Satellite Communication Systems

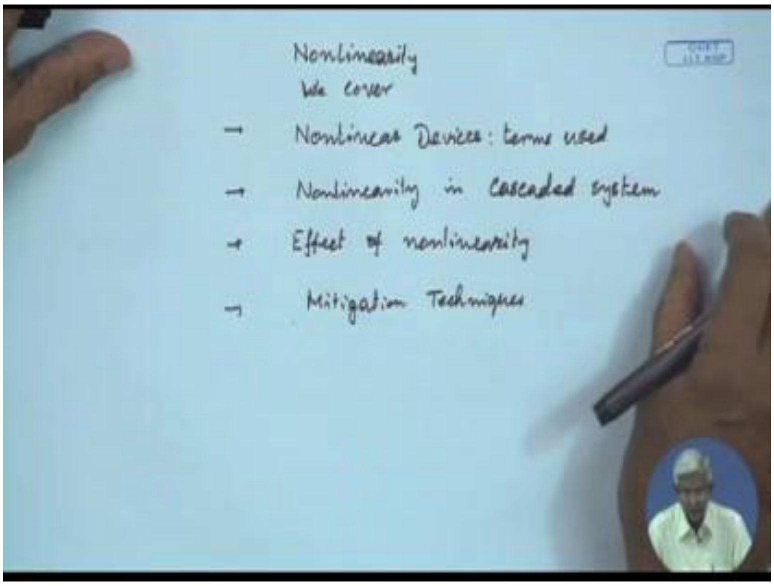
Prof. Kalyan Kumar Bandyopadhyay
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology, Kharagpur

Lecture – 31
Nonlinearity I

Welcome. We have discussed about the orbit space segment, the link budget, the propagation effect, ground segment and then we talked about a network system and that multiple access, different types of multiple accesses. Now, we will try to talk about certain issues we face in this type of communication which is wireless and which is a long delay and which has a probability of error is quite high. Now, let us see the first part that is it is a long distance repeater; the satellites are quite high in the sky. So, the power that is required from satellite to ground to receive properly with good sensitivity, we need to transmit large power from satellite and similarly from the ground to satellite.

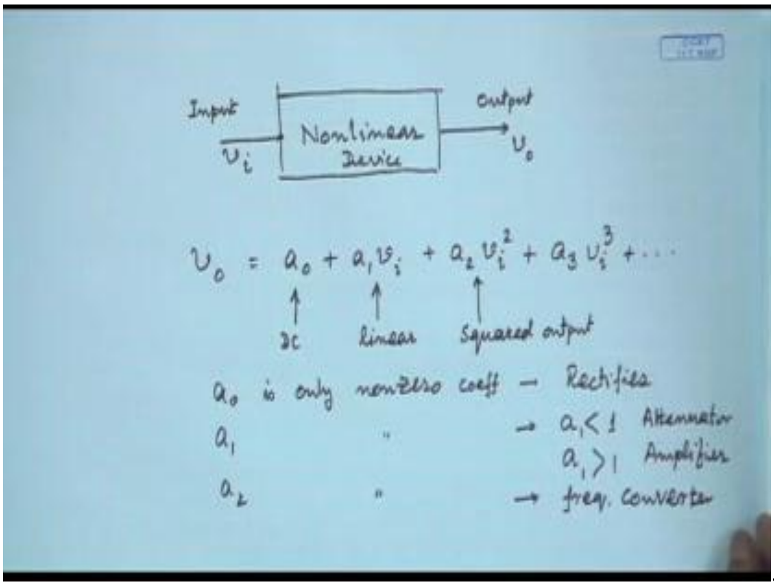
So, once we try to transmit larger power we have to look at the power amplifier and a take maximum power out of it. Now, any device when we try to take maximum out of it, it goes into non-linear. So, as we know that any amplifier at a very low input level there is no yes even if you do not give an input there be certain thermal noise. So, there is non-linearity at the very low level. Similarly, when you go to higher level there will be again certain distortion that is limiting by the power supply to that amplifier. Now, it is not only amplifier there are many devices which generates and proves non-linearity. In fact, almost all practical devices active devices they show non-linearity and non-linear characteristics.

(Refer Slide Time: 02:29)



So, we will see how this non-linearity can affect our communication system. So, our topic is non-linear and what we cover is and this is topic is what we will cover the non-linear devices certain terms, we use terms used those terms define what type of non-linearity it is and then we will talk about non-linearity not only single device when the cascade non-linearity in cascaded system when they put one after another and of course, we will see the effect of non-linearity and very briefly we touch upon the mitigation technique is the general form and there will be mix of this while we discussed. So, let us take a non-linear device and let us say the device is non-linear.

