Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Optical Communications

Week – I
Module – I
Optical Transmitter – I

by
Prof. Pradeep Kumar K
Dept. of Electrical Engineering
IIT Kanpur

Hello every one welcome to the first module in optical transmitters in the introductory module I have spoken to you about the importance of optical communication systems how optical communication systems is driving up the data rates that we witness today it allows you to view video on demand it allows you to send emails across continents it allows you to share data to a wide range of people who are all speared all over the parts of the world now as we saw one of the things that has happened over the last few years is that the communication technology for optical communication as progressively become more complex.

It started off with the very simple modulation technology modulation being a process in which you take the data that needs to be transmitted which would come in various forms and then convert that data into optical means so that it can be better matched to the characteristics of the optical fiber so we have seen that in that early generation optical communication systems this modulation was fairly simple all you had to do was to vary the intensity talking about the digital communications here.

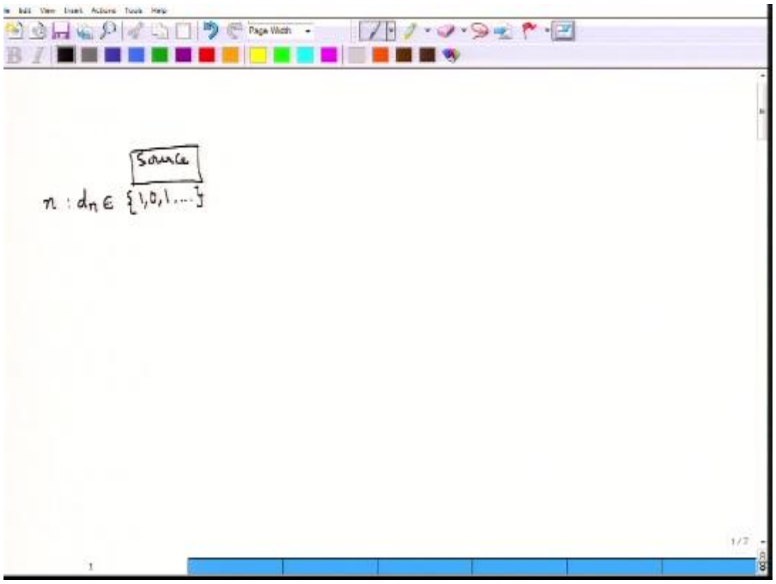
So you had to just vary the intensity of the light source which would be either LED or a laser although today it is laser which are currently becoming used for al long whole optical communication systems so you take that laser power and then vary it in accordance with the modulations signal so if the modulation signal happens to be in the form of 1's and 0's and 1 being represented by a certain voltage level and 0 being certain represented by certain voltage level.

These voltage levels have to be converted into optical intensities or optical powers the simplest of that scheme would involve sending no optical power or 0 optical pulse when a bit 0 arrives as the modulation data and you send some amount of optical power so in order to represents that there is a bit 1 so this kind of a simple ON OFF keying as it was called was the hall mark of the first generation optical communication systems they of course are still being used but with a data rates that are calmed at about 10 to 40gbps you cannot really move beyond that with these methods.

So what we have seen is that this simple method which was hall mark of the first generation, second generation third generation systems are now going to be changed for the current generation and for the next generation optical communication systems modulation hence now means modulation in optical communication now means modulating both amplitude as well as phase so in general what we are going to do is quadrature amplitude modulation and we need to understand first is what different optical transmitters are available or in order to implement these complicated or complex modulation technologies.

So that is what the job of this module is we will began with eth simplest transmitters structure and then we well scale up the complicity as we go in order to cover quadrature amplitude modulation so we began by looking at a typical and at a very high level optical communication system that would first start with an source of data so you need to have a source.

