Basics of software-defined radios & practical applications
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Lecture - 13
Case study-I: Power amplifier Line-up for achieving linearity & power requirement example

Hello everyone, in the series of basics of software defined radios and practical applications, we were discussing the power amplifier their classes and parameters, today we will cover the power amplifier lineup for linearity and power requirement calculations. So, as we have discuss earlier also the main criteria for PA selection, is dependent on it is gain value how much output power, it can give efficiency and while we are maintaining this 3 values, if we can maintain the linearity of the signal also. So, the selection of devices for any particular requirement this is what we will target today.

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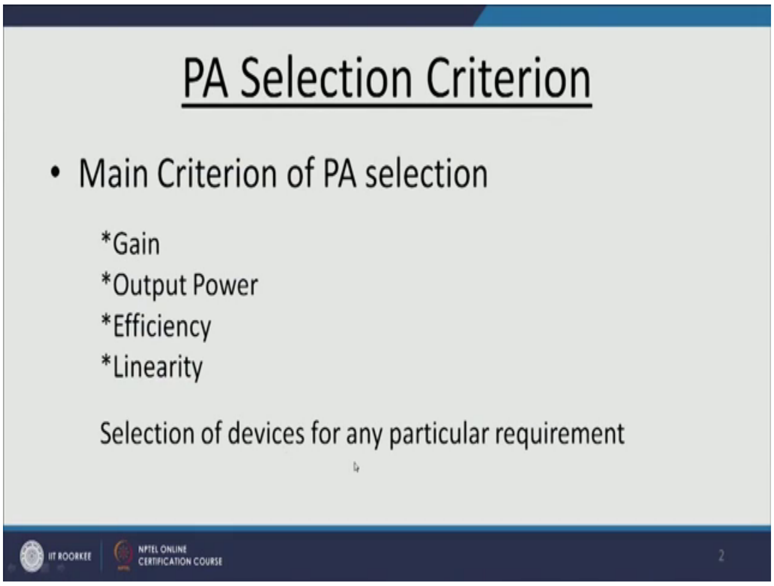

Now, PA assembly can be of 2 types, if we have a series of n pas we can attach them, in series or we can assemble them in parallel.

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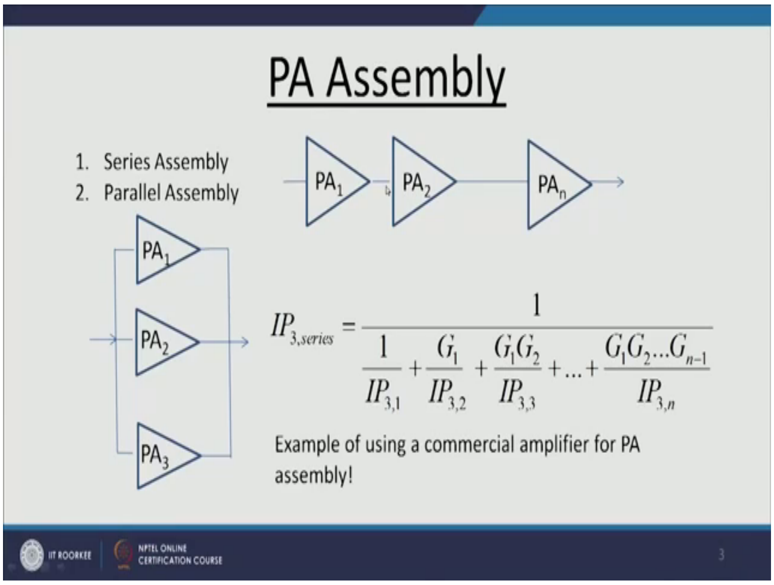

When the pas are in series basically, if you look at it is 3 characteristics means, gain output power efficient and linearity how it will behave.

