Basics of software-defined radios & practical applications

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Lecture - 12
Power Amplifiers: Useful Definitions

So, in the series of basics of software defined radios and practical applications lectures, we were discussing the distortion which has been introduced by power amplifiers and non-linear component, and now we want to concentrate on some of the definitions which we have to know the specification of a particular power amplifier. So, one of the main thing of the power amplifier is efficiency of the power amplifier.

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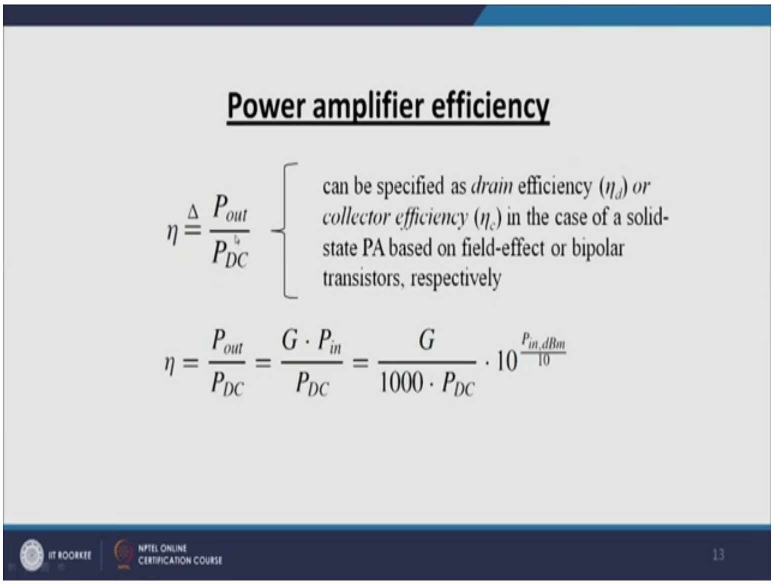

Efficiency of any power amplifier is defined by the ratio of the output power, divided by the input power given to it in the DC form.

So, basically, we have seen that whenever we amplify any input signal to any particular power of the output signal, this power is taken from a DC source. So, the ratio of the power taken from the DC source, with respect to the power which we are getting in the power output, is this is what we call power amplifier efficiency. Now depending on where we apply our DC power it can be called also draining efficiency, and symbol is given with a small d, or it can also be called the collector efficiency and then the symbol contains a small c.

So, it is in the case of solid state power amplifier which are based on field effect or bipolar transistors. So, if you come across the drain efficiency or the collector efficiency most probably, they are talking about the same parameter, now because we want to avoid the distortion in the signal. So, we run it mostly in the linear range, and because of that we lose our efficiency, because we have known that as we increase our signal power our efficiency of the power amplifier increases, but so, does the non-linear components. So, mostly when we are driving it in the linear region, then the output power can be given as the function of gain multiplied with the input power.

In this definition we have to note that the output power and the DC power all the powers given here are in the watts, they are not in the logarithmic scale right, now that is why we are showing the output power is the multiplication of the input power with the gain, and its ratio with the DC power consumed. Now we can further modify this definition; so, that it can be given in terms of dBm, and when that happens then what will we do? First of all we will convert this into milliwatt by dividing by 1000, and then that milliwatt power we have to take this 10 to the power Pin dBm divided by 10 so, that we can get our input power if our power is given in the form of dBm.

So, we can use this formula for the dBm, if we have watt powers we can simply use this one, then this PDC is simply the multiplication of the DC powers consumed by the system which can be calculated by multiplication of the voltage and current values which is provided in the datasheet of a particular power amplifier. Now that was the drain efficiency apart from that you will also hear the term power added efficiency.

