Satellite Communication Systems
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Lecture – 33
Nonlinearity III

Welcome back. We were talking about non-linear devices and non-linearity how it effects. And in that discussion in the last period we have seen it generates a inter modulation products. We are trying to understand inter modulation products and some manufactures how they define the inter modulation product in terms of C by (Refer Time: 00:44) modulation for C by 3 IM. But that inter modulation product C by 3 IM is only for two carriers. What happens when this multiple carriers, what is the term they use?

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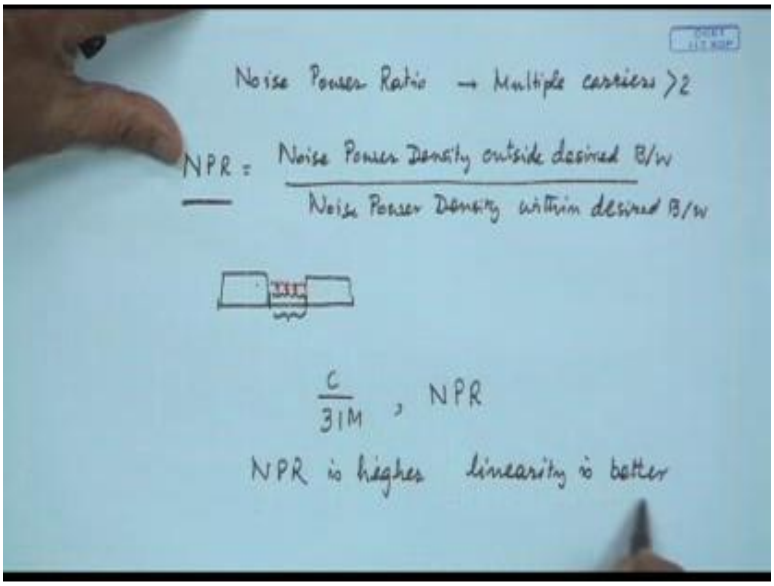

They use a term called noise power ratio, this is for multiple carriers that is greater than 2. And this NPR is defined as noise power density; that noise power which is generated due to multiple carriers is going to fall at once place so that is called desired bandwidth. So, it is noise power density outside desired bandwidth divided by noise power density within desired bandwidth; is very simple.

Let us say over this band the operation is going on many carriers are placed and a particular area in this area we want to see what is the effect of other carriers falling into this. Here is my interest. so here is my actual operating carrier on that how much noise is falling over this. So, noise power density outside this and noise power density which is falling into this that will fall. Initially there is a noise power density and it will increase because of this inter modulation. So, it will measure people do measurement using noise filter and noise generator.

But I just wanted to tell you that there is another term which is NPR. So, we have come across two terms C by 3 IM and NPR noise power ratio. This is defined for two carriers operation or characteristics of the non-linear device with two carrier operation, this defines the characteristics of the device or system with more than two carriers multiple carrier operation that is only there.

Now, the meaning is that if NPR is higher than linearity is better or linearity is poor, it is linearity is better. Because when this is a higher this noise power density within the desired band is low then only this becomes higher. So, noise power density within the desired band becomes low when the inter modulation of others are not falling here; that means, system is operating in most of the thing most of them are in linear region non-linearity can generate the inter mod. So, there is no non-linearity or less non-linearity. So, it is much better, linearity is much better. This much is enough for the definition.