(Refer Slide Time: 03:34)



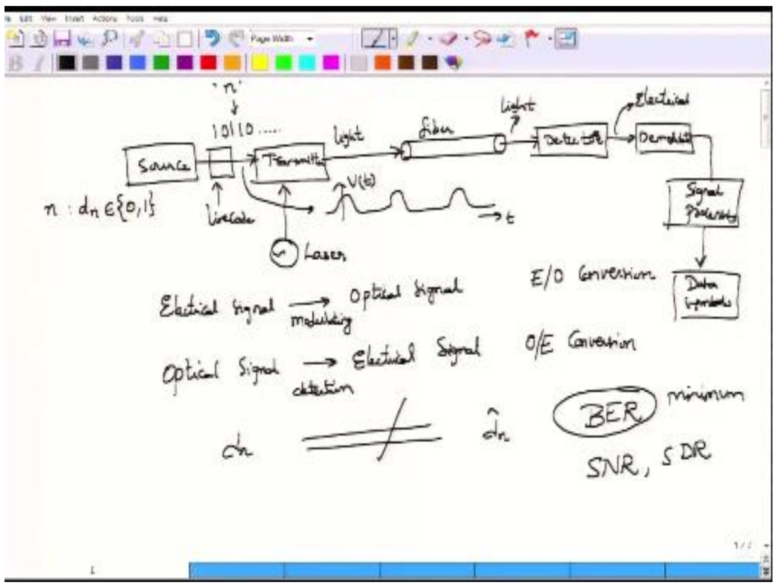
Which produces data in this module and until we talk about it other way we will assume that we are working with digital communication systems for all the advantages that we have listed in the first module so our sources are 1's and 0's of course this 1's and 0's do not come from any where they are just abstract quantities where do this 1's and 0's come from they are actually obtained by a process of converting an analog signal which comes perhaps when you speak on phone or when you have some other continually varying quantity then that needs to be transmitted over the fiber using digital communication.

The first job would be to convert this analog signal into a digital signal by very well known process and these digital signals are then encoded to form the appropriate digital data so in the simplest of the scheme this digital conversation analog digital conversion will mean talking an analog signal and converting into sequences of 1's and 0's and to represent those1's and 0's you have to choose appropriate voltage or current levels.

We will talk about such mapping of bits 1's and 0's which represents the information and their physical realization and how it would affect the communication channel this process is known as line coding we will talk about line coding in the next few modules okay in the after few modules but for now we will simply assume that I have source which I am labeling it as a data carrying or a data producing block and this data that produces will be in the form of 1's and 0's so I have sequence of 1's and 0's which would then form my data pattern.

So at any particular time which I will denote it as n I have a data d_n which can be taken from group of 1's and 0's and it would be sequence of this data okay.

(Refer Slide Time: 05:27)



So let me just rewrite this one is a slightly better way so I have source which produces a sequences of data symbols which would we say 101101 something like that at any given time so if you think of this as discrete time indices at any given time n okay you have one data bit that is generated which I am denoting as dn and dn can could be weather 0 or 1 this is the simplest scheme which where I am assuming of course this data sequence could be complex when it tries to represent more than 1 bit per symbol type of modulation we will talk about that later.

So you have source which is decided the digital communication which gives you the digital sequence then it has to be converted into optical signal okay this sequence of course has to be line code as I said in order to represent the out so the output of the line coding block would be sequence of voltage pluses or current pluses depending on the modulation method that we are doing so this 1’ s and 0’s would be represented by certain pulses shapes okay these pluses shapes are of course functions of time.

And these pulse shape are the 1’s that will go and drive the optical modulator block so this would let us say the voltage pulse v(t) that would represent that particular sequence which we have written so it could be nay sequence which then as to be converted into this physical voltage or current variable next comes an optical transmitter this optical transmitter will necessarily have one more input which is a laser source as I said for long whole optical communication it is a semi conductor laser that is used as the light source and we are labeling that by this laser.

