Fiber - Optic Communication Systems and Techniques

Prof. Pradeep Kumar K
Department of Electrical Engineering
Indian Institute of Technology, Kanpur

Lecture – 31
Light sources, detectors and amplifiers

Hello and welcome to NPTEL MOOC on Fiber Optic Communication Systems and Techniques. In the part 1 of this course, we looked at the reason why long haul optical communications is possible in the first place because we have low loss and large bandwidth optical fibers. Optical fibers have evolved from the early 1960’s or so to 1980’s and it continues to evolve now. The goal being to enable long distance communication by reducing loss, as much as possible and also to increase the bandwidth of the fiber, as much as possible; this means that, we will be able to communicate with very little delay over long distances with very little losses ok.

Of course, if you just have an optical fiber communication would not be possible, communication would be possible provided you have some means of transferring information, which usually is not in the form of light. So, it has to be transferred or converted from non light form into light form and then launching into the fiber and then let that light propagate from one end to the other end of the fiber and then at the output of the fiber or at the place where you want to place the receiver, the first task would be to convert from optical domain, the information that is contained in the optical domain back into the original format ok.

So, unless we have a transducer which we are know which we would require, which would convert information which is in the non light form into light form at the transmitter and a transducer at the receiver which would convert light energy into something that would be non light energy which of course, should be in a useful form, so that, we can process it and then extract the information out of it ok.

So, the task of having a light source and be able to change the properties of this light source had the transmitter is very crucial because, that would be the second and most important part of optical communication system or any communication system requires a source. And for optical communication system especially, for fiber optic communication system you do require a light source and you should have the ability to change the properties of the light source so that, whatever the properties that we change can be changed by actual information.

So, information would change the property of the light source, one or more properties of the light source and this light which is emitted by the source after it is you know properties have been change then it will begin to propagate in the low loss optical fiber. The process by which one takes information and then modifies the light source or the light emitted from the source of light is called modulation. This is very similar to any other type of modulation for example, in the usual RF domain, you speak right and then whatever the speech signal that is there will be usually converted into an electrical form by a speaker and or a by a microphone.

And then, this electrical signal will be used to change one of the properties of the RF source, the RF source could be coming from various ways so for a simple crystal oscillator. And depending on what parameter of the source you modify, you will have different types of modulation. Something very similar has to be done for the optical communication system as well. You have light source and you change the properties of this light source by the information that you want to send it over the fiber.

So, the information changes the property and of the light and this light who travel from one point to the other point. Now at the receiver or at the point where you want to extract the information back right, what you need is a detector. A detector is a device which converts or which detects light is its basic simple idea out there, but we normally talk of a photo detection process where we actually convert light energy into electrical energy. And hopefully whatever the electrical energy that you have would represent the information that has either been generated natively in the electrical format or it has been converted from some other non electrical to electrical format; nevertheless by reversing that process you will be able to extract the information ok.

So, this part of the course actually looks at some of the light sources that are used and the photo detectors that are used at the receiver ok. In addition to sources and detectors, you also need what is called as an amplifier. Now, there is a straightforward way of amplification right.

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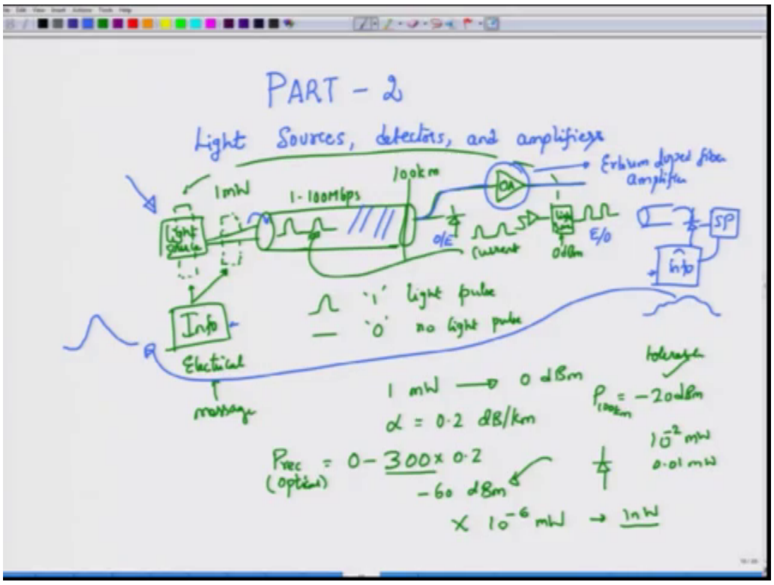

Suppose I actually consider an optical fiber link, so this is an optical fiber ok. Assume that this optical fiber is some hundreds of kilometer long and then you have a light source ok. At this point I am not specifying what is the light source, we are going to talk about that one shortly. And this light source incident slide from the source onto the fiber somewhere here you would have a modulator, it could modulator could be external to the light source or sometimes integrated into the light source itself ok.

