Fiber - Optic Communication Systems and Techniques
Prof. Pradeep Kumar K
Department of Electrical Engineering
Indian Institute of Technology, Kanpur

Lecture – 49
Review of communication concepts - I (Deterministic and random signals, Baseband and Passband signals)

Hello and welcome to NPTEL MOOC on Fiber - Optic Communication Systems and Techniques. In the previous module, we discussed a generic optical fiber communication system, point to point optical communication system and then we looked at the modulator structures which can be used to modulate any of the carrier characteristics such as amplitude, phase and frequency. Although as I have told you in this course, we will be looking at only those modulations which will change the amplitude and free, amplitude and phase in what is called as quadrature amplitude modulation. that is the modulation technique that we are going to discuss in detail because that is the prevalent technique which is used today in all almost all optical fiber communication systems.

Now, if the change of the carrier characteristic is continuous or is it is analogous to whatever the change that the information is undergoing where the information is usually a continuous time signal, then what we have is the analogue communication system and you can actually perform analogue communication system or you can implement analogue communication system by biasing the modulator, the intensity modulator at what is called as the quadrature point that is at point v phi by 2 if you were to bias and then apply a small signal which is continuous time, then your output intensity will be kind of faithful reproduction of the message signal ok. Of course, when the message signal is 0, the output will be non zero, it will be having some amount of power coming out because you have bio sated the quadrature point of the modulator and then when any when the input signal changes, then the output power will also change.

So, that is the analogue modulation and as I have told you analogue modulation is something that is not quite preferred in today's optical communication systems. In fact, in many of communication systems today, communication is kind in communication is mostly digital communication system. In digital communication system, the message signal is not continuous rather it would be represented by binary numbers that is a sequence of 1's and 0's. And you can either code you know 1, 0 with a waveform or 1 with a waveform or you can take the groups of this 0's and 1's and give an appropriate waveform or generate an appropriate waveform for it. And at the output, you just have to sample the received signal ok. Of course, when I say you just have to sample, there are lot of operations that need to be taken place in the receiver which we will some of those operations, we are going to talk about it but the net result of that receiver is that you are going to sample the signal and by looking at the sample you should be able to guess which of the group of bits that were transmitted or in case of a single bit being transmitted in terms of a waveform mapping, then you are essentially looking at what was actually being transmitted whether it was a single bit or a group of bits depending on the sample value that you have received ok.

Because information and the reception is not exactly continuous, it is in the form of bits which are kind of discontinuous or discrete, this is called as digital modulation and digital modulation is what we are going to study mainly; however, even though we are using digital modulation, the signal that comes out of the optical transmitter will still be a waveform. Of course, it will be waveform in the form of electric field which will then be coupled into the optical fiber after shaping a little bit of that signal that comes out of the transmitter and maybe combining it with other channels that are present in the same system, but in the fiber as soon as this signal is coupled, the signal is actually a continuous time signal.

So, all though we do talk about discrete levels and other things, the actual waveform that is being propagated from point a to point b is continuous. But luckily, we do not have to track over all the changes that the pulse is undergoing as it propagates, the pulse being representing some amount of mean representing the digital information, you do not have to keep track of every aspect of the pulse because at the end at the I mean at the receiver, you are going to simply sample the signal and use the sample.

So, which means that if the pulse changes it is amplitude slightly or you know gets distorted a little bit, it is alright because we are not interested in those small details, but as long as these distortions and changes are not too drastic to change the pulse shape itself, then you are almost and this is the reason why digital communication offers a higher immunity compared to analogue communications, ok. We will talked a little bit about analogue communications, we talked a little bit of digital communications, we need some mathematical tools to you know discuss further and this module is actually concerned with review of some basic concepts in both deterministic and random signals that you would have seen, but perhaps kind of not being familiar right away.