We will come to some of the imprtnbat characteristics of laser in a few minutes but for now it simply providers us with an electric analogy of an oscillator so this laser is actually an oscillator for all our purpose in this module so this light coming from the laser will be modulated according to the pluses remember these pulses which are input to the transmitter or the outputs of the line coding block which means that these pluses directly represent the information or the bit sequence that would be transmitted over the fiber.

So you have bits, bits are converted to pluses are in the electrical domain voltage or current which then as to be converted on to the optical domain by this optical transmitter so this process of going from electrical to optical so with the process of going from electrical signal it need not be these pluses of course it can in general any electrical signal from electrical to optical signal which is optioned my modulating a laser so this is optioned by modulating a laser.

Okay is called electrical to optical conversation so the transmitter side is characterized by an electrical to optical conversation so that output of the optical transmitter will be light and this light as I said could be either in the form of pluses when you are performing an ON OFF keying or intensity of the bit sequence it could a different kind of a signal it could be phase modulated sinusoidal signal when you are modulating the phase of the laser light so we will talk about that later so what you have to remember is it is light which is coming out of the optical transmitter which then will be given to the optical fiber, okay. so this will then be given to the optical fiber the fiber will carry light which is incident at it is input at the fiber one end of the fiber, it will carry these light waves from one point to another point at which you locate your receiver, so this is the transmitter block and this is the receiver block.

Depending on what modulation that you have performed you have to demodulate actually you have to first detect and then demodulate, detection means detecting the parameters of light which most often means detecting phase or amplitude or power so you first have to detect by using a photo detector the demodulate the appropriate to obtain the appropriate signal which has been the transmitted signal, you would of course do some signal processing here and then finally retrieve the data symbol, so you finally have the data symbols which have been transmitted, okay so the data sequence which was transmitted will be received at the receiver. If you look at what is happening here you have an optical domain, but once you putting a photo detector right once you put in a photo detector what you get is an electrical signal.

If everything has gone well there has been non noise in the system then this electrical signal will just be the replica of whatever the electrical signal that was used at the transmitter side, so if there is no noise if the fiber has no loss detection process is extremely ideal nothing has gone wrong in the entire system then whatever you have put in at the transmitter input in the form of the electrical signal is what the electrical signal that you would get at the detector, okay.

So with some non ideality such as loss if you include then the electrical pulses would appear but their amplitude would properly be lower, actually that is because the amplitude of the input light itself would have got in lower because of the fiber losses. So I hope this diagram is clear and you have identified the feature that is present at the receiver side where in light or light signals are converted into electrical signals, so the receiver side is characterized by converting an optical signal into electrical signal, so converting an optical signal into electrical signal this one by means of detection by using a photo detector and this is characterized in general as optical to electrical conversion.

So the transmitter can be in a very big picture way thought of as a electrical to optical convertor and the receiver can be thought of is an optical to electrical convertor with the idea that whatever you transmitted at are the transmitted symbol dn was there at the transmitter would be the same symbols that you would expect or would be the same data that you would expect at the receiver, of course the real world optical communication system will not mean that, will mean that dn is almost always not equal to dn′ there will be some errors.

Then the system is characterized by how many errors we make in the form of what is called as a bit error rate, so how many errors we make per second so this is the characteristic of most digital communication systems by giving you the bit error rate. What if the input signal electrical signal work to be in analog signal then most likely would characterized it by one of the performance measures of signal to noise ratio or sometimes signal to distortion ratio, so whether the signal was distorted.

As I said most long hall optical communications today and in fact most communications today happen by digital means so we will not be looking at analog modulation for quite some time we will of course come back to analog modulation after we have looked at some of the transmitters structures, alright in the remaining time of the module I will attempt to describe the transmitter to you, you have to keep this particular block diagram in mind you start with the source you have the data sequence which is produced by the source that needs to be converted into an electrical signal in the form of pulses, this is called as line coding or pulse shaping from this line coded electrical signal which you would provide as inputs to the optical transmitter out comes the light.

