octane. So you see we are doing that now see in the presentation now that B1 turn out to be this, B2 is this, C1 is this, C2 is this.

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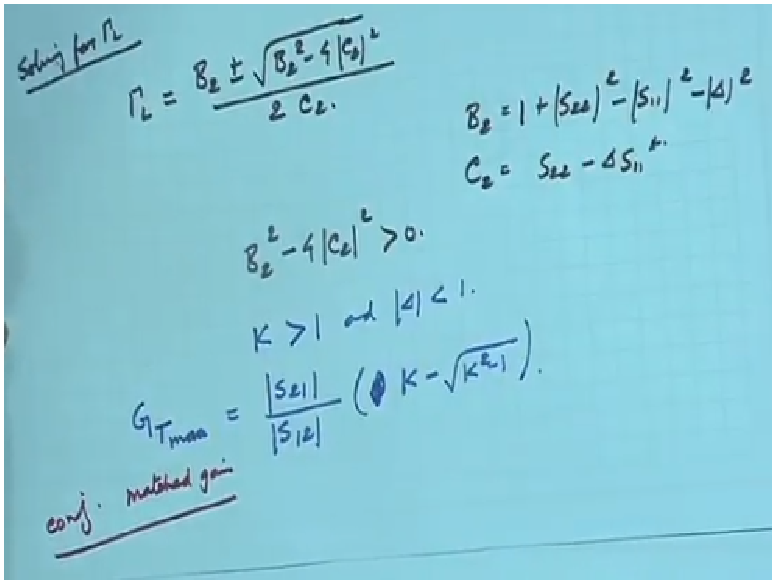

Remember B is are real values C is are complex quantities. So we can find the here we are calling gamma L with a maximum because we are doing conjugate matching. So gamma L will be this 0.87 angle sixty one degree and gamma S with a maximum because it is a conjugate matching that is why we are giving a subscript M.

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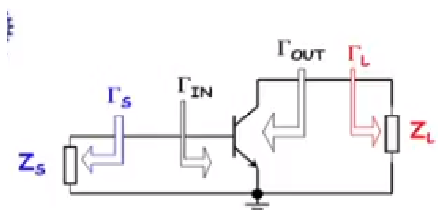

$$S_{21} = 2.60\angle 76^0$$
$$B_1 = 0.7478175$$
$$B_2 = 0.7768175$$
$$C_1 = 0.370415\angle -123.41^0$$
$$C_2 = 0.385047\angle -61.0261^0$$

$$\Gamma_{ML} = \frac{B_2 \sqrt{B_2^2 - 4|C_2|^2}}{2C_2} = 0.8762912\angle 61.026^0$$

$$\Gamma_{MS} = \frac{B_1 \sqrt{B_1^2 - 4|C_1|^2}}{2C_1} = 0.8717592\angle 123.407^0$$

$$G_{TM} = \frac{1}{1-|\Gamma_S|^2}|S_{21}|^2 \frac{1}{1-|\Gamma_L|^2} = 4.166 \times 6.76 \times 1.665$$
$$= 6.19 + 8.30 + 2.19 = 16.71 \quad dB$$

So we have got this values and from that we can easily find out what is GTM that means the maximum possible transducer gain that this device will give. So you see first part that means input part proper choice of gamma S that give us a gain of 4. Roughly then S21 part that means a transistor gives a gain of device itself alone gives as a gain of 6.7 roughly 7 and this one 1.6. So you see that if we did not do conjugate matching we did simple matching.

We could not have extracted this two parts so roughly 4.1 into 1.6 or in db scale you see this is converted to db. So 6 db and 2 db 8 db and RF microwave designer can extract additionally for the gain from the actual device whose gain is only 8.3 db. So this are again so what is that gamma in value you see this and gamma out is this.

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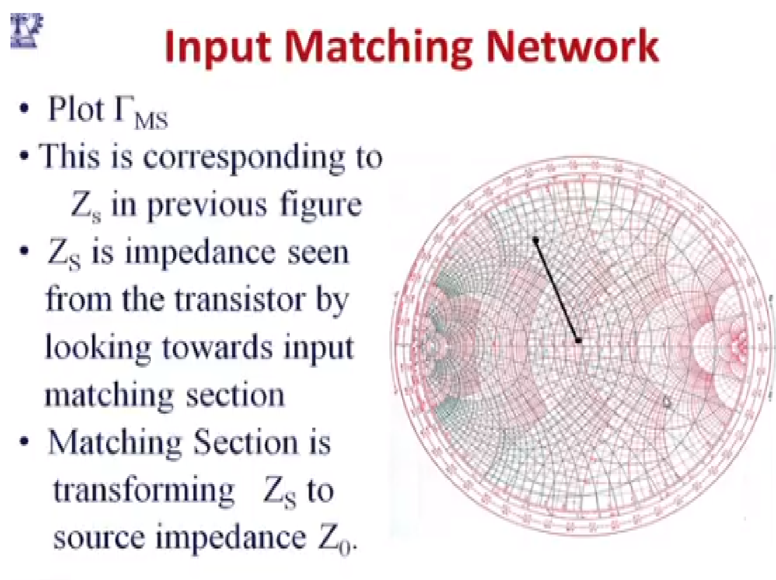

Now let us do the input matching that we need to do input matching because we have got gamma S value so you see that where is the gamma S see the previous one. Gamma S is 0.87 angle 123. So in the smith chart let us plot this gamma S .87 it is inside you see this point and 123 roughly this. This is corresponding to Zs in previous figure.