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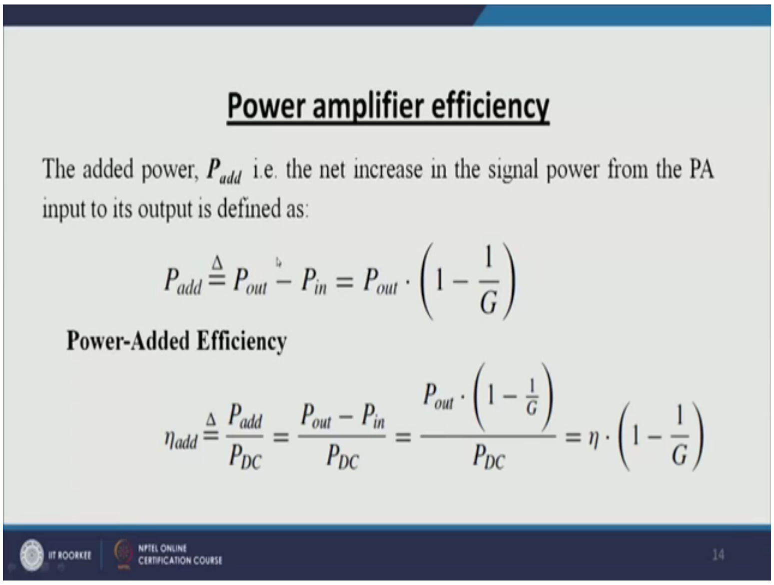

So, what is power added efficiency? It is given with respect to the added power, what is added power? As I said the output power takes it is power from the DC source. So, when we say output power divided by with respect to DC, we are talking about the all the power at the output.

When we say added power, it means we are subtracting the input power from the output power, and then we have net power which is the gain of the power not the gain actually, but the difference between the power, absolute power which we have achieved, and when we give our efficiency with respect to this added power, then it is called power added efficiency.

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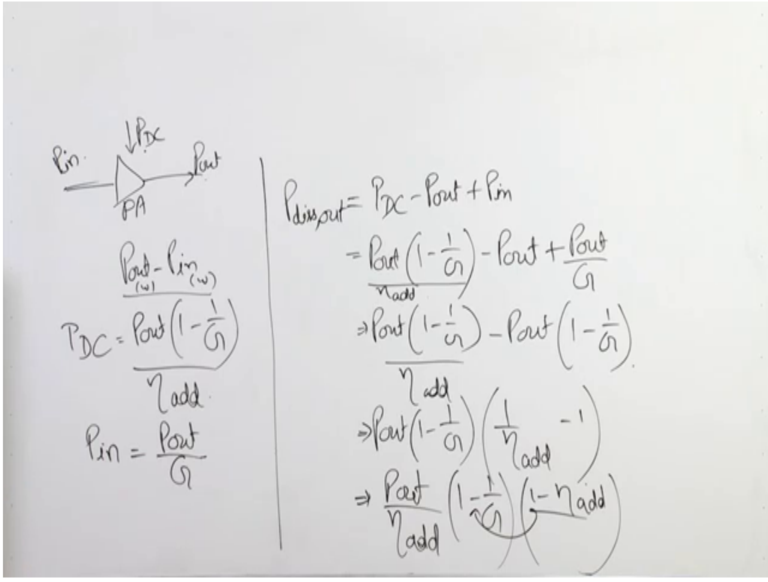

So, I to clarify this thing I remember our original diagram of the PA. So, we had PDC it is in watts Pout it is also in watts, and Pin it is also in watts, so ratio of this and this gives you efficiency and if we subtract this power from here.

So, overall gain of the power we can say all though not it is not division, it is in watts and then that ratio power added efficiency it is called, now we can rearrange the terms of this power added efficiency to give new definitions. So, that we can define in terms of input power output power of, or if gain is known may be in terms of gain.

So, this second expression is simply we are substituting the definition of added power, Pout minus p n upon PDC, and if we eliminate our Pin by using the formula, that Pin is what Pout divided by G then we are getting Pout 1 minus 1 upon G PDC. So, if we just know the gain of the power amplifier and we know the output power of the power amplifier and DC power, we can still calculate the power added efficiency there.