This light which is coming out of a transmitter would represent whatever the electrical signal that was fit to its input and this light signals modulated light signals are carried away by the fiber from one point to another point at which they are detected, demodulated if necessary you perform some signal processing and they finally your data symbol for data sequence emerges with the hope that you want to minimize this BER, so you want to keep making the errors to be very small.

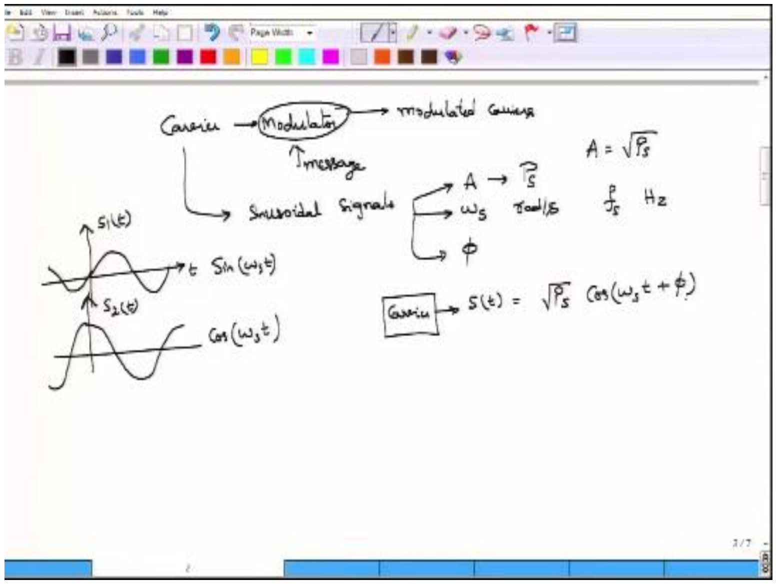
So with the objective that we need to keep the bit error rate of the system to be at its minimum, so this is what we would like to do, so keep this block diagram in mind as we now go to source. As I have said optical communication systems required a laser source because it is the laser which produces us light and that light would have to be modulated in order to carry information from one point to other point over the fiber. So as I said lasers is what we are using for long hall optical communications.

In terms of its functional view point, remember I talked about in the first class that learning optical communications to my mind requires three different layers to understand it completely, first you have the functional approach or the functional layer in which you are concern with what is the input to this block and what is the output of the block, so this is at a very high level without going into the details kind of a relationship, this could be characterized mathematically and graphically and by other means we will prefer to look at it mathematically and then if necessary we will also introduce some pictures to clarify what is functional block is doing.

So this is the functional approach, so the functional layer so at the functional layer your concern with what is input what is output and what is the relationship between these two. The next layer would be to see what physical elements will realize this functional layer, so if I after say that give me an output which would produce 0 for some time and produce a 1 for some time, I have to understand what physical system I have to realize in order to implement this particular functional relationship, so that is the physical layer so or you know as I would call that would be the where you are looking at the physics of the devices.

Once you have understood the physics and you would realize that no physical device can give you the exact functional relationship, there will be some imperfections in the physical system the question then becomes how do I characterize this physical system which is doing its job but it is not doing its job very well, so these problems that are there in the physical system how do they affect my overall optical communication system, so this is at the third level where we are assisting the performance of an imperfect block. So these are the three layers in which we will proceed , so for the source we will today look at only the functional approach as a source you know if you remember your electrical communication systems you had a carrier so you had a typical electrical communication system which had a carrier.

(Refer Slide Time: 16:51)



And this carrier was being modulated so you had a modulator block here to this modulator block you had your data or sometimes called as the message signal and what you obtained was the modulated carrier, amongst different types of carriers we have chosen in most electrical communication systems have chosen to communicate with sinusoidal functions, right or sinusoidal signals. What are the characteristics of a good sinusoidal signal well, sinusoidal signals are characterized by three parameters its amplitude A its frequency ω in radiance per second this is the angular frequency.