Zs is impedance seen from the transistor by looking towards input matching section that means actually if I have this transistor here so from here am looking Zs. I need the input matching network to transfer this to Z0. so my job is from ZS I will have to go to Z0 which is the center of the Smith chart.

So matching section is transforming Zs to source impedance Z0 how we do it you know there are various ways that will follow the will make a after these section our basically input matching network will be like this that I have this then I will put a transmission line and then I will put a stub here either shunt or short series stub that will see various choices this are not unique. But we will follow the particular design already in the impedance matching section we have seen how to design such things.

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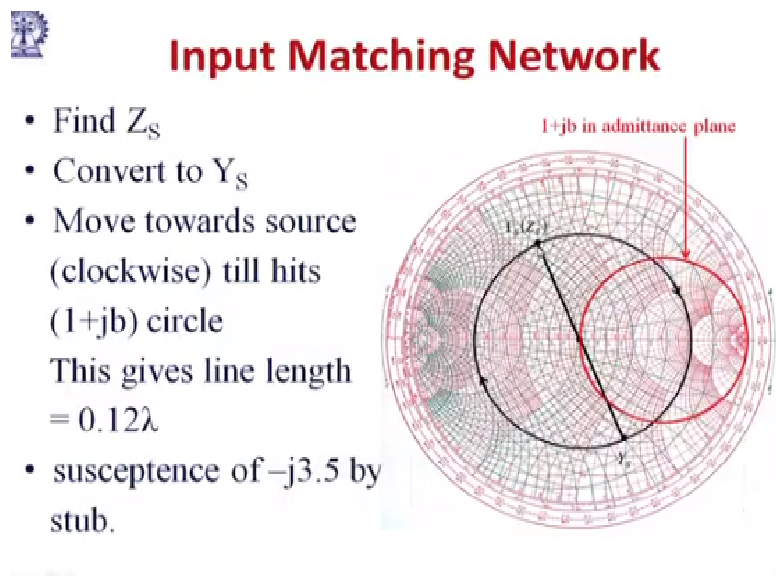

So what will do will we have found Zs delta S means this also consider this as Zs. Now since you convert that to Ys this is the Ys point now move towards source clockwise till you hit this keep this 1+jb admittance circle. You are hitting it here so from here so you know how much length of line of plane is (()) (07:04) because this is the same transmission line. So you require this transmission line and then the length you can find from here.

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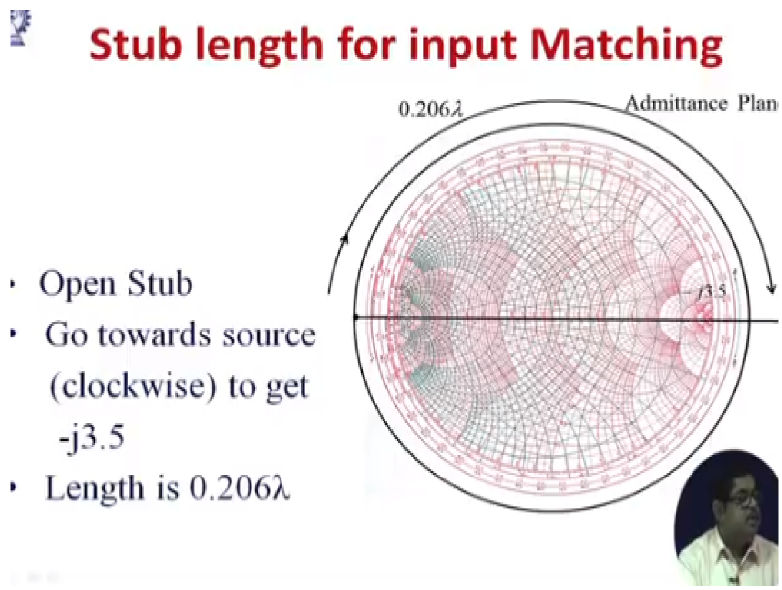

So this give line length to be .12 lambda to know here are those lambda scale so from here you find from here to here upto this point I have point 1 to lambda and then here you find out that what is the susceptance. This is 1+ jb circle so there is some susceptance that susceptance since it is admittance scale this upper portion is – j so that is – j3.5 that you need to adjust by putting a stub that we will do. Here we have taken a open stub so for open means in the admittance scale this is my open circuit.

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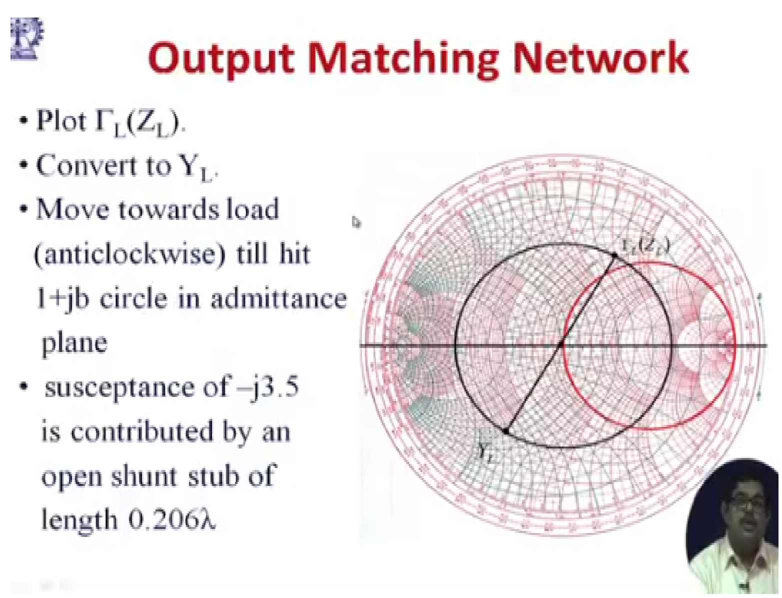