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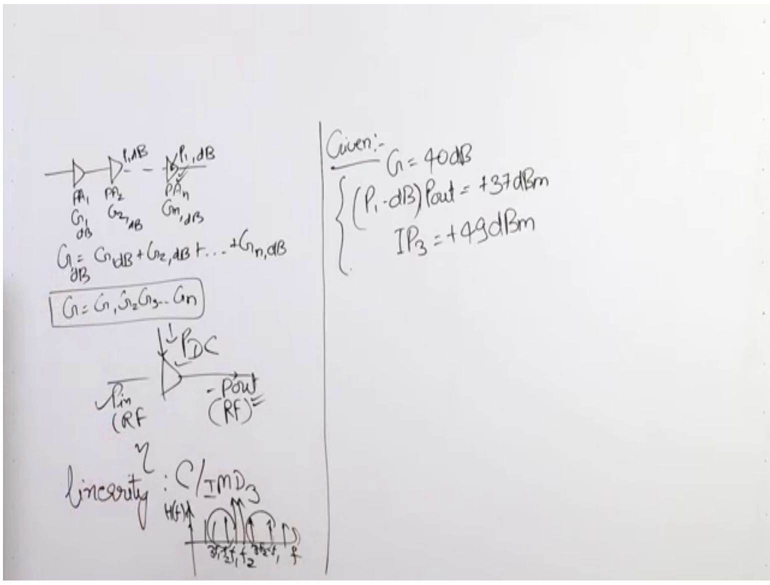

Suppose, we have an amplifiers and each of them has a gain of G. So, G1 is representing the gain of first amplifier, G2 is representing of the second and G n is the gain of the last stage. So, total gain in this case if it is in dB, it can be given by G1 dB plus G2 dB plus G n db.

If it is in the ratio form, the ratio of 2 voltages then this G will be simply G1, G2, G 3 and Gn. So, gain is simply the summation of all the terms in the if they are given in the logarithmic form or multiplication, if they are given the form of ratios, now coming to the second point is the output power, now output power of each stage is defined by P1 dB point of that particular amplifier. So, that P1 dB is the maximum power, which this amplifier can provide and if you want to have more power, then this P1 dB power then it is possible that our device will burn if you will give it more input power.

So, we have to be careful about P1 dB of each of the stages. So, at any stage the output power should not be beyond this P1 dB power, now the power output power is covered here and we know that the efficiencies all type of efficiencies DC efficiency, a simple total efficiency or power added efficiency basically, they are the ratios of the power. So, output power divided by input power, which I mean to say DC power. So, basically, we have input power which is RF power, we have output power which is again RF power amplified power and then we have PDC the power which is provided by a DC supply.

So, this DC supply is giving power to this amplifier. So, that this input power has that gain. So, that it can go to P out. So, efficiencies are always decided by this Ps. So, as long as we are able to do the calculation of power output power, we will be able to calculate our efficiencies now the forth requirement is linearity, now linearity is mostly seen in terms of carrier to intermodulation distortion of third order.

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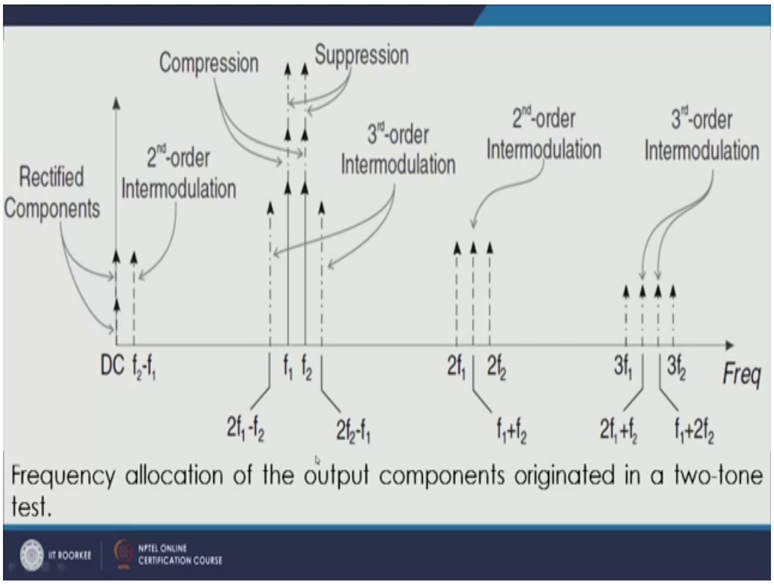

By 3rd order, we have covered it earlier by 2 tone test that the 3rd order products, they are the one which fall near to the original single. So, if it is 2 tone test at f 1, f2 and this is the frequency and it was the signal amplitude here, in that in that case the 3rd order modulations, which is 3f1 minus f2 and 3f2 minus f1, they are the nearest one and others fall much farther away.