If you want to specify frequency you are free to choose that frequency in Hz as well, I denote this frequency by ω with the subscript s indicating that this is the signal frequency and the corresponding source in optical communication is called as the signal laser. There is nothing specific about what a signal laser is, all it is simply I mean there is nothing special about what a signal laser it is actually a laser which is used for communication but the word signal indicated that this laser is found at the transmitter side and it is that light which is coming out of the signal laser that gets modulated, so that is the reason why we put this subscript s.

So if we see it has amplitude A equivalently you can characterize this one by a power p, normally you do not do this, but in optical communications power is a main thing that you can power is the only thing that you can actually measure you cannot measure the amplitude of a light wave, therefore power becomes the fundamental component in optical communication system so we do represent that one and again to distinguish that is the power of the signal laser we put a subscript P_s, okay and amplitude and power are normally related by this relationship that is $\sqrt{P_s}$ so amplitude is related as $\sqrt{P_s}$, okay.

So this is a typical relationship between amplitude and power, so when you square the amplitude you get the power, so this squaring is kind of normalized amplitudes square which will then give you the power in the system so there might be some constant sitting in we do not really bother about that one pretty much.

The third parameter that is important for phase modulated optical system, phases modulated communication systems is the phase, of course in a sinusoidal signal this phase would be with respect to a certain reference signal, right so you have you can take either a sinusoidal signal as your reference or you can take a cosine wave as your reference normally we take the cause signal as our reference and say this other signal sign is 90^o lagging by this cosine wave form, so this remember this wave forms actually extend all the way to $-\infty$ to $+\infty$.

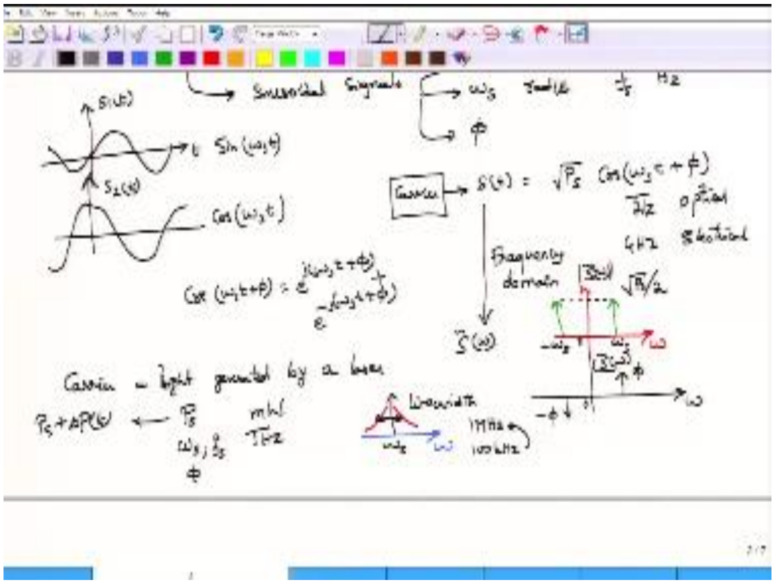
So if you call this as signal S_1 and $S_1(t)$ and this one as your signal s2 (t) then we say that s1 (t) is also a sinusoidal signal but it has a phase of -90^0 it is lagging by this particular signal s2 (t) so that is what the relationship between the sin and a cosign wave is we actually performed what is called as quadrature carrier multiplexing in the sense that be put data on to the cosign part of the signal as well on to the sin part and combine them.

Both have to be at the same frequency this quadrature carrying multiplexing it is also known as iq modulation we will talk about iq modulation shortly. So coming back to what we want from a sinusoidal carrier a sinusoidal carrier has well define power or equivalently amplitude it also well defined single frequency omega s and then it has a certain phase which would not become important unless you modulate the phase.

This is at the functional level where I am looking at so in have a carrier okay and what the carrier does is to produce a signal which let us call it as s(t) okay given by $\sqrt{p_s}$ remember amplitude and $\sqrt{p_s}$ are related cos Ω s(t) +5 where 5 is any phase with respect to cos Ω s(t) so this is the functional relationship for this is the output of the carrier of course it does not take input ion the functional form so there is no input to the carrier.