So I need go how much you see this is my -J 3.5 so this if I take it is .206 lambda so length is . 206 lambda. So from there now we do the put matching network you plot ZL it is here again convert it to YL then move towards load since am moving towards load it is anticlockwise so move here you are here you are hitting here susceptance again here is -j3.5 it contributed by open stub of length this.

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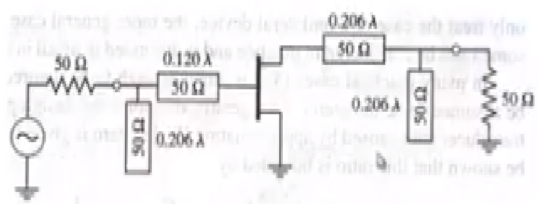
Conjugate Matched Amplifier



So this is the final design you see in the source side I have assumed all the transmission line and stub they are impedance level is 50 ohm same as our characteristic impedance level of the transistor. So I have .12 lambda line length and then a stub 50 ohm stub similarly here. A transmission line of length .206 lambda and stub is also 206 lambda so now from this side the source will see a 50 ohm impedance. Similarly from this side the load will see a 50 ohm impedance this is the conjugately matched amplifier ok.

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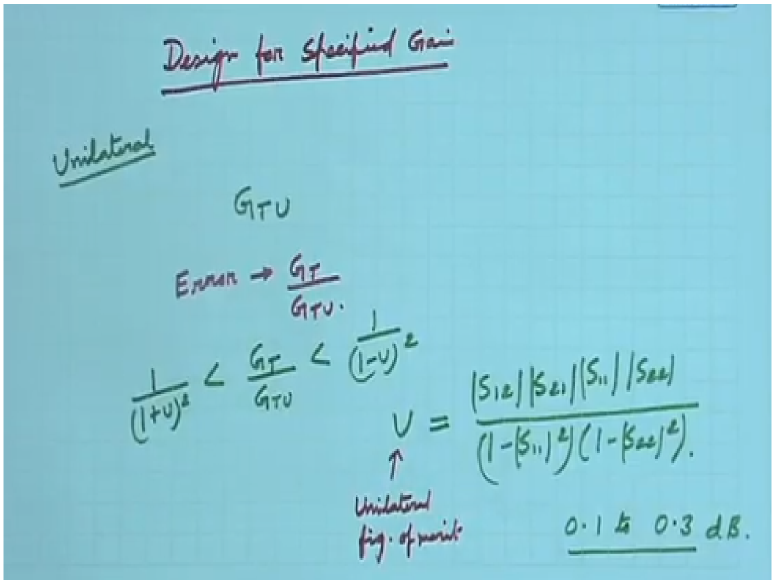

So with this example we conclude the conjugate matching then we do that always we do not do conjugate matching because conjugate matching is a you see that conjugate matching because all this things are frequency dependent. So conjugate matching is possible for a particular frequency. So amplifier that means with conjugate matching design we achieve the maximum possible gain. We have seen that I can extract 8 db extra gain etc in this case But that is over a narrow band of frequency.

So the whole amplifier design is narrow band sometimes we do not need narrow band also that much gain may not be needed. So it is better to have a procedure for specified gain so design for specified gain so let us have a procedure for this.

So again here we generally now we are becoming more practical and we have seen how to do bilateral design here we make an unilateral approximation that generally all practical transistors that we using unilateral if you cannot make this unilateral assumption you know how to design here that you can do. So when we design for specific gain which is less than the maximum gain possible, maximum transistor gain possible.

Definitely we are deliberately putting some mismatch in the device we are not properly conjugate matching we are putting that mismatch that is why we are getting less gain but we are satisfied with that because that must mismatched power loss etc we can suffer sometimes if not then do the conjugate matching which is the best design.

So unilateral actually you see if I make unilateral thing actually a mine GT in unilateral let us call that GTU. So actual device if it is not unilateral can I say that I am committing an error of the order GT by GTU. So GTU is my actual thing people have shown that these as an bound both lower bound and upper bound that can be expressed by a parameter U, it is a unilateral case figure of merit.

So this error or this ratio GT by GTU that means if I make this assumption am committing an error or my gain is (()) (12:19) by this that is have an upper bound and lower bound. Where you it depends on all S parameters of device, so this name of the parameter U is called unilateral figure of merit and people have shown that usually this error it is within 0.1 to at the most 0.34 db.

So I am not suffering in this if I make an unilateral approximation then my error that I commit in getting the gain that is not much. So that generally can be done but that simplifies the procedure, so let us see the procedure for specified gain. So specified gain, so that means people will now tell me that you get this much gain now as I already said that I have the whole gain that always in the GTU case also I can divide as GS U G0 and GLU.