So, one talks about direct modulation and external modulation in these two cases something that we are going to talk about it in the third part of the course but you have this information that you want to transmit. Assume that this information is in the form is electrical signal, if it is not an electrical signal, you can imagine that this first has been converted into the electrical signal. And this electrical signal would modulate the light source. Light source would be for example, a simple digital modulation would look like this, whenever this is written then it means that this is a symbol 1 and light is present or a light pulse is transmitted and when you do not transmit anything that corresponds to 0 and no light pulse is transmitted over appropriate symbol duration ok.

So, a sequence of pulses could for example, represent the information that has been that is in the form of a binary representation and that binary representation itself could be coming from the actual message. So, if the message is non electrical, convert that into electrical. Usually, also encode that electrical signal into certain modulation format or certain formats and then modulate the light source and then transmit that modulated light onto the optical fiber right.

So, if the fiber length is very large, say for example, 300 kilometers and you are using moderate amount of light so you know light power here. So, let us say we are using about 1 millivolt of optical power. Now remember that or recall that 1milli watt of optical power corresponds to 0 dBm in the dB scale ok.

So, this is the launch power of the light that we have sent into the optical fiber and we know that, the standard optical fiber has a loss corresponding to about 0.2 dB per kilometer ok. So, if you were to for example, weight say 300 kilometer, the power that you would receive at the receiver and this will be in the optical domain itself. So, I am going to write this one optical, just to emphasize the fact that, this power is in the optical domain and the power received would be this much; 0 dBm is the initial launch power and then this power gets attenuated by 0.2 dB per kilometer and since, you have gone 300 kilometer, this would be roughly decreased by 60 dB and therefore, the power received in the optical domain would be about minus 60 dBm.

Now, most photo detectors would not be able to sense this very small amount of optical power. How small is minus 60 dBm? Minus 60 dBm is actually 10 to the power minus 6 milliwatt equivalently this is about 1 nanowatt, most detectors without any additional support cannot just detect this amount of power. So, they are actually very low power for the photo detector to directly detect the optical signal ok.

So, what you would do is that instead of transmitting over 300 kilometer. Let us say you break it up at about 100 kilometers, so you terminate the fiber at this 100 kilometer because, at 100 kilometer the signal would have dropped only by 20 dB and for a 0 dBm launch power, the received power at 100 kilometer would be equal to minus 20 dBm. Minus twenty dBm corresponds to 10 to the power minus 2 milliwatt or 0.01 milliwatt, which is in the range of most photo detectors that are used in communication system.

So, this is a tolerable value whereas, this cannot be tolerated in the sense that, we cannot even detect such low powers. So, it is clear that, if you just use fiber without any intermediate stages or without amplifying the signal somewhere in between, we will continue to lose power and after a certain critical length which of course, depends on the sensitivity of the photo detector then the entire link will be totally useless for us ok. To prevent these phenomena, you have to amplify the optical signal.

Now, there are 2 ways of doing it right. In the olden days this approach was actually quite popular especially, when the data rate was actually quite small. So, the data rates were like 1 to 100 Mbps or it may be 10 Mbps, so then, it was possible because electronics was available which could actually tackle 1 to 100 Mbps of data rates, what we would do is, we would actually take this optical signal, put a photo detector right after say 100 kilometer.

And then from the photo detector you extract the electrical pulses assuming that, noise has not really contributed too much and you taken care of that one by properly designing the receiver. Then you would actually get current pulses ok. so these are current pulses, which kind of mimic the optical pulses that have been transmitted. Of course, these current pulses would be present here then, what you can do is you could amplify these current pulses ok, just to bring the current levels up. And then put 1 light source here ok, a second light source if you will of the same characteristic, as the first one and use this current which is the electrical signal amplified current pulses as input to the light source, which will then send out next set of optical pulses and you can set the power here back to say 0 dBm. That is you can use the detected signal and then use the detected signal amplify it you may also can clean up the signal in between and then use it to modulate the light source which is kept in the middle of the link or maybe at the end of one span of the link and there will of course, be multiple such spans, I mean a typical long haul communication system can go easily to about 20 to 30 spans, each span of about 100 kilometer, so about ten spans would correspond to 1000 kilometer and about 20 spans would correspond to 2000 kilometer.

So, it is easily possible for that to happen. And then, if you follow this approach wherein, you have your light pulses or your even optical signal propagating and then you actually put a photo detector or a detector system and then extract the information and use that information back into the optical source or the light source to modulate it and then resend it retransmitted so to speak ok.

So, this type of it is no system was actually used earlier especially, before 1985 kind of a thing 85 86 kind of a thing because, we did not have an ability to directly amplify the optical signals right. So, we will talk about what those amplifiers were which enabled directly to amplify the optical signals not converting into electrical format directly the optical domain itself.