Moreover, because PA out upon PDC is actually the drain efficiency, so if we know the drain efficiency and we know the gain of the power amplifier only, then also we can calculate the power added efficiency. So, in this all different forms we are able to calculate the power added efficiency there, that power which we have lost there which has not been converted to the RF that is what called dissipated power.

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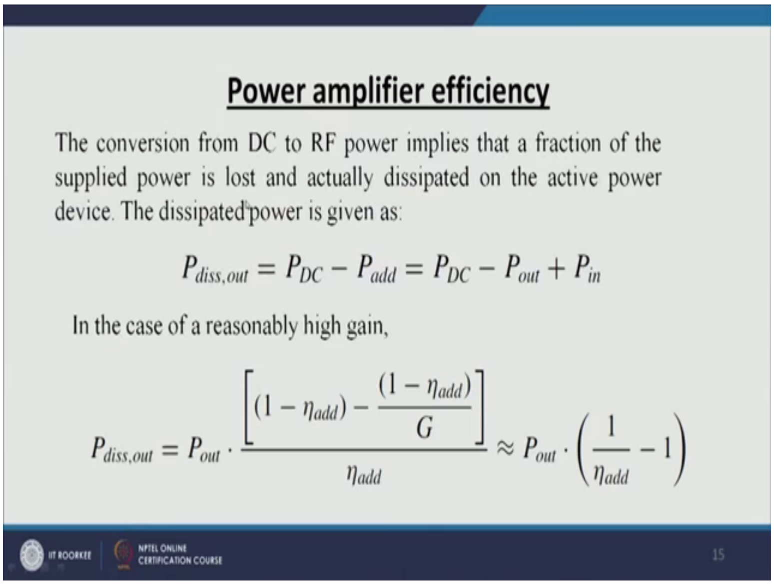

So, as the name suggests it is the def is the deviation of the power added efficiency from the DC. So, PDC minus p added power now this added power is actually Pout minus p. So, PDC minus Pout, minus Pin, it becomes PDC minus Pout plus Pin.

So, if you do not know the added power added efficiency and we want to know the dissipation of the power, this formula can define this. Now dissipated output we can also calculate in terms of power added efficiency by playing little bit with these variations. So, what we can do that our we want to eliminate our PDC from the formulation and we just want to keep Pout. So, let us use the formula, this formula write down PDC as Pout 1 minus 1 upon G divided by power added efficiency, similarly Pin will be Pout upon G.

So, in this formula we substitute the PDC and Pin value here. So, p dissipated at the output yes calculated, as PDC minus Pout plus Pin. So, let us put these values here Pout 1 minus 1 upon G minus Pout plus Pin which is Pout upon G. So, basically, we are just rearranging these terms Pout 1 minus it is divided by p added efficiency, added efficiency minus Pout common and 1 minus 1 upon G.

So, if I take common these 2 terms, then I will get this formula here, or Pout upon 1 minus 1 upon G and 1 minus add. So, by rearranging the terms of this if you multiply this back here, this is the expression we are getting here. Now in this case if we say that our gain is much higher then we can neglect this term and eventually the Pout and the dissipated output may have this relation, but this relation exists only for very high gain.

So, all these parameters are related to each other, they complement each other and if you know one or two of those the third you can easily calculate.