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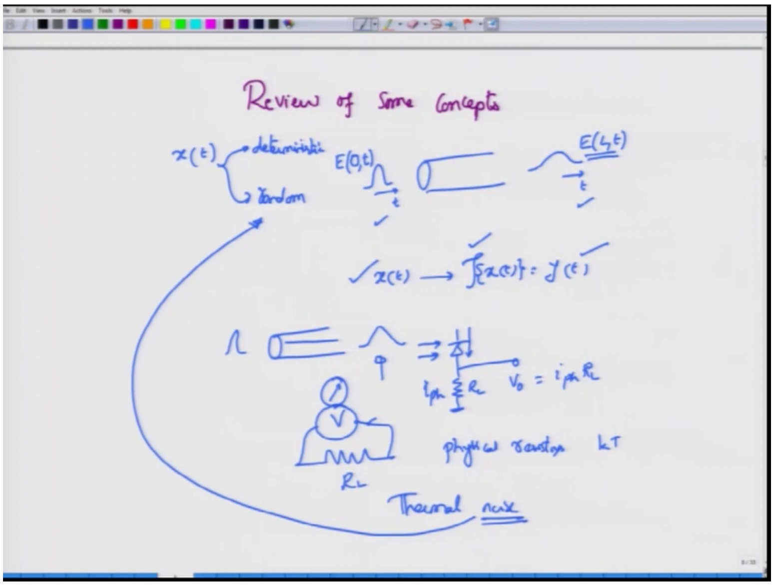

this is a good refresher, but because of the nature of this course being you know not the focus on these concepts, the review will be very fast that is the phase of the review will be fast, but these are standard topics in undergraduate communication system. So, you can actually look at any standard textbook and then you know brush up your knowledge of these concepts. So, with that caution in I mean caution that I have given you let us look at some concepts that are absolutely critical which will allow us to represent to talk about the signals and then to study what happens as the signals pass through different elements, different elements of the optical communication system. What happens when noise is added, what exactly is noise, all those things we are going to review by first stating that signals actually come in two varieties; a signal is essentially a function of time.

We have used these signals a lot in optical communication systems as well, we had for an optical fiber, we had a certain pulse that was transmitted and at the output you had a pulse and a shape of these pulses were different because of the dispersion in the fiber. But never the less, we did represent the electric field at the input of the fiber as a way you know, as a time domain function and this time domain function presumably carry some information therefore, this can be considered as a signal. In this case, this is an optical signal or an electric field and at the output again, you had at the output of the fiber, you had for z equal to L, you had another time domain function which was you know E of L comma t. So, these are all signals which hopefully convey some amount of information to you. If we consider a simple signal such as x of t, this signal x of t could be of two types broadly ok; one is the deterministic signal and the other one is the random signal. The deterministic signal is one whose properties are reasonably easy to predict or rather. In fact, a proper deterministic signal is one whose properties can be specified to any accuracy as you want and if these deterministic signals passed through, deterministic systems that is transformations that would take x of t as input and transform it into some output which we will denote as y of t.

So, if this rule of transformation or mapping is actually kind of fixed, then you actually have a deterministic system and once you have been given a deterministic signal x of t and the deterministic system transfer function or the impulse response of the system, then it is easy to find out what will happen to y of t. Now, it would have been very nice for our communication system to have been composed only of deterministic signals or and deterministic systems. Unfortunately, that is not the case because you may actually have, so for arguments sake, I am going to assume that the fiber is deterministic. So, if I have sent in a pulse, I know exactly what will happen to the pulse at the output, but this is the pulse that is I am not going to measure this pulse right here right, what actually finding at the output of the fiber is the electric field and to convert electric field into something that can be measured in the form of a current, you will have to use of photodiode, right.

So, once you use the photodiode and there is some resistance R L which is the load resistor let us say you are monitoring the output across this resistor R L. So, this optical pulse which is sent into the photodiode would then generate a photo current and this photo current would multiplied through the load resistor R L to generate the photo voltage to so to speak. But unfortunately, a real register this is your R L which is an ideal resistor, but a real resistor is actually a physical register it is made out of physical elements and this elements of course are atoms coming from whatever the materials that are used to make up a resistor and these physical resistors because they are atoms and other things, they actually have some kinetic energy when the temperature t is greater than 0 and you know that one of the properties of this you know atoms is and the electrons that are there is that if they have been given some amount of energy, that they would like to jump from the valence band and going to the conduction band ok. I am just assuming the, these are crystals.