(Refer Slide Time: 04:00)



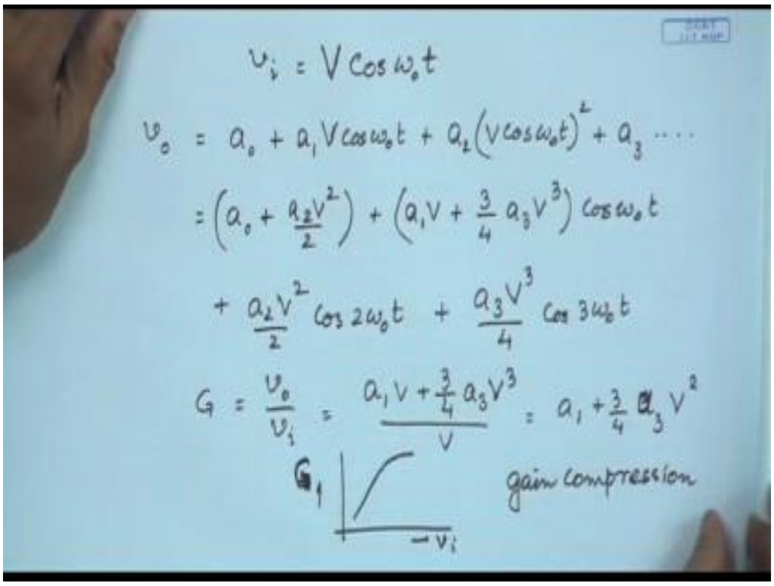
.

It has a input let us say we gave a voltage input V i and it goes to the output and it gives a voltage V o now in general a generalized form of non-linear expression that V output can be modeled as a Taylor series. So, it can be written this way simply a 0 is a co efficient, then a 1 V i, then a 2 V i square, then a 3 V i cube like that we can continue and depending on the coefficient values that non-linearity can be generated. So, this is very, very general term.

So, out of that we can define that this is a DC term if we give a c input and this is a linear term and this is a linear output this could be this is a squared output like that now if we say that all other coefficients are 0 and only a 0 is a 0 is only non 0 coefficient then the device is a rectifier similarly if a 1 is a only non 0 coefficient then the device if a 1 is less than 1 then output will be less than the input. So, it is attenuator and if a 1 is greater than 1 then it is amplifier is how it is expressed.

Similarly, if a 2 is the only non 0 coefficient it is generating higher and higher frequency it is frequency converter. So, that is how the based on the Taylor series model we can define distance define coefficient what type of system it is, but in practice these things occur together. So, several of the co-efficient may be non 0 in practice, but this is ideal modeling situation.

(Refer Slide Time: 07:20)



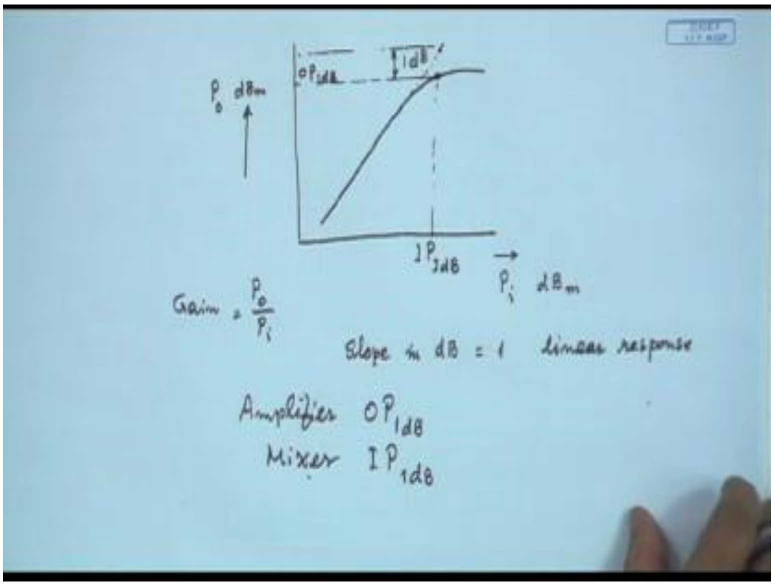
Let us try to give input let us say V i is V cos omega 0 t you want frequency and a voltage. So, this is input now how V 0 will written V 0 will have DC component that is a 0 then will have the linear component omega 0 t then will have a square component then it will have a cube component like that. Now, if we take this cosine square cosine cube this term and use certain trigonometric identity and separate out that single frequency component and DC component and higher other frequency component.