But a physical laser will take input in the form of the current that you need to provide in order to by as the laser. So this is the output in the functional view point mathematical expression which characterize my carrier, this remember if you noticed here the carrier description does not say whether this way form is describing the optical doming or it is describe in the electrical doming because the characterization of a functional view point is the same regardless of whether you are in the electrical doming or you are in the optical doing okay.

(Refer Slide Time: 22:07)



So this could very well representing in electrical sinusoidal signal it could also represent a nice light you know the optical signal of frequency Ω s the difference being the frequency Ω s is usually very large for optical signals it is in the order of tera H_z whereas for electrical signals you normally go up to giga H_z so this is typically the optical frequencies giga H_z is normally how much you can push it to electrical signals, okay.

And this phase as I said unless you modulate it normally does not enter in to picture for intensity modulation systems this phase is totally in material intensity modulation or the on off key is signals this phase is totally in material. Now these decryptions which have given is a decryption is term of time to mind relationship if you remember your signals and systems it is possible to go to the frequency doming and describe what you are getting as output of the carrier.

So how do I describe the carrier in the frequency doming well what I do is I consider the frequency axis so call this as axis Ω and then take the furrier transform of the signal s(t) I can do that because this is a nice sinusoidal signal stepping aside any mathematical difficult is that could be perhaps this arriving because of this type of a function you have probably see this one the decryption of a sinusoidal signal would be to give it furrier transform in the furrier transform to denoted by 2 δ functions.

Here you have 2 δ functions which are situated at the signal frequency of **Ω** s and - **Ω** s remember this is a real signal so it will have it spectrum which is two sided spectrum okay there are certain amplitudes to this so this amplitude is $\sqrt{p_s}/2$ it is the same amplitude for both sides and there is a relationship for the phase as well so if you look at in terms of the frequency **Ω** again and if you go to look at the frequency of sorry if you look at the phase of the furrier transform of s(t) let is call the furrier transform of s(t) as s **Ω**.

So this would represent the magnitude of a soft **Ω** and if you know look at for the phase of s(**Ω**) you would see that this one as a phase of 5 and this one has a phase of -5 okay so I guess that this is all write because you can write cos **Ω** st + 5as ej $^{\Omega st}$ + 5 _$e^{-j\ \Omega st}$ + 5 and then if I take furrier transform of this, this could be a delta function located at **Ω** s this should be a delta function located - **Ω**s and this would be a phase relationship.

You can switch the phase relationship calling this as -5 and this is 5 but they have to be anti sympatric with respect to each other whereas they are magnitudes are sympatric with respects to 0 frequencies, so this is the 0 frequency so this characterization of a carrier it applies equally well to us electrical signal or it will apply very well to a optical signal describes both in the time doming as well as ion the frequency doming.

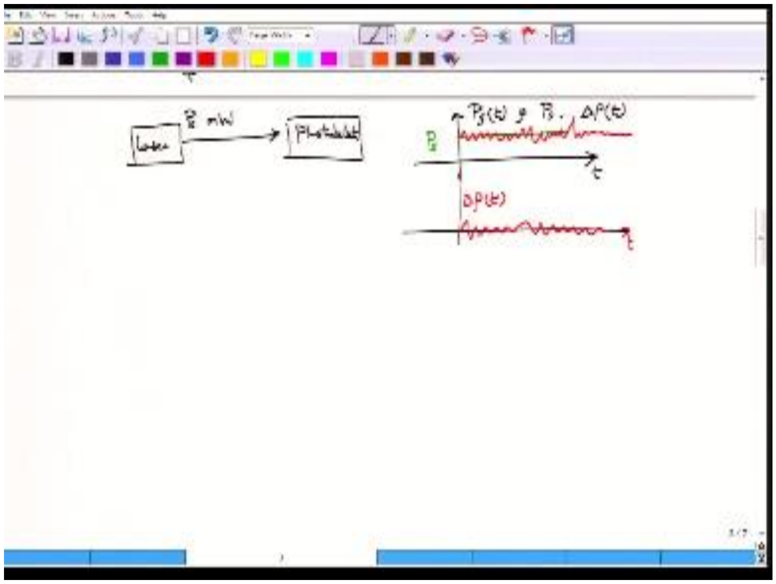
Now we, in our optical communication system this carrier is nothing but a signal or light generated by a laser so this is the light that is generated by a laser we will assume that this laser is well behaved in the sense that is characterized by certain power ps which is typically in mille water agent for optical communications systems one to 10 mille water 1 to 20 mille water depending on the links that your require.