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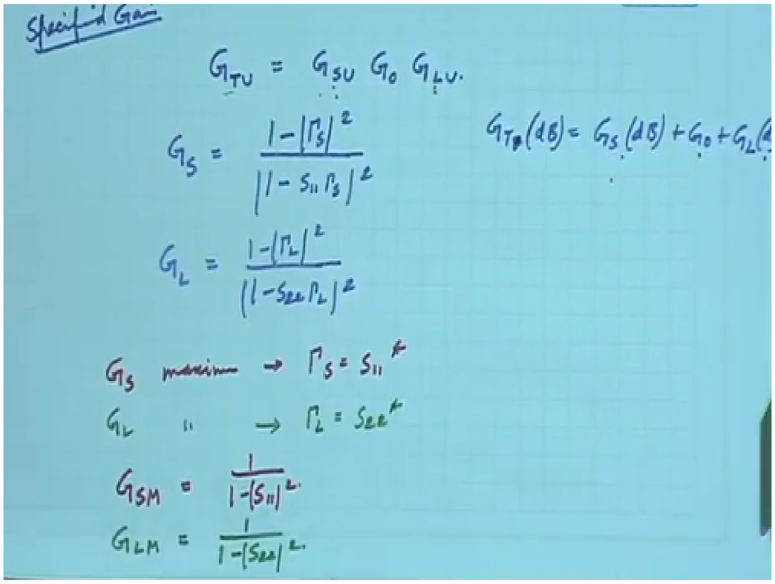

So input matching section output matching section now hence forward I leave this subscript U. So I can say that what is GS you know under unilateral thing it is simplified that gamma L does not come into picture and it is simply 1- S11 delta S whole square so you see that GS I can choose just from gamma S or gamma S I can choose by knowing what is my GS requirement that means input matching circuit how much I want to have.

Similarly GL can be retained as 1 – gamma L square by 1- S22 gamma L square the moment I have this you see that output side I can design from the specification of GL. So I have overall specification of this I know this value this is S21 square of the transistor now this two in my hand. I can have any choice input matching and output matching some gain some portion I take from here. Some portion I take from here and I do that DB gain.

So in the DB scale you know this is nothing but I can write it as GTU in DB is GS or all are under this GS db +G0 + GL DB. So there you can see that I can choose that ok. Suppose if it is 11 db required suppose this is 8 db so 3db now it is upto to distribute either I can 2 db here, 1 db here or 1 db here 2 db here.

Now out of this you see this GS value, GS is maximum if I can choose gamma S = S11 star also this GL will be maximum if I can make gamma L = S22 star if I can do that then immediately there will be maximum this thing just from here you can see and I can write that value that what is GSM that will be GSM that is 1 by 1 – S11 square. So maximum I can do depends on the S11 parameter.

Similarly from the output matching section GLM I can see this 1 by 1 – S22 square so now what you do to facilitate the design we define a normalized gain function so I have a 2 such gain functions GS small gs and small gl. What is GS which is my specified by the maximum that I can get, similarly what is GL it is GL by GLM and what is this if I write the expression all the expression are there.

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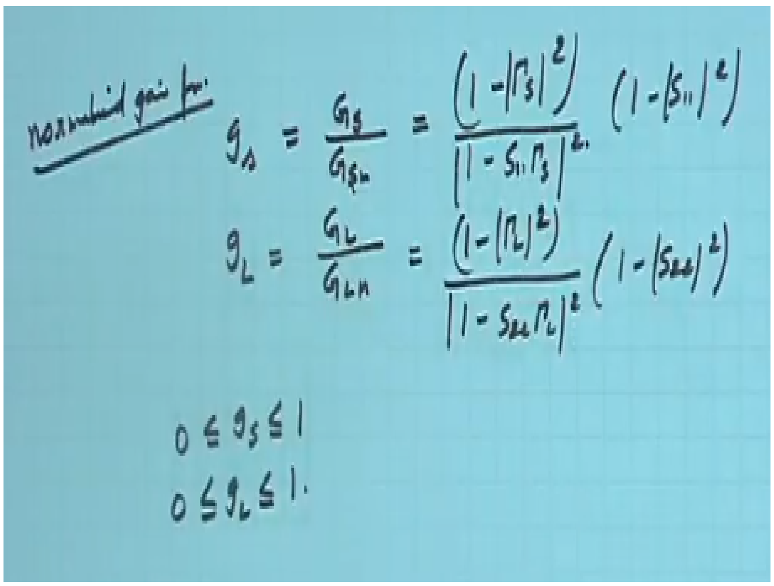

You simply write it 1-delta S square by 1- S11 delta S this is my gs and maximum is 1 – S11 square this was denominator so it as gone here. Similarly here I can write 1 – gamma L square by 1- S22 gamma L square 1- S22 square very elegant and it is obvious that 0 this is the benefit of normalization that this normalize gain function are line in between 0 and 1 and. Now you see this one I can just the manipulate as I have done incase of the conjugate matching what we did we have retained GS.

As a function of GL and GL as a function of GS and then 2 equations to unknown we did that but here already input and output are uncouple. So form 1 equation suppose from this equation I can find out what is solution for gamma S from this equation I can find out what is solution for gamma L I can choose accordingly.

So we will do that accordingly we write this GS equation no forget this GS is this from there we find out the solution for gamma S. One equation one unknown I can always do that so GS I write as again I am writing 1- gamma S square by 1- S11 gamma S square into 1 – S11 square. So solve for gamma s if I do that again I get something like this so you see again this is complex number this is a complex number this is a real number small gs is a real number.