We can group them like this that a 0 plus a 2 V square by 2 that will be our DC component then a 1 V plus three fourth a three V cube cos omega t that is a fundamental component, but is with this coefficient cube then a 2 V square by 2 cos 2 omega 0 t that is double frequency component it will have step of coefficient then a 3 V cube by 4 cos 3 omega 0 t another higher order component of frequency with a different coefficient.

So, in these let us assume that this is amplifier. So, we will take the fundamental component and what is amplifier gain the gain is V 0 by V i. So, this coefficient that is a 1 V plus three fourth a 3 V cube by V and then that comes out to be a 1 plus three fourth a three V square now here a 1 and a 3 that generally practically this a 3 is many times opposite sign of a 1. So, in that case it will grow linearly, but after sometime it will deviate from linearity it will look like briefly it will go straight and then deviate from linearity this is V and this is V out V in I can call, so that capital b as we increase.

So, this is actually what is happening gain compression, I can call it a gain also this is gain I can plot gain if I plot then gain will goes linearly and then it will try to deviate from linearity. So, it is called gain compression. So, this is one of the major effects of non-linearity that gain will go linearly and after sometime it will saturate.

(Refer Slide Time: 11:13)

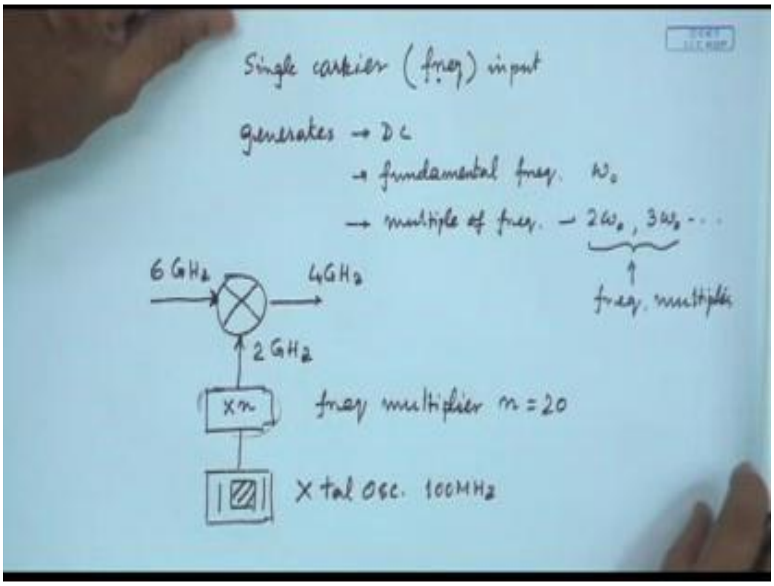


Let us see what happens if we try to draw this characteristics in power what happens in power. So, let us call this 1 as p i in dB, dB m let us call and then this is p out and dB m. Now, once is plotted in terms of power it is linear slope and then it deviates from the linearity. So, when it deviates from the linearity this could have been the linear situation and when it is 1 dB down from here to here, let us call this is 1 dB down this point is defined by the device suppliers or manufactures that at this point we start getting the non-linearity or it is getting into saturation.

So, this point from the input side it is defined as input power of 1 dB compression point. Similarly, this is called output power 1 dB compression point 1 dB getting compressed. Therefore, it is away from linearity it is compressed and it is going away in the non-linearity direction, now this gain of this amplifier of course, power gain is a ratio of p out by p in and this slope when we do it in dB it is 1 that is, it is a linear response and when the p out start from deviating the linear response we get into saturation and when it is away from the 1 dB of linearity is called 1 dB compression. Now, these is a define in terms of either input for 1 dB compression point or output 1 dB compression point, if it is referred to input is called input 1 dB compression point i p 1 dB or output 1 dB compression point which is o p 1 dB have it in here.

Generally, that in practice the higher 1 of this is specified in case of amplifier in case of amplifier output 1 dB compression point is higher than input on compression because the gain is multiplied to that and let us say a lossy device called mixer which is a non-linear where the input 1 dB compression point is higher. So, in case of mixer input 1 dB compression point is referred. So, when simply 1 dB compression point it says then we have to check whether it is referred to input or it is referred to output, but generally we will be talking about amplifier of course, will sometime come to mixer will always refer it we can say 1 dB compression point as o p 1 dB or i p 1 dB compression point. Now, let us see that what happens with a single carrier input to non-linear device that is single carrier means single frequency.

