Basics of software-defined radios & practical applications

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Lecture - 15
Behavioral models for representing non-linear distortions

So, in the series of basics of software defined radios and practical applications, we were discussing power amplifier assembly, it is parameters, it is efficiency and the distortion it introduces. So, today we will discuss the linearization techniques for non-linear distortion, apart from the non-linear distortion, power amplifiers especially the solid-state power amplifiers, they also have memory effects. So, this memory effects they are explained has the time lags between, AM AM PM responses of PA and they are of 2 types electrical and thermal.

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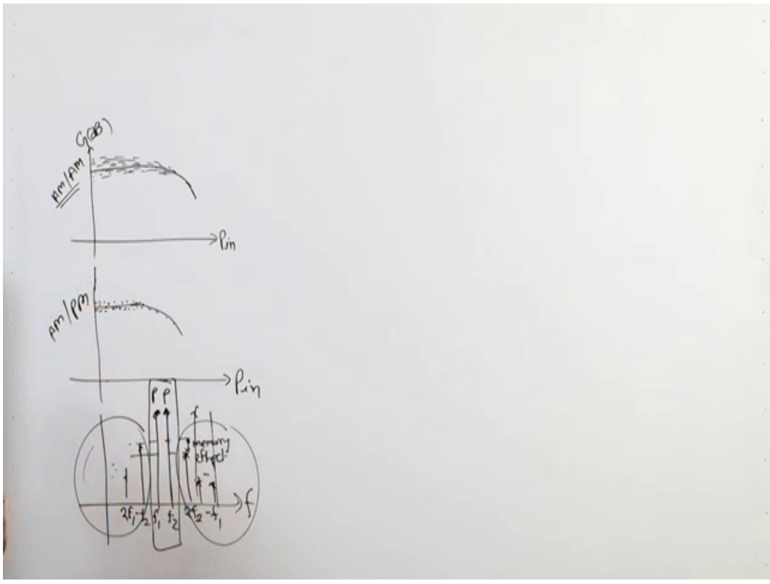

So, what do we mean by memory effects, if you are plotting, AM AM plot, which is basically gain, it looks like this with respect to input power, the gain is constant for some time and then starts dropping and this is we called AM AM. Now, for the AM PM with respect to input power, output phase minus input phase, it also is constant for some time and then, after that it either reduces or it can also expand, depending on the devices you are using most kind of system (Refer Slide Time: 10:48) etcetera, or the gain.

Now, this is simply the definition, how they are defined? It and if you see here, these are one to one relation, for one input power this one output power, output gain and output phase, when we have memory effect in the system, the output is not only function of one single input, but more than one input it, means we will have some more points which are scattered around it is mean value. So, this is how it will look, many curves nearby towards the noise, there more noisy and when you go to pick they become little bit narrower.

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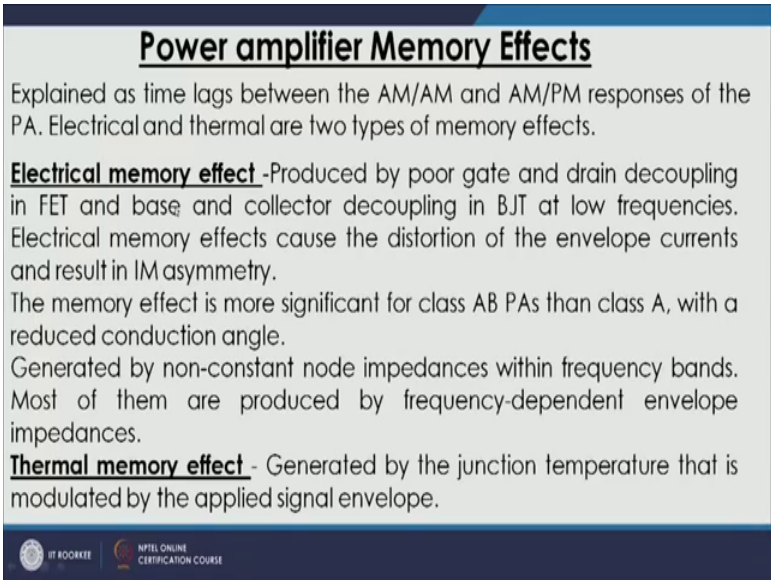