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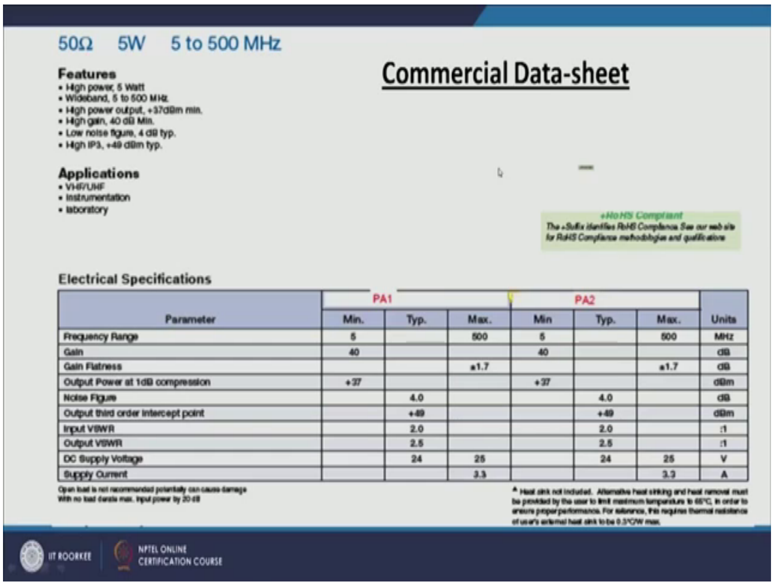

Parameter	PA1 Min.	PA1 Typ.	PA1 Max.	PA2 Min	PA2 Typ.	PA2 Max.	Units
Frequency Range	5		500	5		500	MHz
Gain	40			40			dB
Gain Flatness			±1.7			±1.7	dB
Output Power at 1dB compression	+37			+37			dBm
Noise Figure		4.0			4.0		dB
Output third order intercept point		+49			+49		dBm
Input VSWR		2.0			2.0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

So, let us have this example of the commercial data sheet. So, in this case I am showing you data sheet for the many circuits, and they have 2 p as of the same bench.

Basically, they have very similar kind of parameters, but eventually with respect to frequency they are different. So, this is the example you will get for most of the power amplifiers. So, what it states let us read it and then we will apply our knowledge of selecting this power amplifier, this is a power amplifier of 5 watt which works from 5 to 5 100 megahertz, it is saying that it has high power output power of plus 37 dBm which is the minimum value given here, and it can go little higher than that, but they define the minimum values similarly the high gain of 40 dB minimum they have said. So, we should be able to get minimum 40 dB gain from here.

Typically, 4 dB noise figure has been said in typically plus 49 dBm IP 3 intersection point of third order is given, now if you look at the particular specification then the same thing frequency and gain is repeated there they have said that it is a typical gain, but the gain flatness is plus minus 1.7. So, it can be 40 plus 1.7 or it can be 40 minus 1.7 here the output power at 1 dB compression is plus 37. So, at 1 dB compression means our power amplifier has been saturated enough to get the 1 dB compression, and at that time the output power is plus 37 dBm.

Of course we can compress it little further, and we can get more output power, noise figure is typical 4 IP 3 is plus 49 VSWR values are also given, which is important for the matching we are not discussing them here DC supply voltage is given as typically if 24 volt, but they can also be worked at 25 volt, but at the 25 volt they have will have some deviation from the typical values, supply current is given as 3.3 value. So, by using this current and this voltage value we can do the calculation of our PDC, because of the power consumed by the drain or collector.

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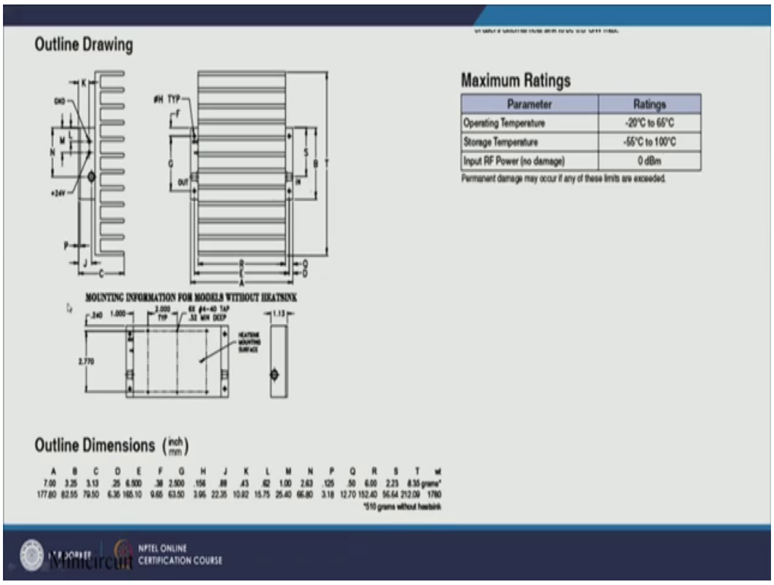