(Refer Slide Time: 15:06)

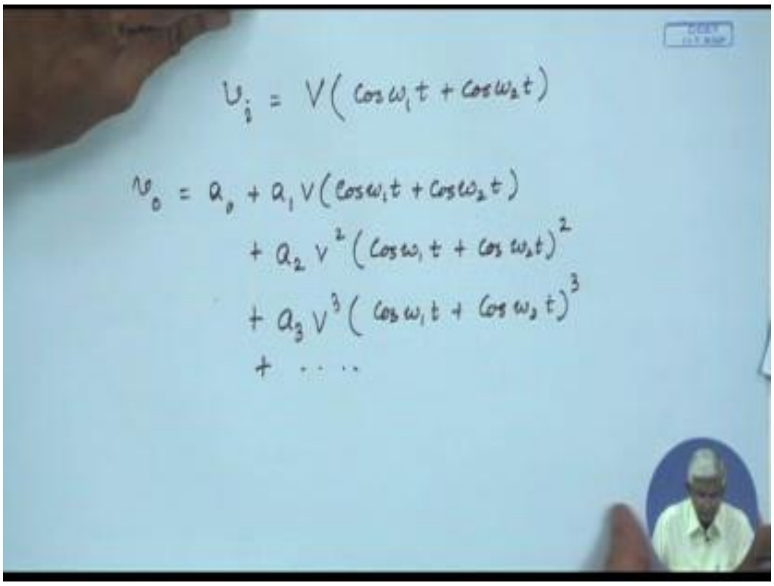


It generates, we have seen that it generates a DC component it generates a fundamental frequency which is omega 0, it generates a multiple of frequency which is 2 omega 0 or 3 omega 0 like that. So, these characteristics of multiple frequency multiple of the fundamental frequency is used in frequency multiplier like this we have at satellite we get input in 6 gigahertz, let us say uplink which is gone to the satellite and after l n a it has come to a down converter which is nothing, but a mixer and then a local oscillator and that local oscillator contains a crystal oscillator which is generally this is crystal oscillator, which is generally of the order of 100 megahertz and to get output of 4 gigahertz which should be the downlink after this down conversion I need to give 2 gigahertz here.

So, this is 100 megahertz has to be multiplied and brought to 2 gigahertz. So, this frequency multiplier is n equal to in this case 20. So, you get a 2 gigahertz. So, this is 1 of the place where this non-linearity is used it using mixer also that for single frequency when it is going up through a non-linear device, we get this multiple of the input frequency which is in times of input frequency and there may be when here it is simplified and shown it in 1 stage it may not be taken as 20, it may be multiple stages and in between amplifier may come, but this is the concept of the frequency multiplier.

Now, let us go in to the amplifier. In amplifier, generally in satellite communication we have seen last period multiple access multiple carriers are coming. So, let us take a simplified case of 2 carriers input.

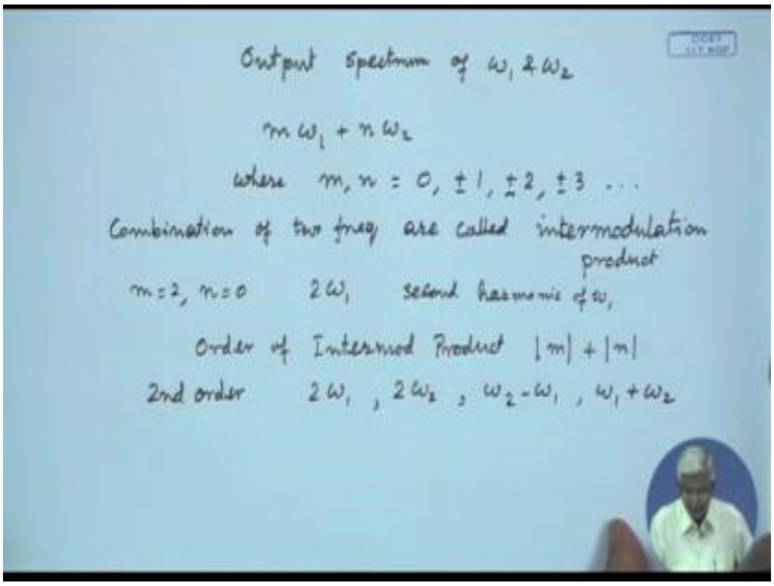
(Refer Slide Time: 18:13)



So, 2 carriers input is let us say V i and that case and both carriers have same amplitude. So, V cos omega 1 t and cos omega 2 t both have this same amplitude V, this is for simplified i mean calculation, in a actual case it may be most of the time it will be V 1 cos omega 1 t or an V 2 cos omega t each amplitude may be different depending on the input what is being supplied by different carriers.