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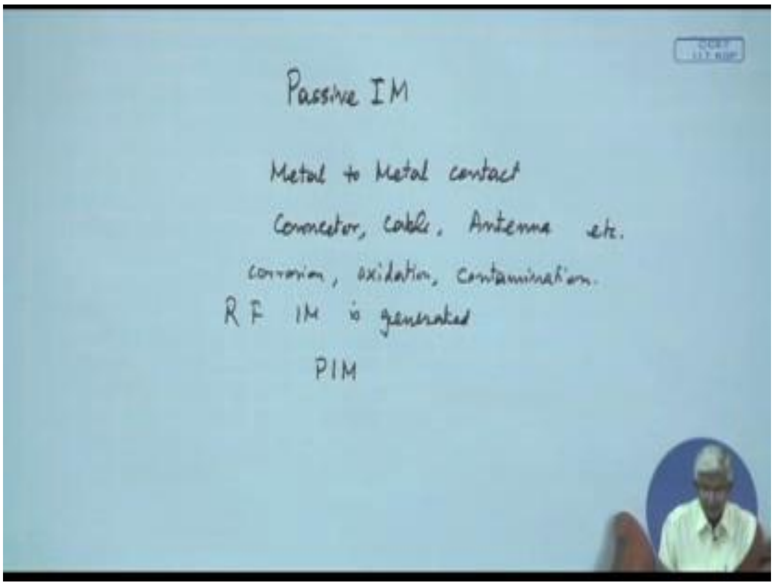

There is one more thing that people come across that is called passive inter mod product, this is a not by active device. When there is a metal to metal connect like in connector, cable, input to the antenna, etcetera. Due to corrosion, oxidation, contamination that RF inter mod is generated. Because of these things it creates a non-linearity in the metal or the conductor which is which is carrying the Rf.

Since there is a non-linearity that inter mod is generated, this is called Passive Inter Modulation product. In case of high power antenna this with higher power that also effects, but this cannot be modeled so easily since the random phenomena, but this has to be taken into account during the system design.

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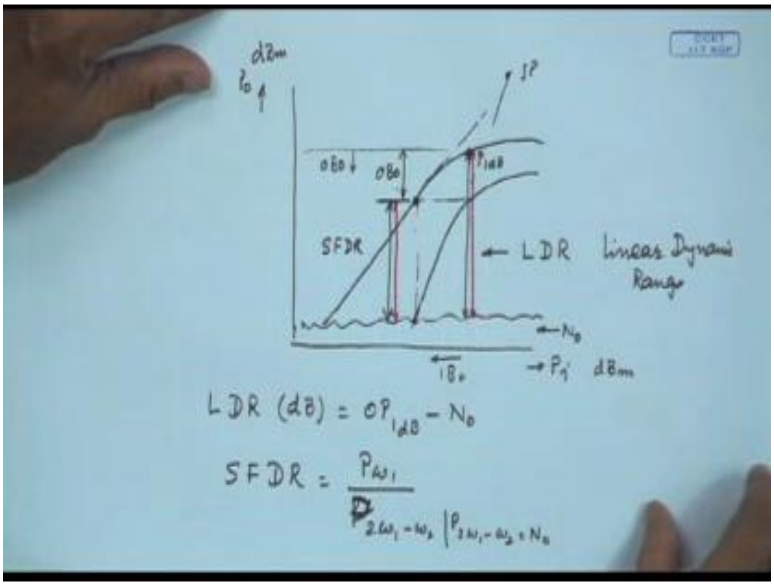

So, will go into further into this non-linearity let us look a little further into it what is other effect. We have seen P i versus P out that is in dBm or dBw normally it is dBm and we have seen these goes as a linear curve and then it saturates, and there is a definition of a 1 dB compression point and third order inter mod which gets generated and that also saturates and its extension goes to a point which we call inter set point IP. And this is 1 dB compression point, in terms of input and output can be defined.

Now there is a noise below this. So, actual operation for linear range of operation we can assume 1 dB is very small compared to the total range on which we can operate. So, if this 1 in terms of output this is our linear dynamic range, this is the linear fundamental power curve P omega 1. So, this is the linear dynamic range. So, this is P 1 degree minus this is the noise flow which is noise power.