Which are harmonics or the high order intermodulation. So, whenever we are talking about our intermodulation mostly, we are targeting our 3rd intermodulation and C by IMDs the one, for which we target. So, we have covered the parameters earlier, now we will see that how we can select our device to actually achieve a particular parameter for according to our requirement. So, let us again take our example commercial data sheet for which, we have done the exercise of reading all the specification of the power amplifier.

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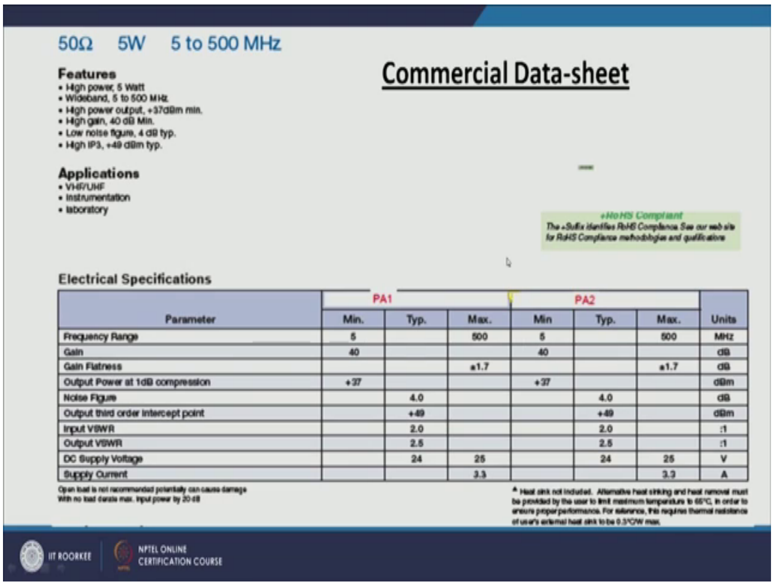

Parameter	PA1 Min.	PA1 Typ.	PA1 Max.	PA2 Min	PA2 Typ.	PA2 Max.	Units
Frequency Range	5		500	5		500	MHz
Gain	40			40			dB
Gain Flatness			±1.7			±1.7	dB
Output Power at 1dB compression	+37			+37			dBm
Noise Figure		4.0			4.0		dB
Output third order intercept point		+49			+49		dBm
Input VSWR		2.0			2.0		:1
Output VSWR		2.5			2.5		:1
DC Supply Voltage		24	25		24	25	V
Supply Current			3.3			3.3	A

Let us say this is the only device available to us and by using this particular power amplifier, we want to achieve a particular set of requirements. So, let us have the problem statement in front of us.

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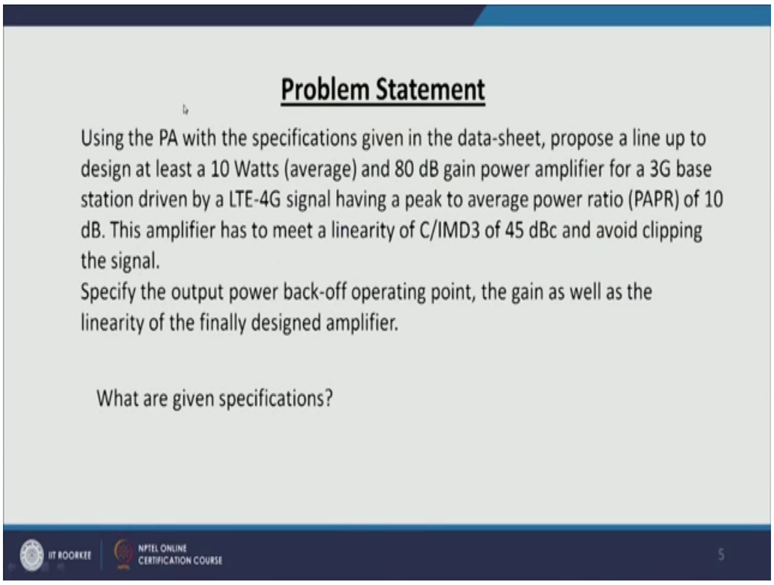

We have to use the PA with the given specifications in the datasheet, and we have to propose the lineup to design at least a 10 watt average power and 80 dB gain power amplifier for a 3G base station, which is driven by a LTE 3G or 4G signal, main requirement here is that the signal has a peak to average power ratio of 10 dB, this amplifier has to meet a linearity of C by IMD 3 of 45 dBc and it has to avoid clipping the signal.