So, the V output will be in the case by Taylor’s series. If you go a 0 a 1 V cos omega 1 t plus cos omega 2 t then a 2 V square cos omega 1 t plus cos omega 2 t whole square then a three V cube cos omega 1 t plus cos omega t cube like that it will continue. Now, if you simplify this square terms and cube terms and then use certain trigonometric identity then you will find that in addition to the fundamental components omega 1 and omega 2 you are getting the higher order components like 2 omega 1, 3 omega 1 like 2 omega 2, 3 omega 2 and also you will get omega 1 plus omega 2 omega 2 minus omega 1 or 2 omega 1. So, like that there will be lot other frequencies which are generated other than fundamentals all those frequencies are called inter modulation product the let us let us try to do it mathematically.

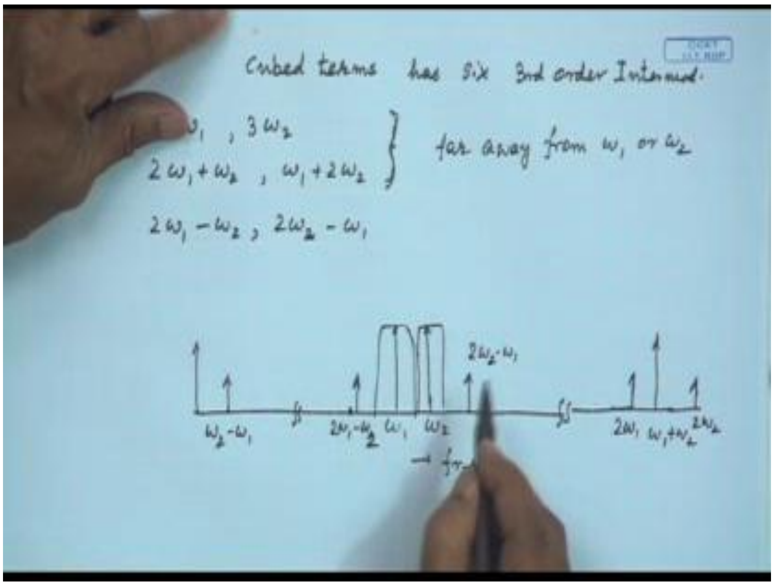
(Refer Slide Time: 20:21)



Let me show you that is that output spectrum of omega 1 and omega 2 will in the form of m omega 1 plus in omega 2 where m and n could be 0 plus minus 1 plus minus 2 plus minus 3 like that this combination of 2 frequency are called either you can call in this case we call them inter modulation. This term I have used earlier that we are not defined it is inter modulation product. So, let us say m is equal to 2 and n is equal to 0 then what will you get 2 omega 1 which is second harmonic of omega 1. So, we can say there is a order of m and n.

So, the order is defined order of inter mod product we can define as mod of m and plus mod of n. So, we can see the second order components are 2 omega 1, 2 omega 2, omega 2 minus omega 1 then omega 1 plus omega 2 like that, any terms now when this omega 1 and omega 2 when they are closely spaced then the multiplication or addition subtraction terms would be far away from the fundamental frequency omega 1 and omega 2. Now, similarly we can see in the cubed term has 6 third orders inter mod.

(Refer Slide Time: 23:02)



It is 3 omega 3 omega 2 2 omega 1 plus omega 2 omega 1 plus 2 omega 2 2 omega 1 minus omega 2 2 omega 2 minus omega 1. Now, these 4 first 3 omega 1 3 omega 2 2 omega 1 class omega 2 omega 1 plus 2 omega 2, you can look at from this you can make out they will be for away from the fundamental or omega 2, but these term these 2 products 2 omega minus omega 2 and 2 omega 2 minus omega 1 if omega 1 and omega 2 are closer the difference also becomes closer. So, there will be coming very near and they may fall within the transformer and with modulation, if it is pure carrier then they will be away by omega 1 minus omega 2 delta omega but if they have modulation then some of these frequencies will fall within the filter bandwidth of a omega 1 and omega 2.

Let us try to draw a simplified diagram, let us say this is the frequency and here somewhere I have close them together, this is omega 1 and 2. So, omega 2 minus omega 1 will be here very near to d c, but 2 omega 1 minus omega 2 will be coming very near similarly 2 omega 2 minus omega 1 then you will find far away that omega 1 plus omega 2 and 2 omega 1 and to omega 2 these terms. So, this first 4 terms will be far away, whereas this term 2 omega 1 minus omega 2 2 omega 2 minus omega 1 which are third product. We fall very near and if there is a modulation here, the bandwidth will be more and modulation here the bandwidth is more than the multiplication of this frequency to this frequency will fall within the band. Now, since the time it is short will continue with the discussion in the next period.

Thank you for the time being.