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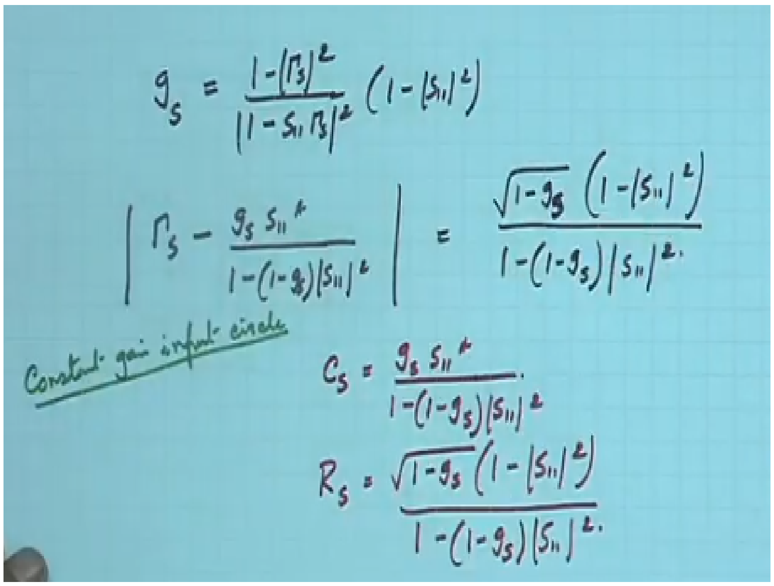

Now what i this in the smith chat if you plot this or this locus can I say this same as before this is the equation of this locus will be a circle, this is center, this is the radius, so we call that now what is this ? This circle is a specified value or a constant value so we call this as constant gain input circle. Because here we are choosing the input side so constant gain input circle or constant gain circle for input section.

So what will be my Cs, Cs will be Gs S11 star by 1 – 1- Gs S11 square and what will be my radius? Radius will be root over 1 – Gs 1 – S11 square by 1 – 1- Gs S11 square Gs is specified S11 value I know from the S parameter. So I can find out this and I can plot that and the smith chart that will be a circle. Similarly I can do for the other thing that the constant gain output circle.

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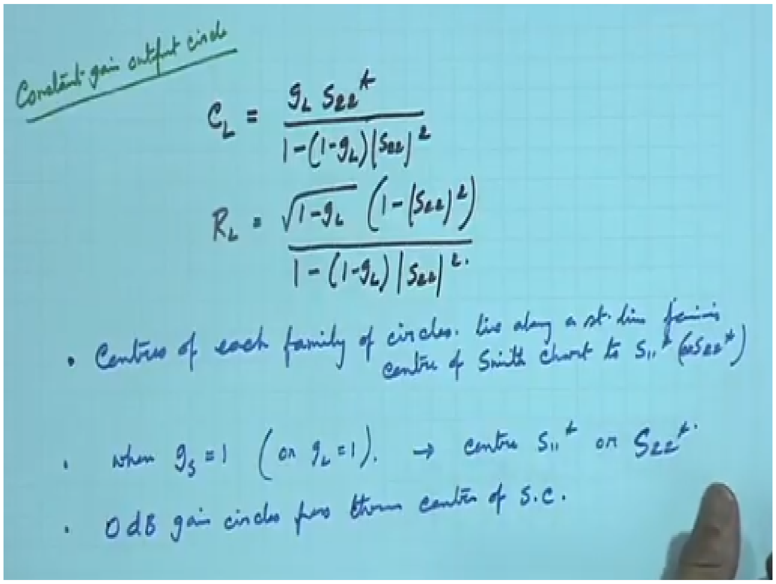

So here we have solve for Gs there will be from this normalize gain function. You solve for gamma L that locus again a circle and there the CL the center will be GL S 22 star by 1 – 1- GL S22 square and radius is root over 1 – GL 1-S22 square divided by 1-1- GL S22 Square. You see so from these we will see an example how to choose but here let us see this two that this constant gain input circle and constant gain output circle.

There are some points that needs to be underscored that we can see that various values of gains. I can have (()) (24:12) because as I said suppose I decide input side I am not sure whether to take 1 db or 2 db or 0 db or -1 db which gain I will take. But one thing is true that centers of each family lie along the straight line joining center of smith chart to either S11 star or S22 star.

You see the center is this is all some real number so Cs is along S11 star in the smith chart that is a complex number it is along S11 star or CLL is along S22 star. Then another point is when Gs = 1 or Gl =1 what happens you see if Gs = 1 then it becomes simply Cs from S11 star and this center becomes S22 star. So then center simply S11 star or S22 star as the case may be also it can be shown that 0 db gain circles pass thru center of smith chart so from there you can always draw the circles plotted.