So, this effect when the output is a function of more than one input, it is called memory effects, it is a 2 types electrical memory, effect these are produced by poor gain and drain decoupling in FET and base and collector decoupling in BJT at lower frequencies, this kind of memory effects, they cause the distortion of envelope currents and result in intermodulation product asymmetry. So, in time domain, when you plot your AM AM AM PM diagram, you can see your memory effects and frequency domain, suppose these are your 2-tone signal at frequency 1 and frequency 2 and, you have IMDs at 2 f 1 minus f 2 and 2 f 2 minus f 1.

For the same amplitude of power at the 2 tones, you will see that the level of IMDs will be different, and this difference is because of memory effect. So, this is what, we mean when we say that, there is a IM asymmetry, normally it is considered that, the class a b PA has more significant memory effect then class a, because it has reduced conduction angle and these are called frequency dependent, envelope impedances and because of that frequency dependent memory effect, which you can see in frequency domain.

Now, thermal memory effects they are long term memory effects and their generated by the junction temperature, which is modulated by the applied signal, amplitude applied signal envelope of the variation. So, one of them is short term and one of them is long term and they both result into output being a function of input, and it is previous value. Now, what was the effects of power amplifier nonlinearity, we had covered in the previous lectures first of all we will see adjacent channel, spectrum leakage.

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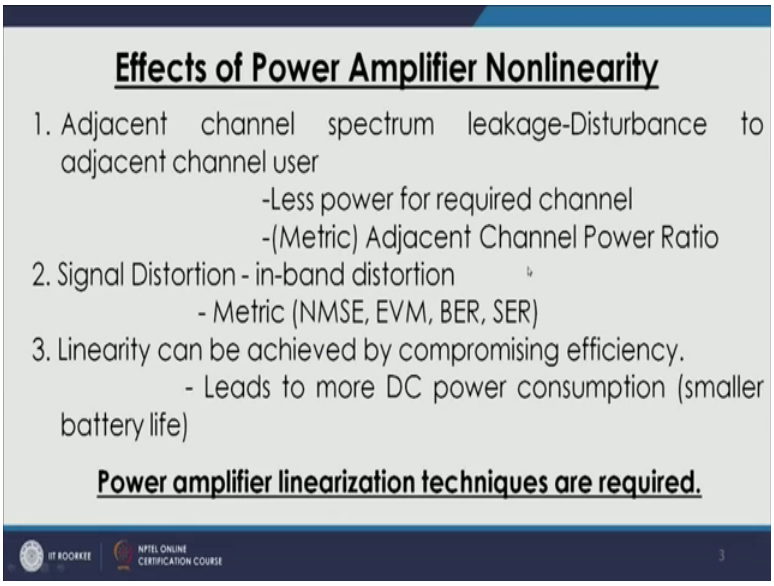

So, if it is your required signal at 2 tones then, you will have this IMD terms and these this was your spectrum of desire, and this is not required and this portion of the frequency band may also be allotted, to some other user.

So, if some of the tones some IMDs are being generated here, then what can be the detrimental effects, first of all it is disturbance to the adjacent channel user. So, we are disturbing this users, because if they have their own signal here, this IMDs are falling on top of them or in between them. Secondly, because some of the power is being leaked into the adjacent channel, less power is available for the required channel. So, if before PA our signal was this, and after power amplifier PA our signal becomes this, and these are the IMD terms, the power which is being used in this IMD terms is being wasted, normally we would desire that this value, this power should also be part of our input signal, but this is not happening. So, our efficiency is going down.