Therefore I am talking about band structure here, but it is not really necessary that way. So, the idea here is that if whatever material that you take, if it is temperature is greater than 0, then there is an associated thermal energy which will then be imparted to the electrons, which will then allow this electrons to move. So, it will move collide with the atoms and then come back to rest and because there is some energy again available it will move. So, there are this random motions that keep happening in the resistor giving rise to what is called as a thermal noise right and this noise is an example of a signal that is random in nature which means that if I were to measure, if I were to measure this thermal noise across a resistor with an ideal voltmeter or whatever the meter that I am using right and if I have no other uncertainties in this measurement scheme; that is I have fix the measurement correctly, I have the voltage voltmeter also working correctly, the value that the voltmeter will actually show is not predictable that is if I look at the value I know what is the value, but before hand I cannot say with 100 percent certainty that this will be the amplitude of the voltage that you are going to measure and I cannot do this even if by chance I am actually correct once, it does not matter much because if I were to repeat this experiment a million and billion times, then my chances of predicting or being right will actually drastically go down ok.

Because I cannot predict the amplitude but I can predict that the amplitude would more or less be this particular value on average that is I look at results of million of experiments and then I say on an average the amplitude should be 3.5 micro volts and the variance that is the deviation from this average be bounded to about plus or minus 1 microvolt. I mean I can say these statements and when I am making these statements, I have a picture in my mind in which these type of experiments are being repeated a million million million times indicating that I am not able to you know give the results of one single experiment but on an average, I can predict the properties of this noise processes as well so.

So, the difference between deterministic and random signals is this whenever I perform an experiment with a deterministic signal passing through a deterministic system, I can always predict the output no matter how many times I repeat that experiment. On the other hand, if I take noise which is an example of a random signal and then I pass it through a deterministic system, let us say the system is known very well, but because the input itself is unpredictable the output is also not predictable and therefore, the output is also random. So, that is not precise, but that is as close as we will get to define what is the random signal and what is the deterministic signal in our modulators in the communication system.

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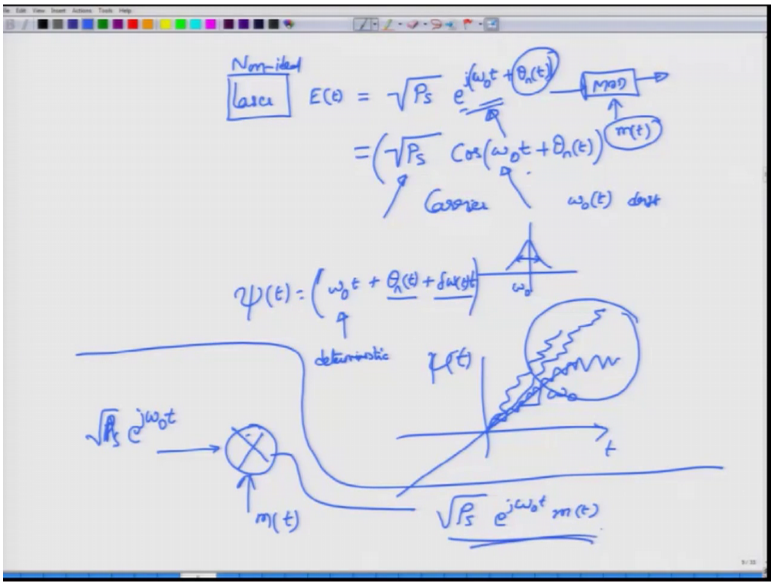

You can represent the output of a laser as the electric field E of t ; for now let us ignore the polarization aspect of it and this output can be given by say square root of P s e to the power j omega 0 t and where omega 0 is of course the carrier and I am using what is called as the complex notation. So, the signal that comes out will have to be a real signal. So, let us say this signal is about route P s cosine omega 0 t as it would be I cannot obtain E to the power j omega 0 t as the output. But I do not want to keep writing cosine and sine; so therefore, this is a short hand notation that we use to represent the output that would come out.