Now, if we see here they are showing drawing mostly they give you the specification. So, that you have some idea of the packaging here dimensions are given. So, that you can put it in a particular place and you can design your space of the transmitter, how this will fit in your total schematic, they have some maximum ratings which should not be exceeded operating temperature is from minus 20 to 65 degree centigrade storage temperature is from minus 55 to 100 degree centigrade, without any depth damage we can give input power till 0 dBm, and it means we should not give any power beyond 0 dBm it wait might burn.

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FREQUENCY (MHz)	GAIN (dB)			VSWR (:1)		POUT at 1 dB COMPR. (dBm)	FREQUENCY (MHz)	NOISE FIGURE (dB)
	22V	24V	25V	IN	OUT	24V		24V
5.00	44.82	44.80	44.79	1.41	2.24	38.75	10.00	4.67
10.00	45.77	45.76	45.71	1.18	2.22	39.69	100.00	3.79
50.00	45.99	45.96	45.93	1.12	2.22	39.68	200.00	3.87
100.00	46.37	46.40	46.40	1.09	2.30	39.68	300.00	3.96
140.00	46.26	46.32	46.35	1.19	2.23	39.71	500.00	3.91
180.00	46.13	46.22	46.27	1.26	2.15	39.59		
200.00	46.12	46.16	46.23	1.26	2.16	39.54		
240.00	45.76	45.80	45.87	1.17	2.14	39.58		
260.00	45.32	45.43	45.47	1.14	2.09	39.64		
300.00	44.40	44.48	44.50	1.27	2.01	39.56		
360.00	44.72	44.82	44.87	1.50	2.07	39.49		
400.00	46.08	46.18	46.23	1.48	2.08	39.23		
440.00	45.69	45.81	45.93	1.43	1.88	39.01		
480.00	43.67	43.80	43.92	1.51	1.68	38.11		
500.00	42.93	43.03	43.15	1.51	1.71	37.42		

Now, as we said initially they have provided typical value, but with respect to frequency, and with respect to applied voltage at the drain, they might change. So, they are giving this data also. So, that we can select for a particular frequency, and correspondingly we can do our calculations, also they provide the noise figure deviation with respect to different frequencies, apart from that they sometimes provide this kind of diagrams with respect to frequency.

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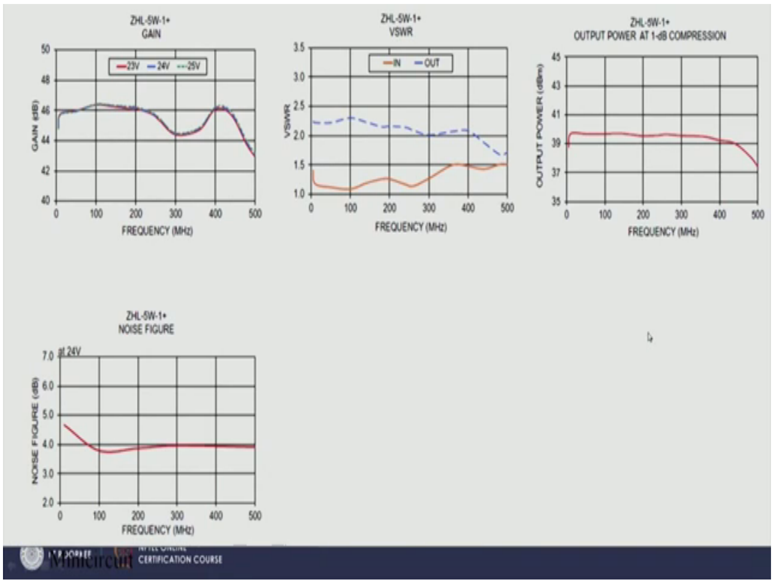

So, that you can have some idea gain is quite high near from 50 to 150 megahertz after that it is dropping near 300 megahertz it is quite low.