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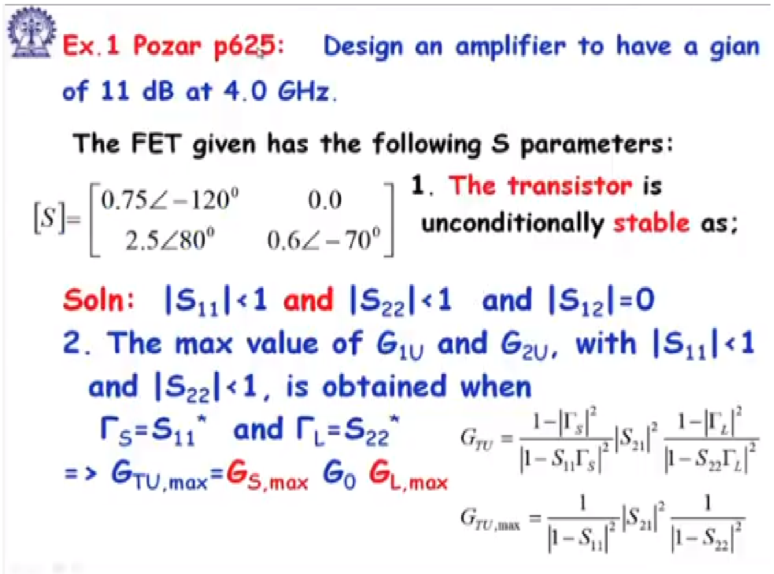

And then you can choose which gamma S and gamma L value so that you get the desired gain. Now this choice is not unique, there is no unique design this is your a but one thing you try to choose gamma S and gamma L as near to the smith chart center as possible because that will reduce mismatch. Though you are deliberately giving some mismatch you cannot choose the center value but if you choose it keeping your gain requirement if you choose it as near to center as possible that will be better.

Amplifier design for specified gain so here you see unilateral case this are all this thing again unilateral figure of merit so pozers problem page 625 design an amplifier to have a gain of 11db at 4 gigahertz. The transistor is given with this the first check the unconditional stability S11 is less than 1 S22 less than 1 you see this is unilateral already S12 is 0 so maximum value will be obtained here. So find out those values and you see the I have written everything so GTU from the input section here instead of S am calling G1.

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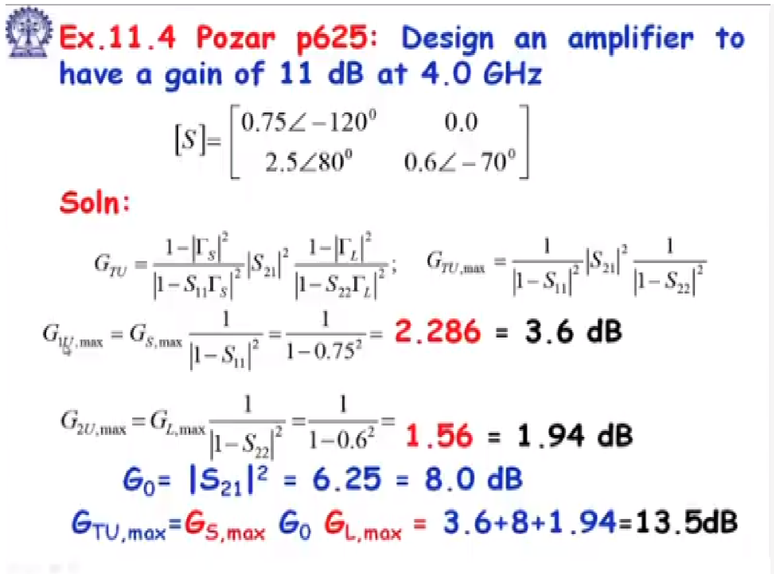

So input section can give you maximum 3.6db the output section can give you 1.94 db and the transistor itself gives you a gain of 8 db. So maximum you can have 3.6 + 8 + 13.5 db but it is required 11 so you can cut down here or here as per your thing. So you draw constant gain circles determine so let us say that we have determine here suppose this is the 3 db circle in the input side the red one is 3 db circle the blue one is 3 db circle.

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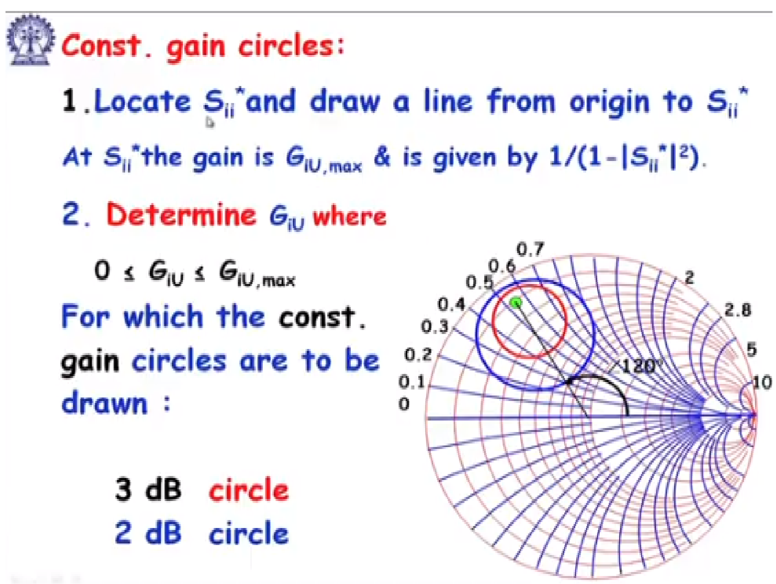

Now where I will choose you see that a prudent choice will be as near to as possible. So if I decide I will take 2 db from input side I will choose the point here that is a good choice I can choose also here but if I choose it here that will be more prudent. So here you see that gain is this normalize gain factor you see distance of circle, radius of circle.