So, this is in fact, related to what is called as a Phasor and in terms of the phasor, you can also write down you mean you can write down whatever the signals that are coming out of the transmitter and further as they propagate through the various elements, you can look at what is happening to these phasors or to these complex signals and analyze the system. So, let us just before going back to the complex domain, so let us actually look at this square root P s cos omega 0 t now this is my carrier correct. So, this is the carrier that I have and here the two parameters that you can see are this power P s I have use square root because I am writing the amplitude out there and then I have omega naught which is the carrier frequency. If these two are well defined and they actually have a unique value, then the carrier will be a deterministic signal. Unfortunately this is an idealized expression because I have to account for the fact that this omega 0 itself can be a function of time called as the drift of the central frequency in the lasers and moreover the spectrum will not be exactly an impulse like spectrum centered at omega 0. In fact, they will be a small amount of curve around this frequency omega 0 which will then cause a certain noise to appear and this noise appears. Noise remember is just another a function but that function is non deterministic or random in nature. So, that noise would appear here as what is called as the phase noise of the laser ok. So, in the complex representation that would be E to the power j omega 0 t plus theta n of t.

So, you can in fact, right down that the overall phase psi of T of a non ideal laser. So, this was a non ideal laser or non ideal oscillator will be the linear phase that comes because of the centre frequency plus theta n of t which is the phase noise plus delta omega of T times T. Of course, I could have combined omega 0 and t and delta omega of t into t, but that anyway is alright we can put them separately out.

So, this of course, is the deterministic linear phase that you are going to get if the laser were to be ideal, then the other two terms would not exist. If you were to plot this psi of t as a function of time t, it would be a straight line passing through the origin and the slope of this would have been equal to omega naught but because of the phase noise, this total phase will not be exactly same it will be having some kind of change or you know different or you know slope and other things. And if delta omega of t, E which is which would then referred to the which is which usually referred to the frequency drift what the effect of this frequency drift is to actually change the slope right.

So, you may actually have this kind of a behavior overtime the slope may actually change. So, maybe this is also another behavior and as we can see, I cannot write down a single graph and then say this is how the total phase would change because all these terms theta n of t and delta omega of t times t are random signals. So, that is what we actually have anyway. So, as this laser comes out, you are going to modulate the laser correct. So, you are going to modulate the laser with whatever the modulation signal that will be there. So, let us say the modulation signal is sum m of t. It does not mean that m of t is a continuous time signal only, it could be a discrete time or digital signal as well, but that is we have just at this point left it as it is.

So, what will be the output of this modulator? Well, depends on what kind of modulation we are performing right. So, but if you were to consider the simple a tumble sideband suppressed carrier type of modulation. So, what you have to do is to imagine that this m of t is going to multiply this carrier which I am going to write this as square root of P s E to the power j omega 0 t and for now, I am going to imagine that this theta n of t and delta omega t of e are equal to 0 because I want to first look at what happens to the deterministic case and then come back to the random case.

So, here is what I am doing. So, I have this m of t and then when it you know when it gets multiplied to this carrier, you get square root P s E power j omega 0 t m of t ok. This is a signal that would come out.

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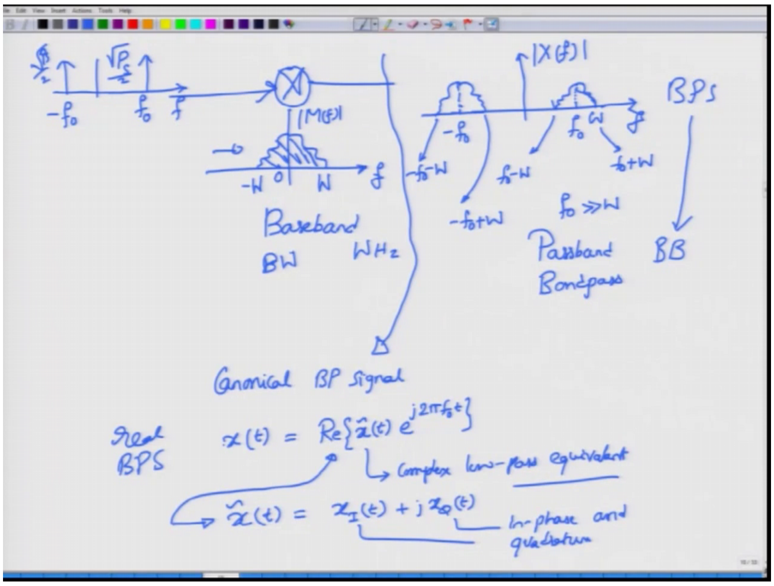

Now, in terms of frequency domain, what exactly has taken place? So, this is your multiplier, this is your carrier. Now square root P s E power j omega 0 t is you know, we will have a spectrum which is center at omega naught and it spectrum will be a sharp P cut omega naught called as the impulse function here. It will have amplitude of square root P s, but you do not need to worry about the amplitude at this part.