So, this kind of information helps us in selecting our device, similarly if we increase the frequency we can say that output power is fairly constant near almost 40 dBm for most of the range, but at the high frequency range when we are going, from 400 to 500 megahertz then it is dropping by. So, we have to keep that in mind. So, keeping this in mind, let us try some of the concept for the practical datasheet, now first question you have to select.

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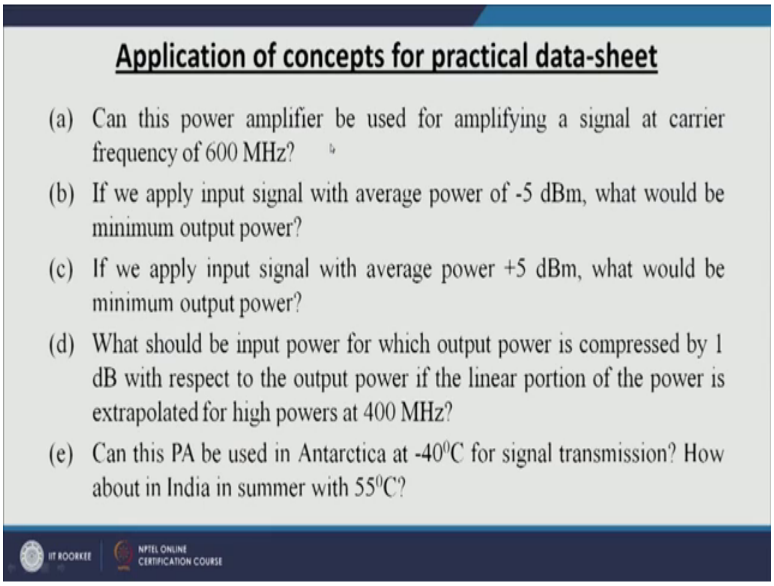

I want to use this power amplifier for amplifying a signal which has the carrier frequency of 600 megahertz. So, can I use power amplifier?

So, let us have a look at our sheet and it specifically says that, it works from 5 to 500 megahertz. So, at 600 megahertz it will not work like it has been proposed here it might still give you some results, but it is not supposed to be working at 600 megahertz; so no this power amplifier cannot be used for amplifying a signal at this frequency. Now the second query appears suppose we apply input signal with the average power of minus 5 dBm what will be maximum output power. So, we are given the average input power, if you want to calculate the minimum output power, we should have a look at it is gain characteristic it will give us some idea.

So, what should be the minimum gain right. So, we are looking for the minimum gain here. So, they have said that minimum gain is 40 dBm sorry 40 dB, because it is a difference between the volt powers. So, it is dB not never dBm. So, this is 40 so, by this calculation if a minimum gain we can achieve is 40 input power is minus 5 dBm.