So, what is the metric for that and we already discussed before, adjacent channel power ratio or adjacent channel leakage ratio, ACPR or ACLR, are the metric which we looked towards, to check that how much power being leaked into the adjacent channel here. Now, apart from the adjacent channel spectrum leakage the other unwanted defective signal distortion, for sure if signal is going through a non-linear system may it has some distortion, the out of band we can see from eyes, but as you can imagine, if this is a bourbon signal, here at frequency f and it is being amplified with this power amplifier, then with the gain it looks like something, and this form.

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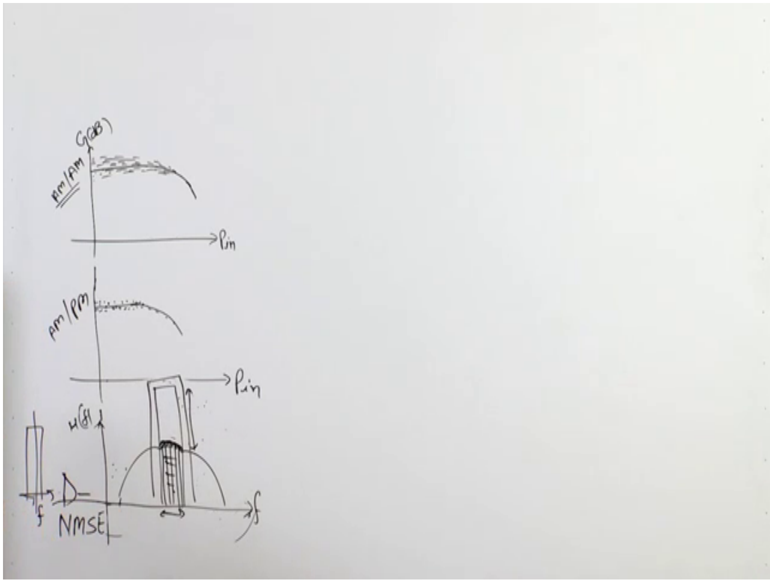

So, this is the band of required operation and this is not desired band, we can see the ACPR very easily from our eyes, but we have to keep in mind, that we have some error in the band also, which we cannot see because it is hiding in the signal. So, whenever you do the fft, you was simply see this kind of profile, but it has this hidden components in the in band which is also disturbing our signal. So, in the in band also suppose, we put a very sharp filter, somehow and we take this letter is still, we will have some in band distortion which we cannot remove.

So, of course, it will lead to bad EVM error vector magnitude, bit error rate and symbol error rate, they should go down, because of this kind of distortion and normally when we are talking at the put of power amplifier, NMSC normalize mean square error is also one of the parameters which we had discussed earlier now apart from this effects, if you want to reduce the effect of this nonlinearity and we decide to work in the linear region, then it can be achieved by compromising efficiency. So, we had seen this example, in the last lecture that when we are using output power back off, we need more devices more power to get that linearity and the output power requirements. So, of course, it leads to more DC power consumption and it will lead to smaller battery life.

So, for sure we require some techniques, which can linear power amplifier. So, that we can avoid all this unwanted effects. So, to start with a linearization technique, first of all we need some models. So, that those models can be ported in a simulation environment as you can study the effect of amplifiers, and you can find the way to come back the effect of this nonlinearity. So, again because nonlinearity can be of any orders 2nd 3rd 4th 5th 6th any order for particular power amplifier, you should be able to model what is the actually order of the nonlinearity.

So, that is the purpose of this kind of model, which we call parametric model because, they are given in the form of some equation, we are discussing some of very popular models, which he will find in the literature one is Saleh model, this models mostly.