Now, we have to specify the output power back off operating point for each of the power amplify stage, the gain of the each stage as well as linearity of the finally, designed amplifier. So, let us first of all review what are the given specification, let us have a look at this commercial datasheet and let us note down those specification, because we will be using those. So, what is given is a typical gain for this device is given. So, typical gain is given as 40dB, do we know the saturation power if we look here the output power at 1 dB compression, it is the P1 dB point. So, it is given as plus 37 dBm.

So, output power P out for P1 dB is plus 37 dBm, now what else do we require gain and P1 dB is known, and when we are talking about linearity condition then IP3 also given as plus 49. So, this is the given requirement here and we have to design a system so that we are able to qualify all this criteria. So, while we are starting these calculations, first let us review our conditions of linearity so that we can apply this formula wherever applicable.

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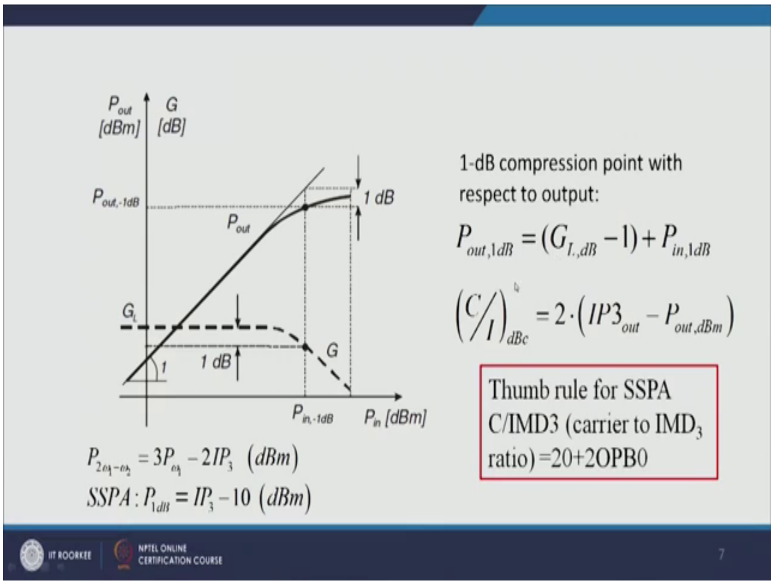

If we see here the relation between IP3 and P1 dB for the SSPA, it is given by this formulation means P1 dB is equal to actually IP3 minus ten. So, if we knowing the IP3, we can calculate our P1 dB from here, but in this case, we know both of them we know our IP3 and we know our P1 db.

So, if we see here it is holding that relation almost 49 minus 10 will be 39, which is near to the plus 37 dBm. So, in a case when you are not given this value you can calculate the approximate P1 dB point for the AAPA from the given value. So, in this case we will do our calculation from here, and again it is the approximate calculation, but it gives you idea to select your power amplifier, now if your P1 dB is given then you can convert Pout 1 dB, by using this formula is small signal gain minus 1 plus P in input power 1 dB point.

If you are given P out at that when you are also given IP 3 power, they you can use the formula C by I,0 upon this which is carrier to IMD 3 ratio as this formula, now because we are not talking about any particular P out, but the maximum P out. So, first of all we will do the calculation of maximum P out and then we can either use this formula or we can also use thumb rule for the SSPA, C upon IMD which is 20 plus 2 times output power back off. So, these are the formulas we will be basically dealing with and what are the step for this.