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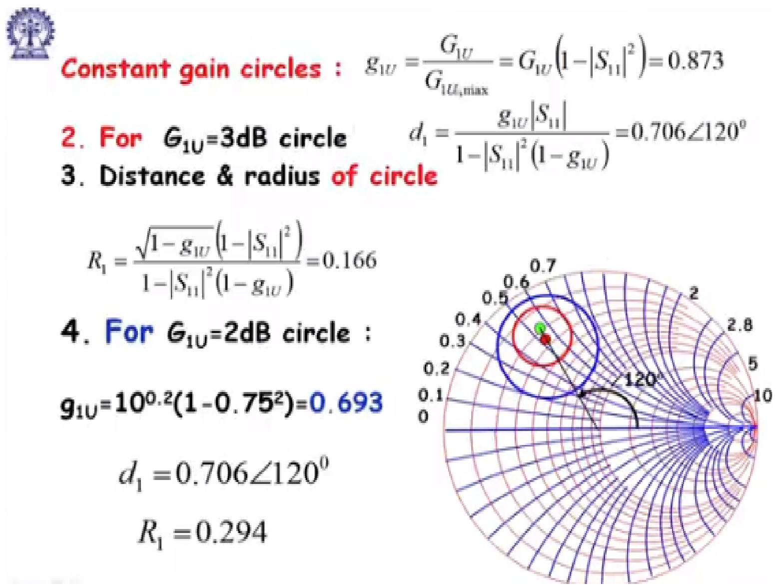

So by that we are plotted constant gain circle so for 3 db circle this are the values given. Similarly, for the 2 db this are the values given.

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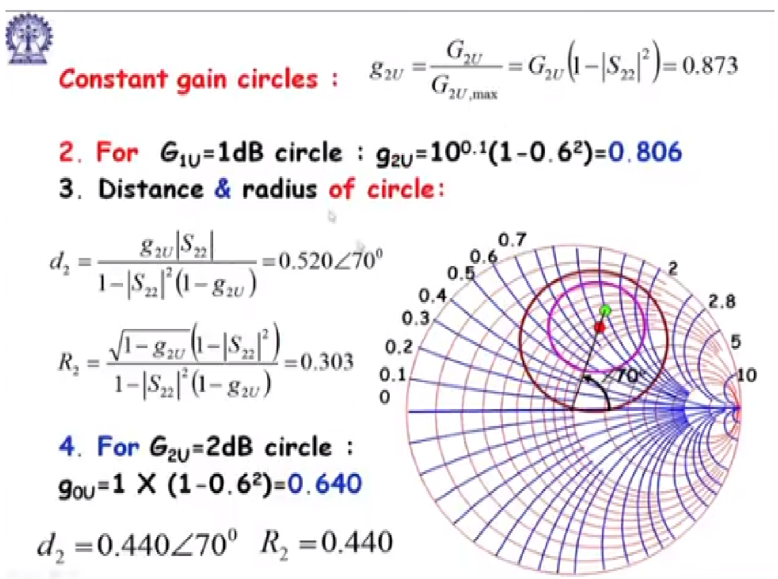

Similarly for the output side you see we have chosen this two that for 2 db circle like this then choosing we have decided that already 8 db the device was giving 3 db we decided from the input we will take 2 db and output we will take 1 db. So choose this you see I have chosen the nearest point for this so that gives the value if I read this value it is 0.32 120 degree and for the load we have chosen 0.22 70 degree.

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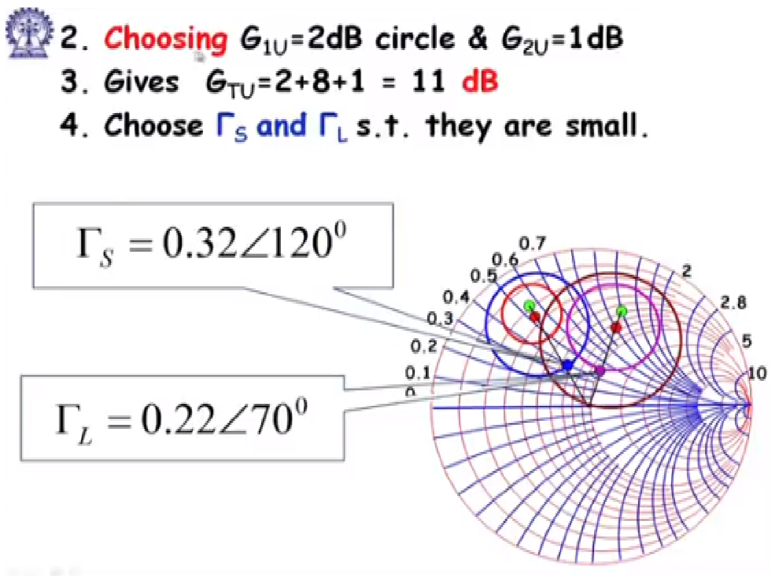

Now gain you can find this you can design the matching networks because the moment you choose gamma S is this you can find out locate that point gamma S then gone back to YS.