So, LDR linear dynamic range in dB is o 1 dB that is output 1 dB compression point minus noise power, so that is the linear dynamic range. But though it is linear dynamic range our spurious starts coming in this is the third order inter mod product P 2 omega minus omega 2 or P 2 omega 2 minus omega 1, one of them you take. Now this starts going above the noise level at this point. So therefore, we can see that below these points that the spurious noise which is supposed to be the third order inter mod that has not come, spuriousness start at coming from here, as we go more input spuriousness start coming here. So, this dynamic range this one; we can call spurious free dynamic range. I can color it.

This one is spurious free dynamic range where this spurious is started coming in just that point to the linear dynamic range point and this is the linear dynamic range from the output point of view. Same thing can be said in terms of input points since we are talking about the amplifier is the output spurious free dynamic range. Now so spurious free dynamic range is P omega 1 by 2 sorry, by P 2 omega 1 minus omega 2 at 2 omega 1 minus omega 2 when it becomes N 0, so from N 0 this is given in ratio it can be put into dB also. Let us try to calculate how in terms of our inter set point because that is the specification.

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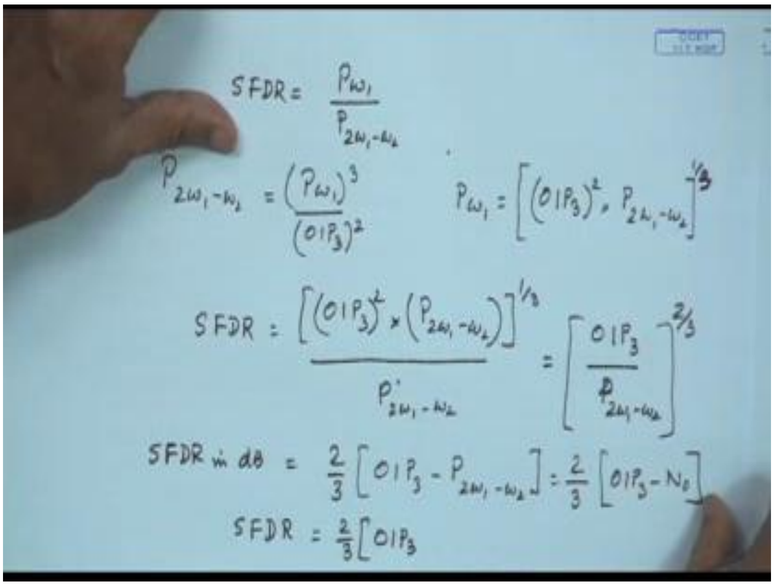

So, SFDR is equal to P omega 1 by P 2 omega 1 minus omega 2 and P 2 omega 1 minus omega 2 we have see it is P omega 1 cube by OIP 3 square output it is a point square. So therefore, I can write P omega 1 is equal to OIP 3 square into P 2 omega 1 minus omega 2 and to the power one third because this was cube.

So, P omega 1; now this P omega 1 we can substitute here so we can get SFDR is equal to OIP 3 square multiplied by P 2 omega 1 minus omega 2 to the power one third by P 2 omega 1 minus omega 2 P 2 mega minus omega. So, P omega 1 I replaced here and by readjusting this we can get it is equal to OIP 3 by 2 by P 2 omega 1 minus omega 2 two third. This is in ratio, so in dB SFDR in dB we can write two third of OIP 3 minus P 2 omega 1 minus omega 2.

Now this is the definition of the spurious free dynamic range in terms OIP 3, but you know it is not only the dynamic range at the lower side this is the noise. And therefore when these becomes the noise power, so it is two third of OIP 3 minus N 0. But many of the devices and systems they would not work until a particular SNR is achieved after that minimum SNR they will start functioning.