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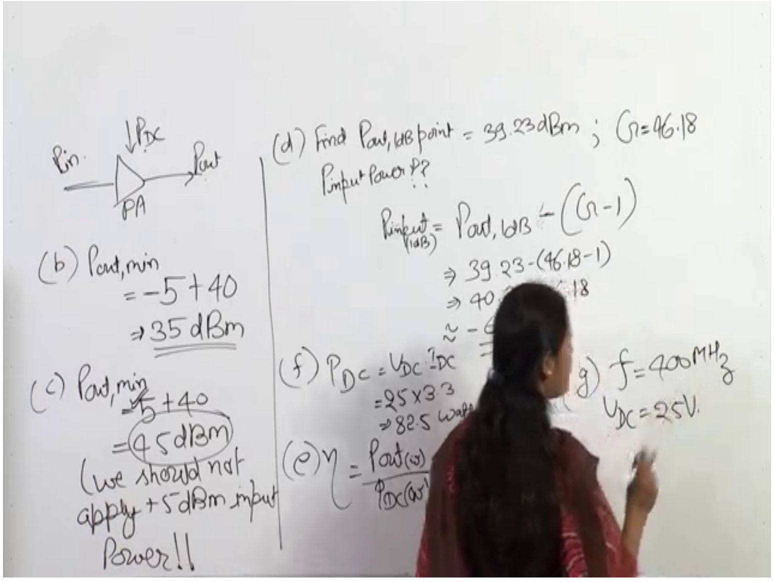

So, minimum watt per we can get is minus 5 dBm, plus 40 dB since become 35 dBm. So, this is the minimum power we can get, if we apply minus 5 dBm input average power, now what will happen if we apply input power with this average power plus 5 dBm.

So, what would be the minimum output power now, if we do the calculation for the c part, Pout minimum will be 5 plus 40 which would be 45 dBm by calculation right, but now let us have another look at our data sheet, if we see in this sheet it is saying that input RF power which should be applied safely is 0 dBm right; so plus 5 dBm power should never be applied, if there is a chance that it will burn out.

So, we will say we should not apply plus 5 dBm input power, because it may burn we might not get this power and we will lose our device. So, no it is not advisable that we apply this voltage this power at all, what should be the input power for which the output power is compressed by 1 dB, with respect to the output power if the linear portion of the power is extrapolated for high powers at 400 megahertz.

So, basically if we look at the this definition they are asking what will be the output 1 dB compression point power, at 400 megahertz and what should be input power for that. So, first of all at 400 megahertz we have to find the 1 dB output power compression point. So, d part says find Pout 1 dB point and then calculate corresponding input power. So, first of all let us read the output 1 dB power at 400 megahertz. So, if we look at this list, at 400 megahertz output at 1 dB compression is clearly given. So, as we have seen earlier, 24 volt is it is typical applied voltage other than that is it can have it can work at 22 volt also and 25 volt also or in between also.

But 24 volt is the given value. So, if we read that this value 400 megahertz, we get 39.23 dBm, now at 400 megahertz at 24 volt what was gained. So, let us have the look at the gain and it is given as 46.18. So, this is a small signal gain read linear region. So, when you want to calculate this output power it should be what, sorry input power if you remember our formula for 1 dB, compression earlier formula was Pout 1 dB point, plus not plus minus gain minus 1.

So, we do 1 minus 1 dB here also, if you remember our formula. So, it first Pout is equal to input power at 1 dB compression, plus G minus 1. So, for calculation of Pout we subtract this from this values. So, input power at 1 dB will become 39.23 minus 46.18 minus 1. So, it becomes 40.23 minus 46.18. So, approx minus 6 dBm. So, at minus 6 dBm we will have 1 dB output compression point at 400 megahertz.

Now, next question arises that can we use this PA in antarctica at minus 40 degree centigrade for signal transmission. So, if you remember they were showing a giving us the temperature range also. So, minus 40 they have set in the operating condition. So, it can work only from minus 20 degree centigrade to 65 degree centigrade in the operating condition. So, no for the signal transmission we cannot have this much we cannot use our device for minus 40 degree centigrade. So, answer is no for this one how about in India in summer with 55 degree centigrade. So, let us have a look again.

So, upper range is 65 degree centigrade for the operating temperature. So, of course, in India we can use it, but for in antarctica we cannot use it at minus 40. So, this is how we can select with respect our temperature, now what should be PDC based on given data. So, the data is given here originally typical DC supply voltage and supply current is given as 3.3 ampere and 25 volt. So, current is this one typical voltage if you take 24, then you take V like this and whatever supply volt current is given to you. So, suppose you are driving your PA at 25 volt then your calculation will be 25 into 3.3, because it is given as the RMS value.