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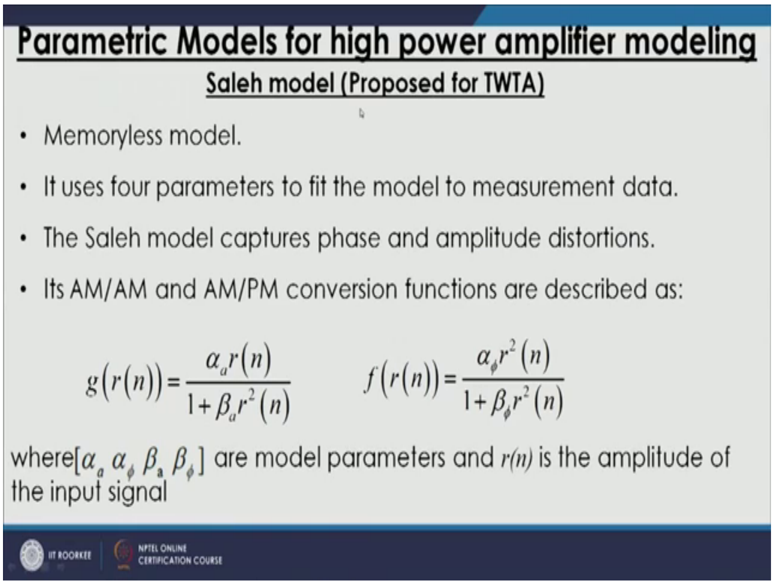

Proposed for TWTA it is a memoryless model, means output is a function of input itself and not the function of it is previous samples, it uses 4 parameters to fit the model to measurement data, it captures phase and amplitude distortion separately and independently and this functions are defined by g r n and f r n. So, this g r n is AM AM or the gain in the voltage form, when I say gain the voltage from it, means it is not a dB.

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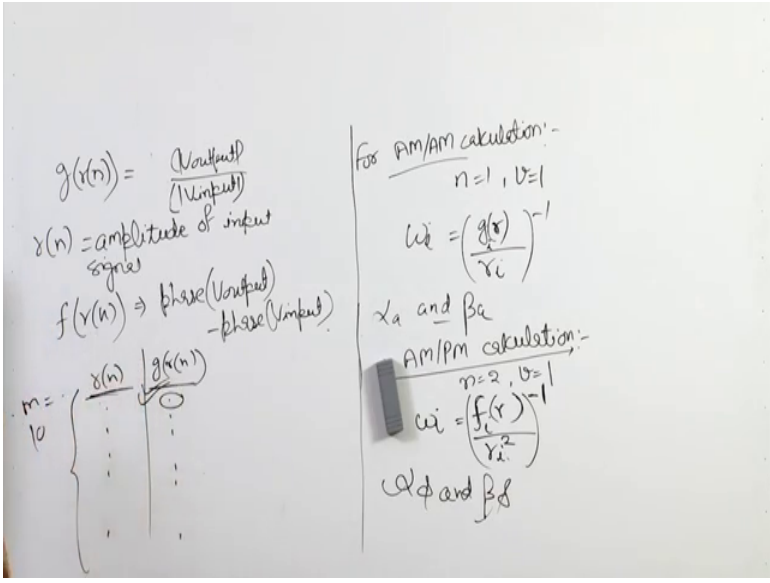

So, here g r n represents gain or mm value of power amplifier, which is a function of input, amplitude of the signal and this is the ratio of V2 upon V1. So, it is not in dB it is in ratio form. So, if you look at this equation, it is a coefficient multiplied with the amplitude of the input signal and divide by 1 plus second coefficient, into squared of this amplitude of input signal, similarly phase also has similar kind of expression with the exception that in the numerator instead of r n choosing r square n.

So, this structural has been given by researcher’s name Saleh, that is why it is called Saleh model and he found that, this kind of structure can fit TW properties in a sufficiently accurate way. So, this alphas which are related to the AM AM characteristics and this betas, which are in the denominator of this AM AM and AM PM characteristics they are called model parameters. So, one step is to get the data from the input and output of the amplifier, once you have your output and input then you calculate your gain values by V2 which is the v output amplitude divide by v input.