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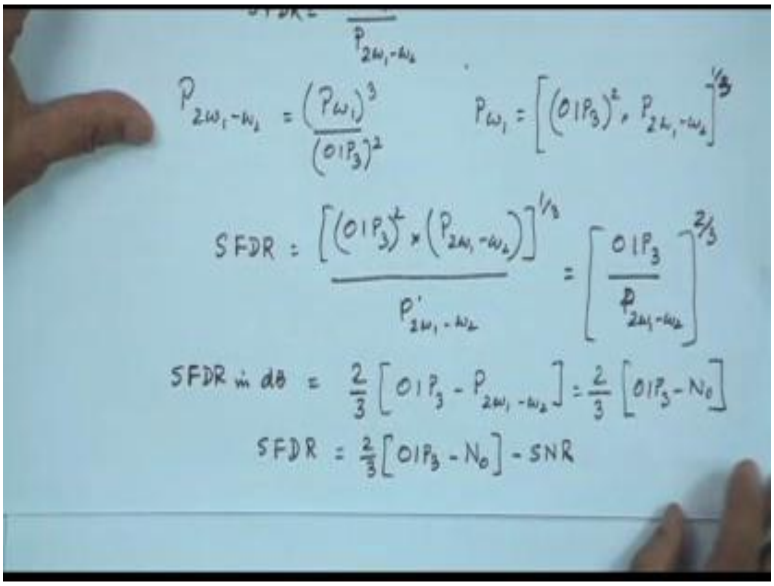

So, the dynamic range should have been define that when I consider the SFDR in dB will be two third of OIP 3 minus N naught minus SNR noise ratio that is the minimum signal noise ratio with which should operate. With that this can be expressed in this form.

Now, let us do some quick calculation. One thing I missed let me explain that this very important. This curve, that is we have linear dynamic range and we have spurious free dynamic range we may consider the SNR you may not depending on their requirement. Now really my spurious free operating point is this, this region started getting into spurious and non-linearity. So, if we want to offer avoid the non-linearity as well as the spurious how much back up we should give go.

So, we have talked about the back of that is input when it is getting into saturation 1 dB compression point from there if I reduce the input it is called input back off. Similarly, from the 1 dB compression point it will come down as output back off. For spurious free operation one is non-linear operation. For spurious operation how much back off this, this, minus this; so for spurious free operation this OBO this much for spurious operation. This you know another interesting idea.

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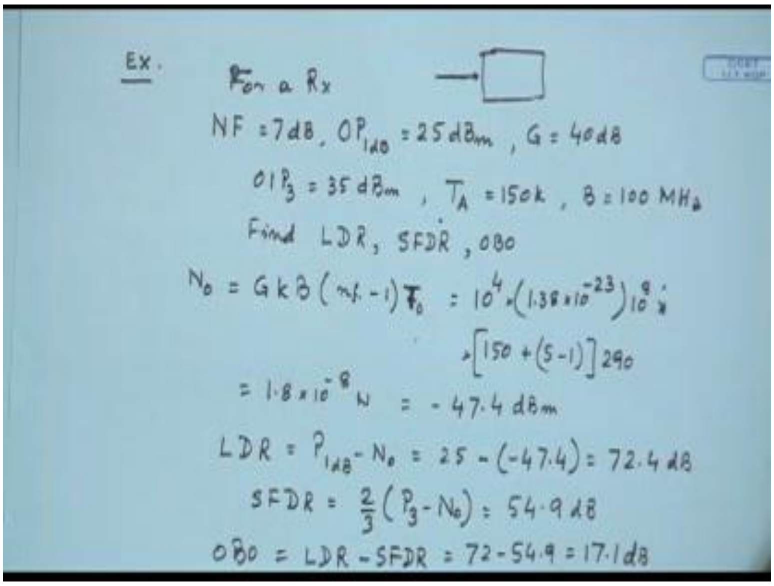

So, let us take a quick example for a receiver let some data is given noise figure a 7 dB 1 dB compression point is 25dBm and let us say it is output reference, and the gain is 40 degree that output inter set third order inter set point is 35 dBm; that receiver is receiving a input and it is a antenna in front it so that temperature from the antenna it is receiving 150 k, it has a bandwidth of 100 Megahertz. Now can we point that linear dynamic range, spurious free dynamic range?