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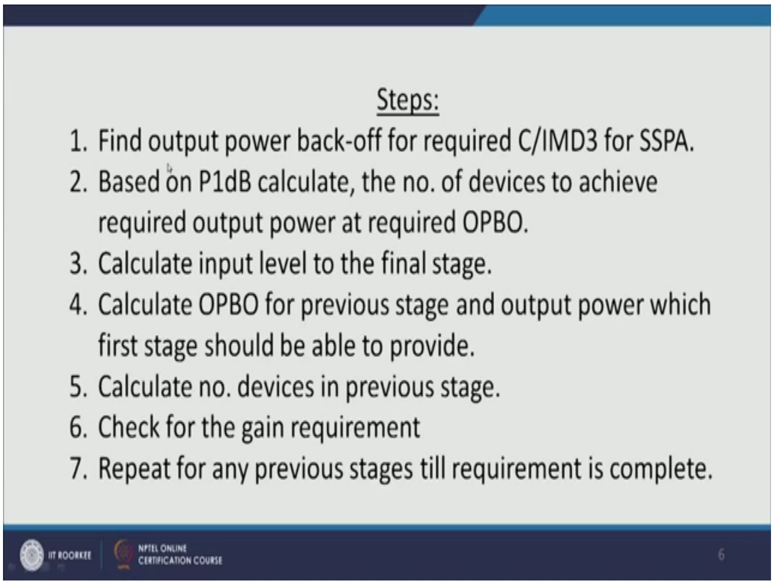

First of all, we have to calculate the output power back off, for required C by IMD 3 for solid state power amplifier, now looking at our problem statement we require at least 10-watt power from our power amplifier. So, let us converted back into dB logarithmic scale, because most of the calculation will be in terms of dB and if you see C by IMD provided in terms of dBc and our gain of the power amplifier it is given in terms of db. So, let us calculate this output power into dB first of all.

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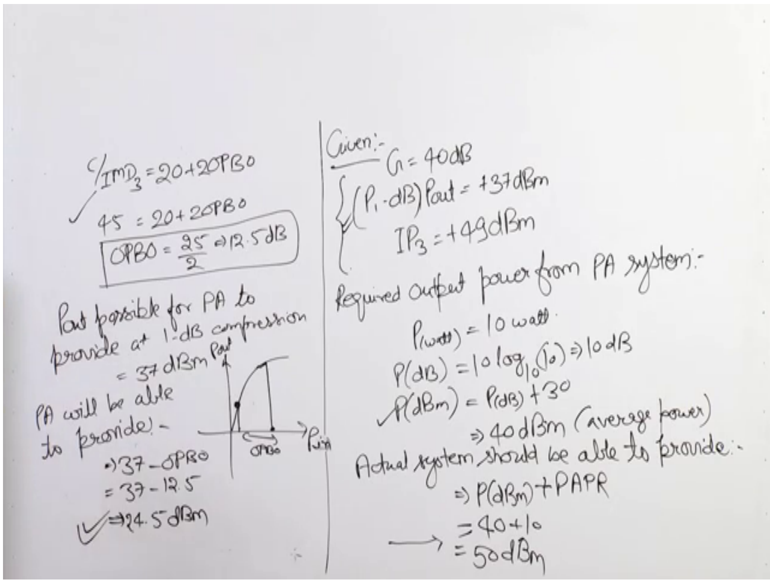

So, required output power from PA system, I am calling it system because eventually we will select number of power amplifiers to make this system. So, the P in watt is given as 10 watt. So, P in dB will be 10 log 10 10 is actually 10 dB and P in dB m, will be P in dB plus 30 this was a relation. So, 40 dBm so we should be able to get 40 dBm average power, now it is also given that we should avoid clipping of the input signal and the signal has the peak to average power ratio of 10 db.

So, if you do not want our signal to clip, then actual system should be able to stand or able to provide P dBm, which is calculated here plus PAPR. So, whenever the signal peak will be here it should not be clipped. So, power amplifier will be working at this average power, but the signal peak will be sometimes reaching to this P dBm plus PAPR value. So, it will be 40 plus 10 which is 50 dBm. So, we know that we have to have 50 dB m actual system power from here.

Now, let us do our calculation for the system, now we have to find output power back off for required C by IMD 3 for SSPA. So, for SSPA we had seen that we can apply the formula if you know the C by IMD 3, we can actually calculate our output power back off. So, let us do the calculation C by IMD 3, 20 plus 2 times output power back off. So, it is 45 or output power back off would be 25 divide by 2 all 12.5 db.