I mean at this point. So, when this spectrum goes through and then you have an m of t signal multiplying with respect to I mean multiplying this input signal or the input spectrum here, we need to specify slightly more about this m of t. Let us assume that this m of t spectrum would look like this maybe this is deterministic or maybe it is not deterministic, but you can assume that this is the spectrum that would be coming out of this m of t. For now, we will just take it to be deterministic m of t ok. So, I have this m of t spectrum. Let us assume that the spectrum is centered at 0 frequency and instead of working with omega I will switch and work with the frequency f.

So, similarly the carrier will not be omega 0, but it could actually be f naught. And then, the maximum m of f, so, this is m of f. I am only showing you the absolute spectrum the phase spectrum I am not showing at there, but it will be there ok. So, it will have both magnitude as well as phase spectra. So, we will assume that the spectrum is non zero only over this band which is say from minus w to plus w and because the significant spectrum is concentrated around 0 frequency; this is called as Base band signal ok. That is, this is the spectrum is that of a baseband signal. So, m of t is a baseband signal and then it has a bandwidth of w ok. So, it has a bandwidth of W because the maximum frequency is W Hertz.

So, it has a bandwidth of W Hertz and why did I write W and naught the total width to W because in base bands signal, the bandwidth is counted only from positive frequency part ok. So, it will be 0 to W. So, this is bandwidth of W Hertz and this operation of multiplication by the square root what it would do is to you know take this was baseband signal and then, you know shift the centre of that one shift the center instead of at 0 it would have shifted the center to f 0. So, what you know how is an impulse f naught, but of course, you do not actually get to have the impulse the way I have written it.

So, so, this is just used to place hold where is f naught is this is on the f axis of course, and around this will be your baseband spectrum ok. So, around this is your base band spectrum of whatever the band width that you now have the highest frequency here will be f 0 plus W; the lowest frequency here will b f 0 minus w I am of course, that f 0 is much larger than W and this signal which I have shown has only positive frequency components and therefore, of course, is complex is not really going to be there in your actual signals.

Because in actual or systems, in actual systems you will have not E power j omega 0 t, but you will have cos omega 0 t or cos 2 phi f naught t that would be multiplying, so therefore, the spectrum of the carrier would be having two impulses. The amplitude of course will reduce by half ok. This is all coming from simple Fourier transform theory that you must be familiar with and if you look at the carrier the carrier has two impulse one at g naught and the other at minus f naught and when you multiply that one with m of t, you are going to shift the spectrum m of f into two portions; one to the right that is centered at f naught and the other one centered at minus f naught.

So, again you will have your baseband signal both will actually have the same aptitude, this will have the same amplitude and this frequency will now be minus f naught plus W and this one will be minus f naught minus W. So, this signal which we have written let us call this signal as x of t and the spectrum of this one as x of f and if you look at the significant spectral content of x of f that does not occur at 0 Hertz rather it occurs at f 0 which is greater than 0 Hertz and therefore this is called as pass band signal, sometimes also called as band pass signal.

Usually, this band pass signal or pass band signals are not represented in this manner because you do not want to keep carrying around everywhere e to the power j 2 phi of 0 t. So, rather you want to be able to talk about what is called as the canonical representation of the band pass signal. So, canonical representation means that any band pass signal whose carrier frequency f 0 is greater than 0 and usually much much greater than 0 can actually be written as x of t as the real part of x tilde of t E to the power j 2 phi f 0 t where this x tilde of t is called as the complex low pass equivalent signal ok. The complex low pass equivalent signal and this is the complex low pass equivalent of the band pass signal.