So, maybe we can simply write it like this v output amplitude divide by v input, now similarly you calculate your f r n based on the given data as phase of v output minus phase of v input, now we make a table with respect to r n, we put values of g r n and f r n and once, we have this values based on this captured value from the actual device with try to fit our coefficients. So, this is one of the curve fitting method which has been proposed by Saleh itself for his particular model.

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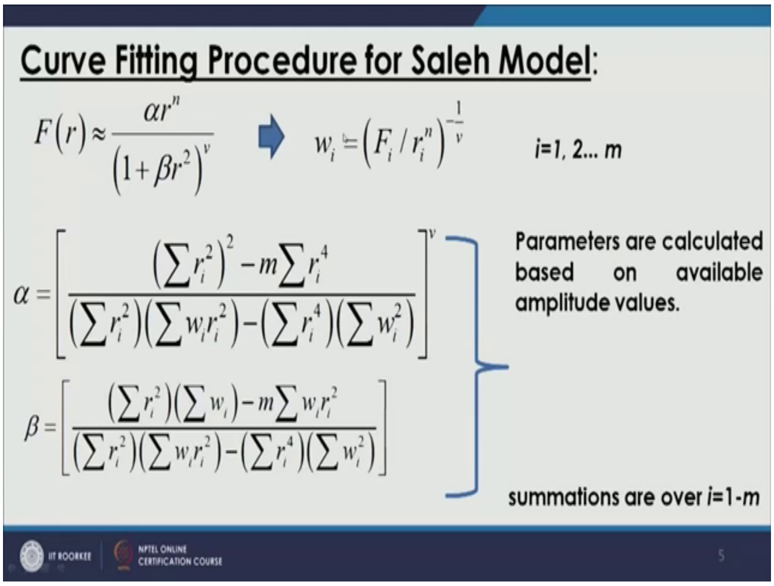

So, by using some mathematical approximation he has proposed that whenever we have any function, which is the function of independent variable r, which can be given by this kind of rational function alpha r, to the power n upon 1 plus beta r square whole to the power v then, we can find the values of alpha and beta by defining a coefficient w which is a function of f and r and v and then, we can use this value here in this case for calculating the values of alpha.

So, this w ones we calculated based on your f and r you put it there, r is in input amplitude and m is your order, for which you are calculating this alpha and beta. So, this I summation I it is actually being done from 1 to m how to select our v here. So, if you want to calculate alpha a and beta a, which is the coefficient for the AM AM diagram, then this g r n is actually this f r n. So, this f r n value instead of this, you use this g r n values from the table and when you would compare this formula, with the actual formula here then, you can identify here that this r to the power n this n is actually equal to 1 and this whole power to the power v, this v here is equal to 1.

So, for AM AM calculation, we are having n equal to 1 and v equal to 1 in our formula of capital f r. So, and n v is equal to 1, we can put that value here, this F is a capital F here, will be this g value from this table and we can calculate different number of samples different m values, or suppose we have 10 samples m equal to 10 here, then we can make our w I values, w 1 w 2 w 3 up to w n, w 10 by keeping g r divided by r I and n is 1 and these also one here.

So, this value and it will be simply f I upon r I inverse, once we know this value and we know our value of m which is 10, we just simply put this values here. So, w I which is basically g r n divide by r I inverse for AM AM calculation, we put simply those values of w here in this expression and calculate our alpha a and beta a for AM, PM calculation let us compare our function with our AM PM value. So, our n is equal to 2 and v is equal to 1. So, our n is equal to 2 and our v is equal to 1 right?

And based on that, we can define our w I, which is f I and this f I, in this case will be f r n here. So, f r n and this I value here, will be here because it is dependent on that particular value of I, which is going from 1 to 10 divide by r I to the power minus 1 upon v. So, it if v is 1. So, it is minus 1 n, n is 2. So, it will be like this. So, in this case I think we can remove n, because this m is taking care of that. So, we do not have to put n in this here, we can simply write it n, because to calculate the number of samples we are putting this subscript I here. So, we can do the same for g here also, simply we can say g r at index I.