So, what we have to find out that if we remember spurious free dynamic range and linear dynamic range we have to find out what is the noise, because OP 1 dB output 1 dB compression point minus noise power, so noise power has to be calculate. For noise power we have been given some information let us see what is noise power, if you recollect it is g into k into the bandwidth and then it is multiplied by f minus 1 in case of we can say noise figure noise factor minus 1, because f is given in noise figure is given in dB will convert into ratio and multiplied by the normal temperature T 0 which is 290.

So, if you put these numbers the gain is 40 degrees so it is 10 to the power 4, I am converting all dB into linear ratio. And then k value is 1.38 into 10 to the power minus 23 if you recollect. Then the bandwidth is 10 to the power 8, and then we have this multiplied by 150 that is antennas temperature. And that 7 dB noise figure you convert into ratio it becomes 5 S minus 1 and this multiplied 290; so this multiplied by this. And when you calculate it comes out to be 1.8 into 10 to the power minus 8. What? It is minus 47.4 dBm. Do your own calculation, do not just copy my number what I have done. So, the LDR value will become P 1 dB compression point minus N 0, in dB now is 25 which is given 25dBm and this is also in dBm. You have to remember to convert if this is in dBm this also was to be dBm if this in dBw convert into dBw so both of them should be same. This minus minus 47.4 and that becomes 72.4 dB. And then the SFDR value is two third of P 3 minus N 0. And that is you have the P 3 supplied that OIP 3 is 35 dBm N 0 is already obtained and two third of that you get in dB 54.9 dB.

Now if I ask you this question I extend that find out that output back of spurious free condition. So then as we have seen that it is LDR that is output back off will be is equal to LDR minus SFDR that is 72 minus 54.9 which is 17.1 dB. Now this is just example for you to work out similar example we try to give in assignment.

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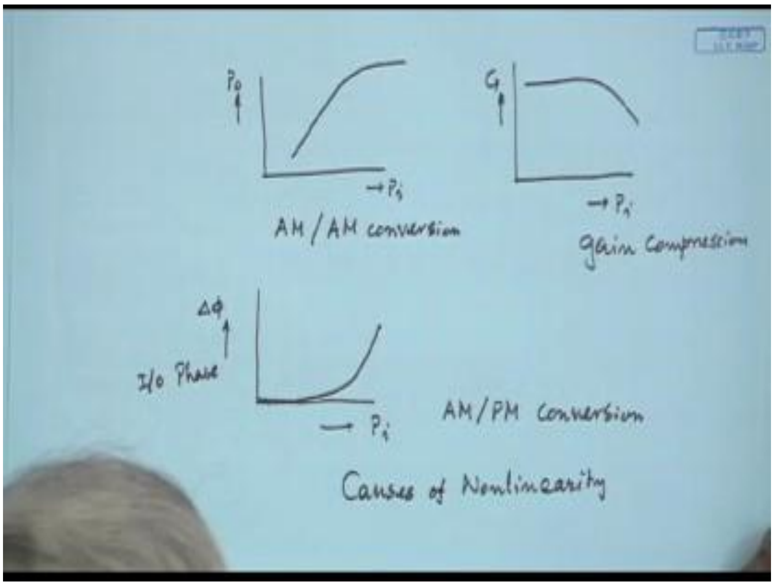

So, let us see that three effects we have seen that is we have seen that power in to power out in dB, the curve goes like this linear and then non-linear; so this one is termed as AM to AM conversion. Similarly, we have seen there is a gain compression, if there is a gain this said and power in this side initially there is a constant gain then gain will start falling when (Refer Time: 21:12) point coming and beyond that.

But this on amplitude there is one effect that happens that is in phase. So, input phase to output phase if I take the difference and call it delta phi that is phase; input to output phase that is delta phi. And if we input increase then it is constant and then the difference increases. Now this is called AM to PM conversion. Now these are the causes of non-linearity. In briefly that amplitude its non-linear gain gets compressed is called gain compression AM to AM conversion and AM to PM conversion takes place.