So, in terms of pictures, this was a band pass signal that I had and if you were to obtain the equivalent low pass signal of this one which in this case turns out to be the m of t signal, but in general you do not know if you do not know m of t, that is fine you can start with the band pass signal and then go back to the base band. So, when you do that band pass to base band transformation or transition, then you essentially generate this complex low pass equivalent signal. And if you take that complex low pass equivalent signal multiplied by e power j to phi f 0 t and then take the real part of it, that will give you the real band pass signal ok.

So, that will give you the real pass signal and this complex low pass equivalent is sometimes simply called as the base band equivalent signal or the complex envelop. Because this is already complex, you can write this as x i of t plus j x q of t where you identify this i and q as the in phase and quadrature components. So, in phase component and quadrature components are again time varying functions and the information is usually present in these two arms; utilizing these two you can construct first the complex envelope and from the complex envelop, you can construct the band pass signal ok.

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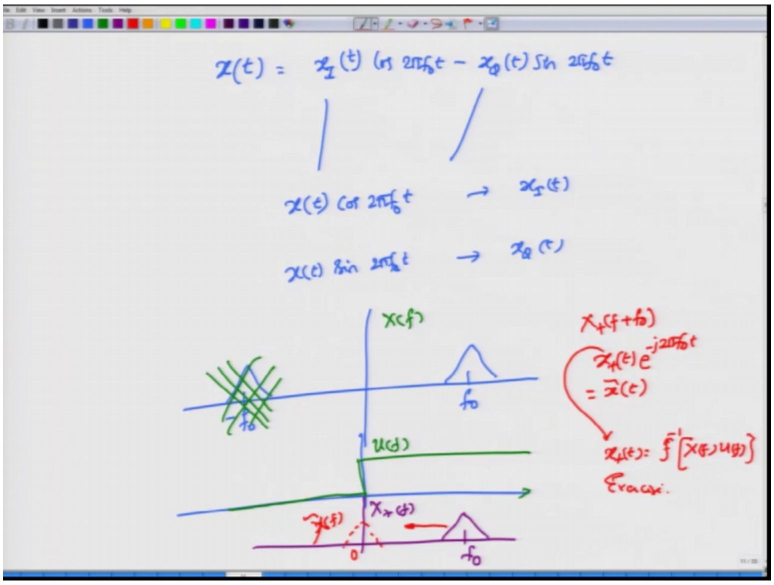

So, the by substituting for x the complex envelop x of t can be explicitly written down in terms of x i ok. So, this is x i of t cosine 2 phi f 0 t minus x q of t sin 2 phi f 0 t ok. So, this cosine term that is that E signal which is or the function which is multiplying the cosine term is called as the in phase term and the one that is multiplied to the sine is called as the quadrature term. You can recover x i and x q independently by multiplying on one branch of x of t by cosine 2 phi f 0 t and on the other branch by multiplying cosine with sin 2 phi f 0 t.

So, what would that would do it would actually correlate these two and f 0 t and then it would actually extract out x i, so the output would be proportional not exactly equal, but it is amplitude will be slightly different. But it is possible for you to actually extract these signals as you know you can verify from your communication system takes place.

So, this is what the equation wise was, but what actually happened out here was you started off with some base sorry pass band signal or the band pass signal which had centers at f 0 and then, you can multiply this one this entire spectrum. If this is x of f, you can multiply the spectrum by a unit step function, a unit step function would be exactly one for f greater than 0 and it would be 0 for f less than 0. What it will do is it will eliminate this set of frequencies right and the result of applying this or multiplying these two will be a single spectrum which is centered at f naught you can call this fellow as x plus of f. And next what you do is to actually shift this x plus of f on to the left by the factor f 0. So, if you take this x plus of f plus f 0. What you would have done is to actually push this spectrum which is originally centered at f naught onto center at 0 and of course, this x plus of f plus f naught would actually be in time domain look like x plus of t, E to the power minus the j 2 phi f 0 t and once you have done, this one you have obtained the complex envelop x tilde of f.

So, therefore, in terms of time domain this would be the complex envelop x tilde of t. So, x tilde of t is x plus of t E power minus j 2 f 0 t and exactly what is x plus of t ; x plus of t is the inverse Fourier transform of x of f multiplied by u of f ok. I will leave this as an exercise for you to figure this out. So, we will rap this module now and consider several other concepts in the next module.

Thank you very much.