So, w I take this form, and for this form of w I we can simply put the w I here and use the amplitude values for particular value of I'm is 10 and we can calculate our alpha phi and beta phi. Now again I will repeat, this data AM AM and AM PM was seen from the actual device from seen from the actual curve and then fitted back, and then we got this 4 coefficients. So, this 4 coefficient will provide us the AM AM and AM PM value as long as we have providing any input data to this 1.

So now, we can say these models are the parametric models, which will be able to give us the amplitude in the phase values, of an TWTA of that particular TWTA for which we have defined our alpha a, alpha phi beta a and beta phi, similar to the saleh model Rapp is given another model.

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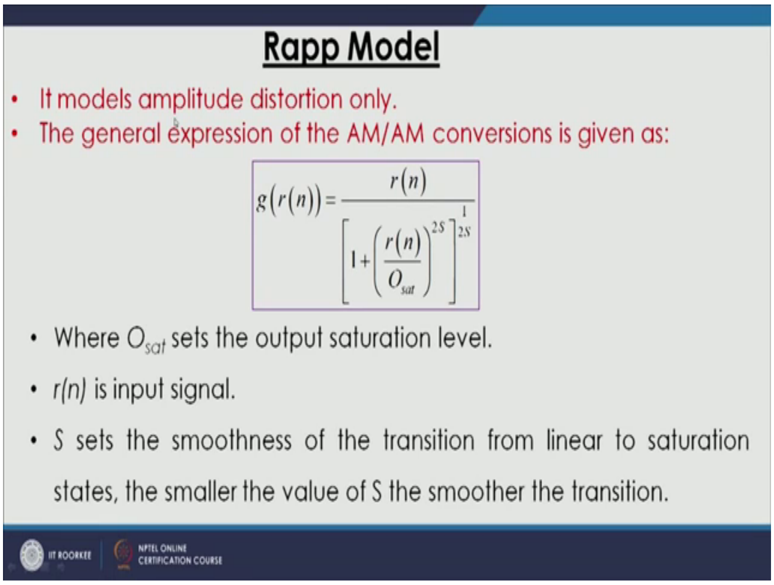

Basically, it focuses only on the gain distortion. So, it does not cover the phase distortion. So, general expression for the AM AM conversion is given as g r n, which is the gain, with respect to input signal amplitude and if you see here, it has input signal amplitude here and apart from that, it has Osat which is the output saturation level.

So, this is the parameter, which defines the saturation level and s is something which sets the smoothness of the transition from, linear to saturation states. So, basically what we do, we take the actual data from that actual amplifier and we do not have any phase requirement. This model is only given for this model is only given for the gain value. So, we are just dealing with these 2 values, amplitude values and the gain values and then, we put this values for given ms into this formula and we define our Osaturation level which is based on our particular device, because p 1 dB value will be given to us and we will calculated the voltage, respect to that. After that we keep tuning the value of s and whenever we get the best fit for that value of s, we will say our model is complete and we note down the value of s, O sat and then we can apply any input and we can get the output, which will be equivalent to the output, what we should get from our device.

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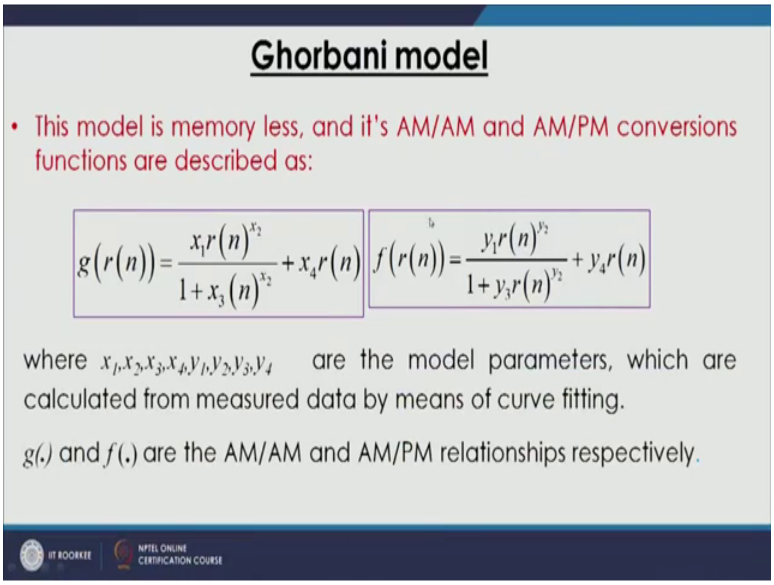