So, our signal will be actually driving at 12.5 dB power back off, from whatever our signal can actually provide to us, now what was the power amplifier P1 dB output power plus 37 dBm. So, basically power amplifier can provide this much output power at it is 1 dB saturation, but because we have to maintain the linearity requirement of 45 dBc, that is why we should work at 12.5 dB back off. So, P out possible for PA to provide at 1dB compression is 37 dBm but, because you want to maintain this linearity criteria we cannot work on this output power, we will work at a output power which is much lesser and how much lesser, if we remember sorry P in versus P out, we have discussed this that if it is the output power, than this is what we called output power back off. So, that it can work in the linear region. So, as higher OPBO or higher is the linearity and has lower is the OPBO, it is near to the saturation point and this C by IMD 3 will be reducing in size. So, for this calculation PA will be able to provide 37 minus OPBO minus 12.5.

So, to maintain this linearity requirement the individual power amplifier will be able to provide 24.5 dBm power only now how much power we required this much and how much this is providing single PA is providing this much now keeping this in mind let us move forward with this calculation.

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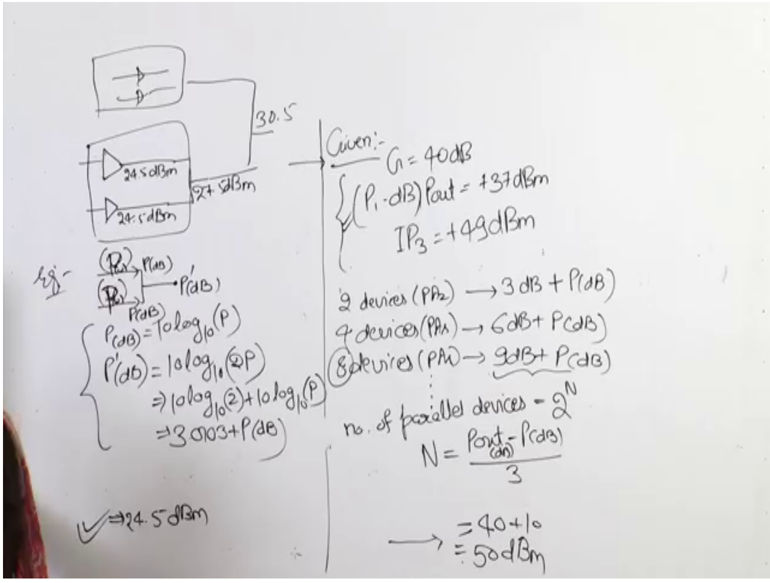

Now, this particular PA which we are studying and specifications are given here, we are able to get only 24.5 dBm from it is output, because we have to maintain the C by IMD 3 ratio of 45 dBc, but we have to achieve 50 dBm from the system. So, how can we do that.

If we add 2 of such devices together, there output will be the summation of this to. So, the output power will increase. So, form here we have this idea if we keep adding this power amplifiers in parallel, then there summation might eventually reach this value. So, let us do the calculation that how many of this devices we have to put in parallel to achieve that output power. So, how can we do that suppose we have V voltage from a system and V voltage from other system and we are summing up together and we are doing the calculation in dB then what will be the increase in the dB power or dB conversion of this value particular.

So, suppose if it is power like the power here, then I am talking about the logarithmic calculation at this point and at this point. So, at this point PdB is equal to 10 log 10 P, if I increase this power and I kept it P dash dB here by adding this 2 similar branches, then P dash dB is actually 10 log 10 and this is watt power. So, let us say 2 P the power have doubled in the watt value. So, in the dBsk, it will be and this value comes out to be. So, from here we see, if we add 2 branches and each of them has a power of P in the logarithmic scale.

Then by adding those to identical branches our new power will be just the addition of 3 to the old power factor. So, keeping this in mind we will do the calculation of our number of devices here for example, for 24.5 dB m at the output of this PA and PA there summation will be 27.5 dBm here right. So, what is happening here if you put do 2 devices let us say pas in parallel we have increase of 3 db. So, the eventual power will be 3 dB plus original P db.