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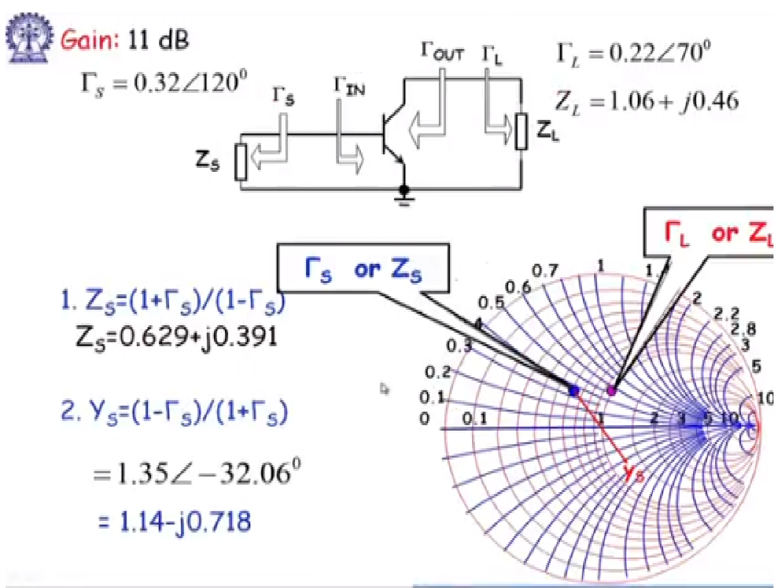

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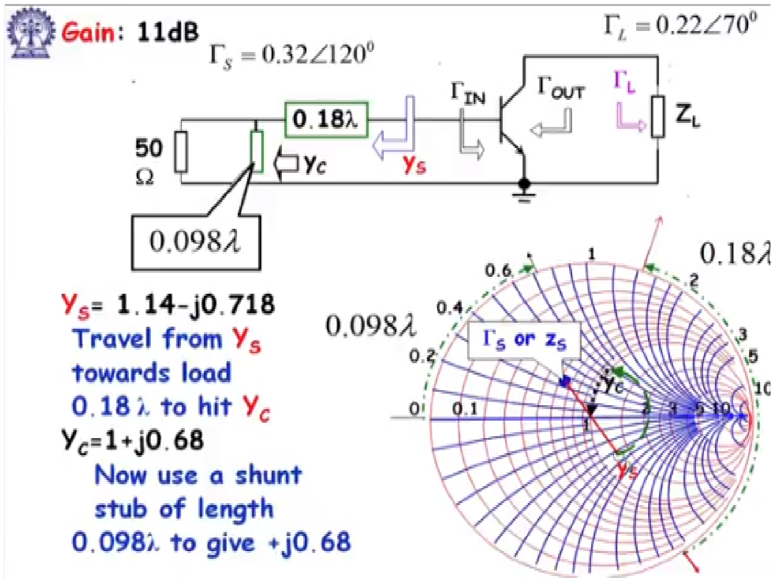

Then C where the cutting 1 + Zs circle from there you can design the stub so here I have seen that 0.18C .18 lambda you will have to have the transmission line then you have to cancel this stub. So that similarly gamma S so here I have given all the values and by that again I do the input matching and output matching.

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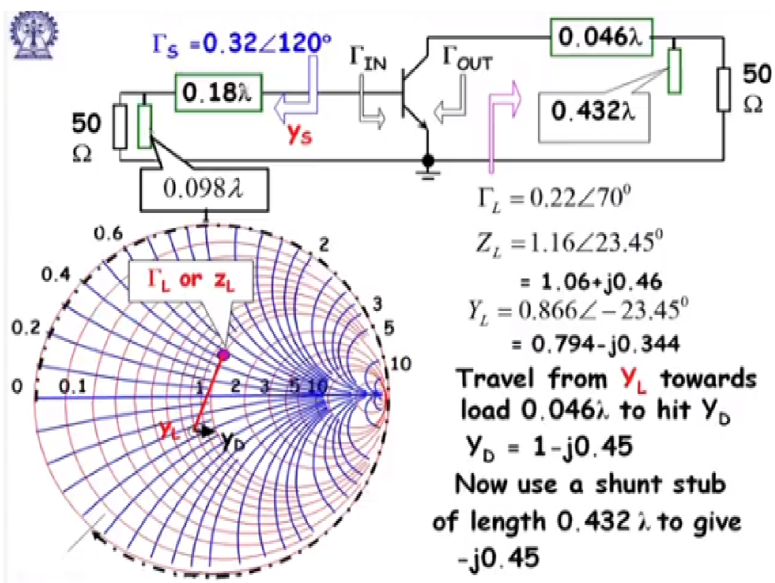

So this is the final circuit you see I have used a transmission line then a stub of this much length then here also a transmission line and stub this length. So this constant gain thing that gives you 50 ohm here though actually the source and load impedance where different but we are matching now it appears as 50 ohm here. So this is the total design for given 11 db thing.

I hope now you understand how to design for constant gain circle two more things we need to see that one is the sometimes we need to have instead of gain another very important parameters sometimes particularly for L and S that is the noise figure. So we will have to make a particular noise figure or minimize the noise figure gain may be anything moderate gain so that design we will see that design also.

We will see broad band design also we will see that sometimes in a power amplifier the non-linearity things comes stability we are enforcing everywhere in a every amplifier but if I give very high input then non linearity comes so how to design under that non-linearity or keep that non-linearity away. How to design the amplifier if my amplifier as non-linearity then sometimes I will give rise to additional spurious frequencies which is non-desirable.

So how to make power amplifier design if we do that this whole RF amplifier design part will be completed. Thank you