So, Rapp has only concentrated on the amplitude or the AM AM, but it is also very popular model, Ghorbani is another model. Given by researchers name Ghorbani and this model has 4 parameters for the gain, and 4 parameters for the phase, as you can see, they look very similar in nature, similar in their fitting profile, similar to the Saleh model process, we have to do the curve fitting and once we get the value of x 1 x 2 x 3 x 4, y 1 y 2 y 3 y 4 then, we say that our model is extracted. Gorbani model is given for the SSPAs while Saleh model was given for the TWTA. So, that is one of the difference between these 2 models.

Now, what will happen once we have acquired all these models, we have our Ghorbani models rapp models and Saleh models and we have the parameters for a particular PA, this can be used to analyze the system level performance, for any proposed communications scheme.

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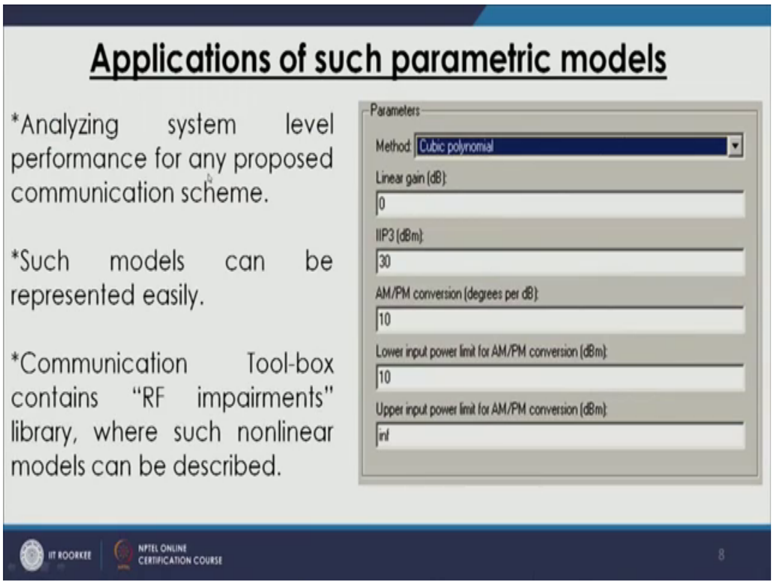

So, because we are moving from 1G to 2G up to 3G and beyond 4G, now looking for the 5G, we keep introducing new schemes, but power amplifier which will destroyed the signal, we do not know how it will intact with those. So, this kind of models allow us to put this models in the simulation and see the effect of nonlinearity of power amplifier, on this schemes, at the output and the transmission and receiver performance level.

Now that can, this models are basically equation based, parametric models they can be represented very easily in the equation form, as long as you have access to the input signal amplitude, you can code them easily in any software moreover now there. So, popular that some software such as matlab they actually provide them as a tool box for example, in matlab communication toolbox contents RF improvements library, and such non-linear models can simply be selected from there for example, they are showing cubic polynomial. So, it is just third order polynomial and you can also selects Saleh, Rapp and Ghorbani when, you from here and put define their different parameters here and then you can see the output.

So, by using these models you can actually get your IMD terms at the output and then you can start designing your linearization techniques, to reduce those distortion. So, this lecture and see you are see in the next lecture, we will concentrate on actual linearization techniques.

Thank you.