If I put again these 2 devices in parallel with other 2 devices, then it will increase by other than the 3 dB right or I say that I repeat this block here and add them together then it will be what 30.5 and then the 3 dB incase will be there and there will be 4 devices in parallel. So, 4 devices or Ps will give raise to 6 dB plus P dB, if I increase it to 8 devices or pas and again repeat these here then the addition will be 33.5. So, it will be 9 dB improvement over the original PdB right.

So, if you look at this trend, the number of parallel devices are actually 2 to the power n and this n is actually P out minus original P dB this is also in dB divide by 3 right. So, basically 9 dB plus P dB minus P dB will give you 9 and divide by 3 will give you 3 and 2 to the power 3 will be actually 8 right. So, this will be number of parallel devices 2 to the power n, where n can be calculated as output power minus input power both in dB divided by 3.

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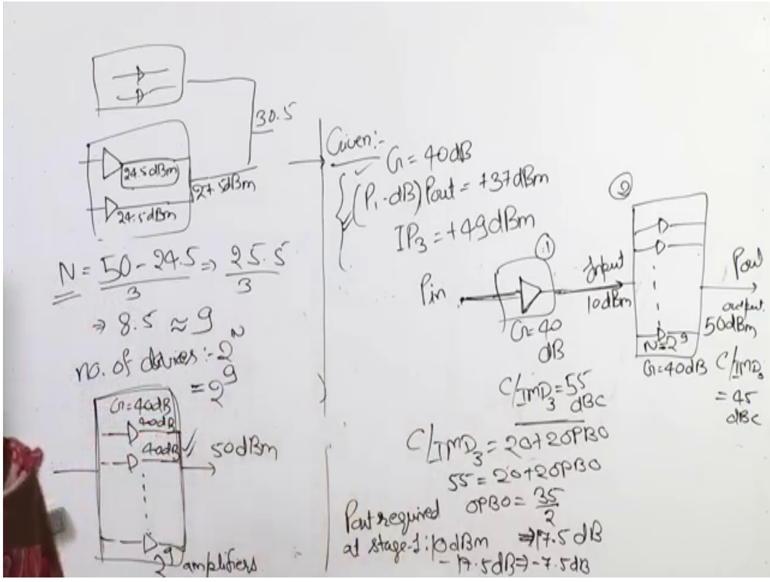

So, let us use this calculation here to know, how many devices do we require in parallel here. So, n which is number of devices will be P out which we require as 50 dB m minus input P dB and that input P dB, which works for only single device was 24.5 dB m divided by 3. So, let us do the calculation from here. So, N equal to 8.5 of course, N is number of devices number of pas it cannot by 8.5. So, let us go to the 9 that higher number of devices. So, we have chosen N equal to 9. So, number of devices will be actually 2 to the power N. So, 2 to the power 9.

So, it is quite high number here right. So, we have to add 2 to the power 9 amplifiers, so that we can have 50 dB m at the output so that we can have C by IMD 3 ratio of 45 dBc. So, 2 to the power 9 amplifiers here now of course, there so many amplifiers, that it is not a good idea to use actually this device for the specification, what is even better if we choose a device with high P1 dB suppose if it will be 46 dB m with that 46-dB m will we will have very high value of this calculation, and if this value is high then we will have less number of devices here.

For example, our Pout we required at to be 50 and suppose our PdB at this stage can be 44 here, then it will be 50 one as 46 divided by 3 only 2 to the power 24 devices we have to connect in parallel. So, if you have to do connection in parallel try to find high P1 dB value devices. So, that you have to use low number of devices. So, any how we are able to calculate here our last stage and this last stage is able to give us 50 dB m of the output signal. So, that our signal is not clipped it is able to give us 40 dB m average power or 10-watt average power as was required.

Moreover, what was our other requirement here other requirement as that, we have to have 8 dB gain from this power amplifier. So, till now what is missing the gain here of each amplifier is only 40 dB, and because they are in parallel they all will be giving only 40dB. So, the gain of this whole system is only 40dB, because there in parallel right. So, difference from here it to here is always 40 db. So, we are not getting our 80-dB gain requirement which is a much for this design. So now, what we can do we have designed our final stage which is this stage.