It is also characterize by it is frequency **Ω**s which as I said would be some tara H_z or rather the corresponding o frequency Female Speaker: will be in tara H_z okay and this is also characterize by certain phase 5 okay this is a single frequency optical signal you will later see that there is no such thing as an ideal laser and a laser typically has a spectrum which looks like this. It has a spectrum I am just showing one half of the spectrum here which is located Ωs what you would see is that the spectrum is actually a broad scout around the central frequency or the signal frequency of the Ωs.

And this broadness is characterize by the line width of the laser the laser has a non 0 line so in the popular language or in the popular thinking laser means it has a single way of length and it has the spread around that particular single way of length. But in practice no single wave link or a single frequency laser can be obtained and most lasers have some amount of line width which is measured typically in some mega Hz so these days you will get very good lasers which have a few mega Hz line widths.

So this line width typically is around anywhere from 100 kHz to 1 mega Hz okay we will see what is the implication of having the line width later on. Also the power of a light wave there is generated from the laser will not be constant but it would actually be fluctuating okay so this δp of t represent the random fluctuation so you would expect that the laser to have a constant power but it does not really have a constant power it has a power which is average power is ps around that there would be fluctuations.

(Refer Slide Time: 27:57)



You can see that fluctuations assuming that you have a ideal photo detector you take a laser and then take a photo detector if your photo detector was ideal producing no noise then if you give laser set it is power output to some pls mille watt what you would expect is this characterize so if you look at it a function of time you would expect the power to be constant and has value of ps however if you actually look at the measurement the real data the real data shows that there is an average power okay.

And around that average power there are this fluctuation so you could characterize the power of the laser has not being a constant but rather changing with time and this time changing has two components it has an average value, okay so it has an average value Ps and it has a fluxion $\Delta P(t)$ so the fluxions are obtained by subtracting this green line from the red line, okay. So when you subtract that green line from the red line what will happen the red has 0 average value because it has been subtract the green has been subtracted so this would be the fluxion that you would see, so this is the fluxions $\Delta P(t)$ that you would see a function of time.

This completes are functional description of the laser at this point we will see the imperfections of $\Delta P(t)$ which is there in the physical system as well as the line bit we will see what physical mechanisms are responsible for this line bit as well as this fluxions in the power and how would they affect the optical communication system, how would they affect the performance of an optical communication system as we go along with the course.

<u>Acknowledgement</u>

Ministry of Human Resource & Development

Prof. Satyaki Roy

Co-ordinator, NPTEL IIT Kanpur

NPTEL Team

Sanjay Pal

Ashish Singh

Badal Pradhan

Tapobrata Das

Ram Chandra

Dilip Tripathi

Manoj Shrivastava

Padam Shukla

Sanjay Mishra

Shubham Rawat

Shikha Gupta

K. K. Mishra

Aradhana Singh

Sweta

Ashutosh Gairola

Dilip Katiyar

Sharwan

Hari Ram

Bhadra Rao

Puneet Kumar Bajpai

Lalty Dutta

Ajay Kanaujia

Shivendra Kumar Tiwari

an IIT Kanpur Production