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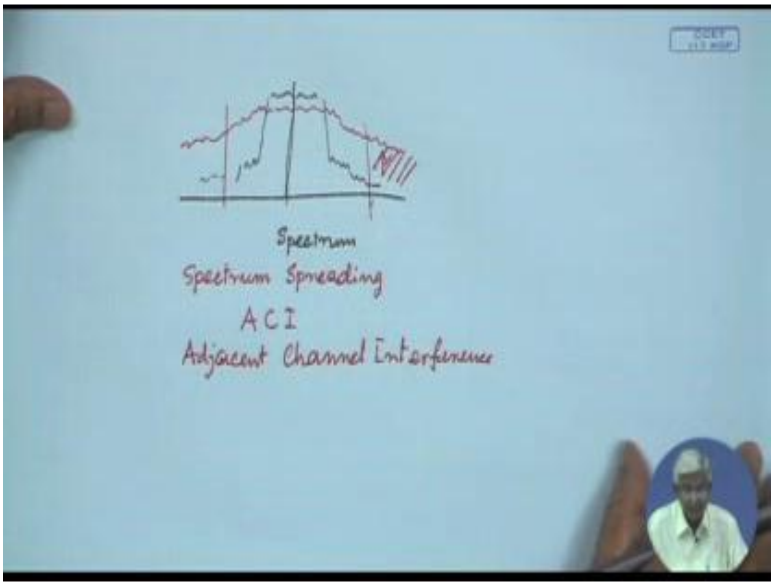

Now, because of that there is the effects are; if I draw a spectrum initially the spectrum may look like this due to our filter it will be like this, this is the spectrum. Now due to inter modulation this spurious generated and the new spectrum spurious will be spread at different frequencies, so new spectrum will be enhanced and it spread further amplitude spreads further. So, if you are operation area is this and the adjacent channel is coming you are interfering, so spectrum spreading generates that adjacent channel interference.

This effect of spectrum spreading, this is one of the one of the serious things that happens due to inter mod. One is the inter modulation product generates the spurious within the channel so that your signal to noise ratio dynamic range reduces, another is split the spectrum so that it interferes in the adjacent channel; adjacent channel interference increase. There is more problem because the free non-linearity. Let us see our nowadays our operation in this recent days communication are mostly phase modulation BPSK, QPSK phase shift key modulation.

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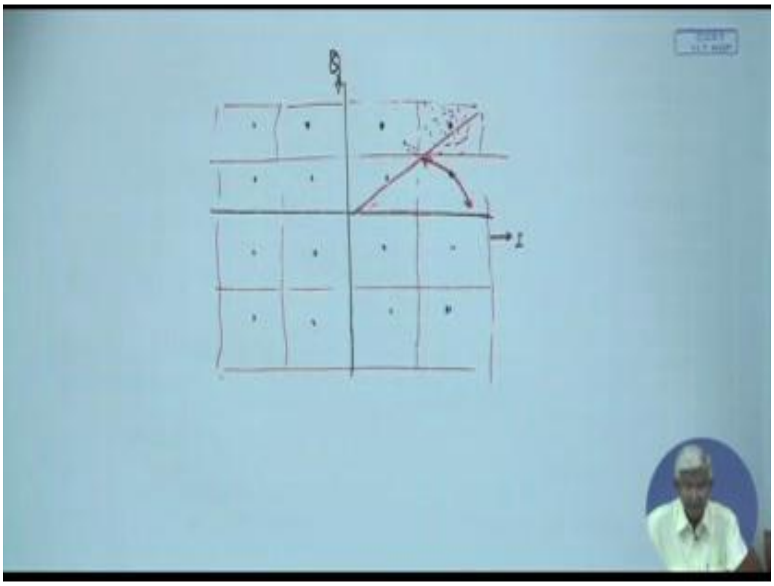

Now, let us try to draw a conciliation diagram of a quam. This is I Q channel say 16 quam conciliation diagram is like this these are nothing but the vector points. So, the decision boundary at the receiver to identify where the vector is and decide let which bit should be. Each of this vector point represents a particular symbol.