Now, we have this one stage before this. So, output and we have chosen our devices here N equal to which is number of devices here 2 to the power 9 and this will be input. Right? So, at the output of each device we had 24.5 dB m and eventually, we had 50 dB m at the output now the system gain is 40 db. So, what will be input power 50 minus 40. So, 10 dBm, now this 10-dB m is the requirement which any power amplifier which we are going to attach here should be able to provide and because we are using the same power amplifier, we know that what was it is a requirement there it was able to provide us 24.5 dB m at the output. Right?

So, 10 dBm it can easily provide it is within the range. So now, what we have to do actually, we have to just simply attach one of the device is with which has already 40 dB gain, and it is able to cover this requirement of P out of 10 dBm, because it can give up to 24.5 dBm. So, it does not have any problem now let us check that what will be the output requirement at the output power back off to maintain the linearity.

So, if at the output level our C by IMD 3 was 45 dB c it is previously should have even better C by IMD 3 otherwise the intermodulation term which are coming from here, it will be input to this one and they will become even more non-linear. So, the C by IMD requirement becomes higher for the first previous term. So, if a previous term let us take even better C by IMD 3 requirement let us say 55 dBc it has to be always better than this one and as rule of thumb, we try to take almost 10 dB better than the last stage.

So, for this C by IMD 3 what should be the power output back off C by IMD 3 equal to 20 plus 2 OPBO, again because it is again the small signal power sorry solid-state power amplifier SSPA. So, we can use this formula. So, 50 for 55 what should be the output power back off. So, 17.5 output power back off should be there.

So, actually output power which we require here is even lesser. So, output power required at stage one, and let us call it is stage one is 10 dBm minus 17.5 db. So, minus 7.5 dB now again we require minus 7.5 dB and our pas able to give 24.5 dBm. So, we are very, very safe from that point of you now our system is from here to here. So, we have to give this specification of each stage, how much output power back off operating point we have to keep.

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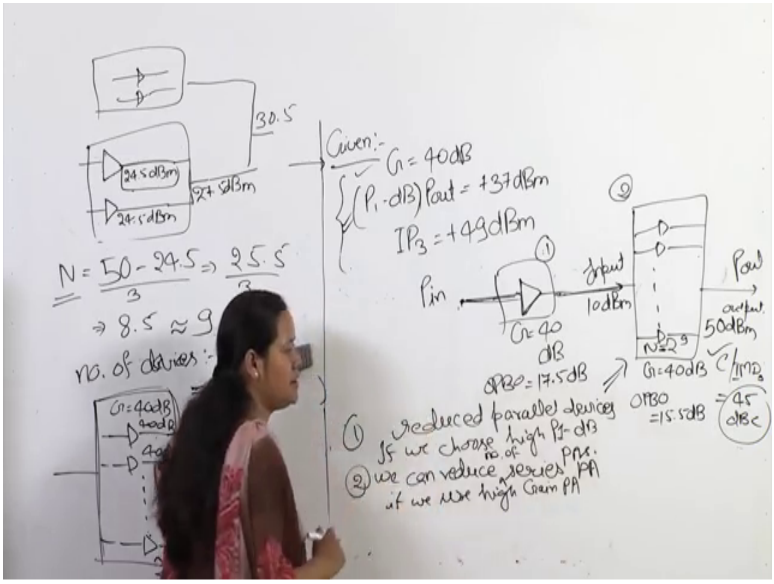

The gain of the stage and the linearity of the finally, designed amplifier. So, G is 40 or both of them OPBO was 17.5 dB here and the previous stage here it was 50 minus 12.5. So, it was I think 15.5 dB we are maintaining C by IMD 3 of 45 dBc, because we have done our calculation for keeping this linearity requirement, and we are getting our output requirement of 50 dB m. So, our signal is not being clipped and we are able to design the system completely.

So, this was one example and we can if our requirements are not achieved, we can repeat keep repeating this for the previous stage, what we can see from here we could have reduced parallel devices, if we choose high P1 dB pas then we can reduce this one and we can reduce series pas number of series pas, if we use high gain pas.

So, for example, if this pas were able to give us 80 dB in one shot we are not required to use this stage we should be able to get everything from this stage only. So, keeping this in mind in the next lecture we will do the mix and match up of some of the devices to choose the best among these.

So, this was a lecture where we covered the requirement and how to choose this specification.

Thank you.