So, normally it is defined there if it is RMS value or not, when DC value you will simply multiply those values. So, V into I will give you PDC. So, this is f portion PDC will be V DC into I DC simply calculation because it is DC power. So, V DC was 25 it was 3.3. So, 82.5 from calculation it is coming out to be 82.5 watt.

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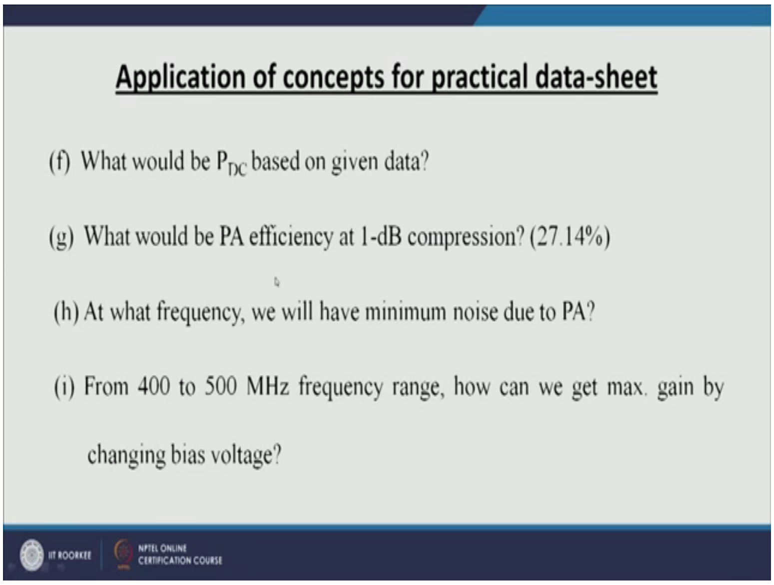

Now what would be PA efficiency at 1 dB compression; so basically, we have to know the Pout at 1 dB compression, and because that is the definition of PA efficiency normal efficiency.

So, output power in watt divided by PDC, this is the definition of the normal drain efficiency. So, output power at 1 dB compression. So, here we can see the output power at 1 dB compression, we are not given any frequency range. So, let us take the typical one. So, typically it is plus 37 dBm. So, we have to convert that back into watt first of all. So, it will become a 10 to the power 37 minus 30 divided by 10, all right because we have first we converts from dBm to dB by it subtracting 37 by doing say 37 minus 30 now it is dB and then that dB we are converting back into watts.

So, it should become if you do this calculation it is coming out to be 6.07 percent. So, because we are not we are not given any frequency data we have taken the typical value, if you are given the frequency then we can take the proper value. Now the next portion is at what frequency we can have the minimum noise due to power amplifier. So, if you consider it on the noise, minimum we have to select among these. So, minimum I can see at 100 megahertz. So, at 100 megahertz from the data sheet we can say minimum noise figure, and suppose you have to select a power amplifier in a way that you have to select a frequency range from 400 to 500 megahertz.

So, how can we get the maximum gain by changing the bias voltage. So, we are told 400 to 500 range is our power amplifier can work in that our system can work in that range, and we want to have the maximum gain by changing the bias voltage. So, we have to have the maximum gain. So, we have to look into this region here from here to here, we want to maximize our gain which is the maximum value here.

So, I can perceive that maximum value is 46.23 which is given at 400 megahertz and 25 volt. So, so last portion. So, f should be 400 megahertz and voltage condition V DC should be applied as 25 volts. So, by that you will have maximum gain of the 46.23. So, by using this kind of data sheets you can select a your power amplifier accordingly.

So, in the next lecture we will see how we can combine different kind of power amplifiers to achieve a particular output power or a particular gain and what will be the impact on it is nonlinearity in that case.

Thank you.