In case com this would be for bit symbol let us say this is 0 1 0 1, this is 0 1 1 1 like that. Each of them represents a symbol which is a combination of couple of bits. Now if this is detected properly in this detection can takes place within a decision boundary, so we can call that this decision boundary is in this square. Now these vectors may get into different type of noise, so its vector location in amplitude as well as in fees it will vary so in terms of phase when it varies it may move in this direction or in this direction. So, because of our non-linearity as we said that the phase may change, so this vector will change these direction this direction.

And similarly there is a possibility that due to Gaussian noise there will be the vector may be anywhere in these ratio. So because of the phase non-linearity this system may change, the conciliation may change and a vector will go into the other decision level so that it will wrong decision is taken. This is let us say, decision boundary for this, this particular vector decision boundary. Now if we change is more than the decision boundary then it will be detect as a wrong symbol, this symbol let us say it was 0 1 0 1 and this symbol is 0 1 1 0 and so this will be detected wrongly when it crosses wrongly, now this is another effect of I mean in a little more explanation the conciliation until due to introduction and this increases the BER.

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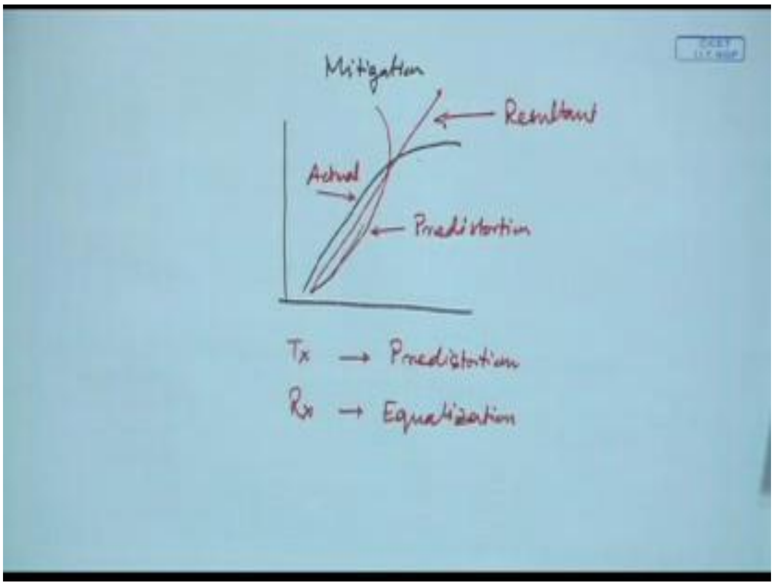

Now, one quick thing is the mitigation is very simple that is if you have non-linearity like this so you pre distort the signal like this so effectively you get linear. This is predistortion this is actual and this is the resultant. At the transmic side it is done predistortion of the signal so that when it passes through actual non-linear you introduce a non-linearity passes through other way non-linearity get resultant linear. And in the receive side it is done by equalization. This is very brief idea of the mitigation of the non-linear system.

So, till now what we have covered is the definition of some terms. And then we have in the definition terms we have come across 1 dB compression point, third order inter set point, C by 3 IM, then NPR, then we have try to estimate the values individually in the device or sub system or in a cascaded sub system, then we try to show you what is the effect of non-linearity in terms of gain compression and dynamic range reduction. And then we have very briefly touched how mitigation is done that is by linearizer or equalizer.

So, with this we have covered briefly the non-linearity aspect of the devices and sub system will come across in the satellite communication.

Thank you very much on this topic.