So, how would that link work? So, instead of putting a detector converting then putting a light source all that you had to do was to actually put a optical amplifier. It would just raise the level from say minus 20 dBm to back to 0 dBm depending on how much gain you want in the optical amplifier and this is this is precisely what you were able to do that one. So, you could offset the losses in the fiber, by directly amplifying in the optical domain not converting into electrical domain ok.

So, this conversion from optical to electrical domain is sometimes characterized as O slash E, standing for optical to electrical conversion. And then converting from current or electrical format on to the optical is called as E slash O, which is electrical to optical converters So, before the advent of optical amplifiers or before the discovery of optical amplifiers, it was this method wherein, at the end of 1 span, you take the optical signal convert that into electrical format, amplify it, reshape it, do all of that and then convert from electrical to optical signal back.

So, this O to E and E to O conversion would actually work out only for low data rates because, the electronics could only process things like about 1 to 10 or 1 to 100 Mbps if, the data rate became higher say more than 10 gigabits per second, as is currently the data rates then, this O to E, E to O conversion does not really make sense because, electronics is not fast enough to process optical signals at such high data rate. And of course, we do not really have to do that one because, luckily around in the mid 1980's people discovered or invented optical amplifier so that, you would never have to convert the optical signals back into electrical domain and again convert from electrical domain to optical signals. And this optical amplifiers and the prominent optical amplifier which was studied first and then brought into market is called as erbium doped fiber amplifier ok.

And this was a fiber amplifier in the sense that, the optical amplifier was not a device wherein, you had to take light from a fiber amplified and then convert back into the fiber because, you could have significant losses in taking light from a fiber and then putting it processing it and then converting back into the or you know focusing back into the fiber. So, fiber to free space conversion is also avoided because, these early amplifiers the optical amplifiers were actually fiber based amplifier, so you could just connect 2 fibers and light would propagate into the second fiber which is doped with an atom called as erbium or erbium ions as we would call them and then by adjusting the current through which this fiber amplifier is you know or by actually properly adjusting the optical pump to this (Refer Time: 15:38) fiber amplifier you could get any gain that you want that could offset the losses in the fiber. And then, out of the erbium doped fiber amplifier would be the signals in the optical domain.

So, you did not have to do an optical to electrical and electrical to optical conversion in following at every span, you could simply place in erbium doped fiber amplifier and almost be done with it ok. So, this trade off of course, if since you are putting it through an optical amplifier, the optical amplifier does not give you free lunch because, it adds a noise of its own. So, if you go over say 10 or 20 spans and each optical amplifier is added some amount of noise then, the final signal that you would get would be substantially noisy. However, if you follow the older approach of O to E and E to O conversion at every span, then you could clean up the noise at every span. So, therefore, there is no noise or there is very little noise when it comes to the end of the fiber link right if you follow the old approach, but the old approach as I have told you is only valid for lower data rate applications and they cannot be used for high data rate applications.

So, even though in this optical amplifier approach, you do end up with signals which are substantially noisy compared to the older approach it is worth the effort because, you are going to be able to work at very high data rates. And that is a very key you know principle behind this a long haul optical communications with optical amplifiers ok. So, we have motivated the reason for light source, light source are or light source is necessary because, information is mostly in the non electrical format, it has to be converted into the optical format and to convert that into optical format means that, the light emitted by the source will be modulated with whatever the information that you are transmitting. And that modulated light would be launched into the fiber, I am saying launch into the fiber because, this coupling usually comes from free space to optical and there is significant loss involved in those unless you design this correctly, if you design bad launch optics then most of the light would not be launched into the fiber, but it would simply fall way outside of that one and then be useless ok.

Assuming that you have done a good coupling optics or launch optics then most of the light from the light source after modulation is launched into the fiber, the fiber carries light at the end of each span you put an optical amplifier and finally, at the receiver side you convert the information back into the electrical format by putting in a photo detector followed that one by signal processing electronics and finally, you will be able to extract the information.

Now, I denoted the information with the hat on top what is the meaning of that. By putting a hat what I want to convey is that, the information which you launched at the transmitter may not be the same information that you actually get, that is occasionally, your system would induce error. Why would there be error because, there is noise introduced by the optical amplifiers and noise is something, that you cannot simply throw it away you cannot separate signal and noise and then say i will make noise completely to 0, it cannot be done. You can kind of minimize the effect of noise and you can come up with very nice signal processing algorithms some of them we are going to see in part 3, but there will be effect of noise residual effect of noise, which shows up by an occasional error in the information. Of course, when I say error, what I am implicitly assuming is that I am actually doing digital communication. If I were to perform an analog communication, that is if my light would not be modulated digitally, but it would be modulated in an analog modulation format then, the signal that you would get would be distorted version of the information that you have transmitted.

So, for example, if you have launch this pulse then, the pulse that you would get would look something like this despite all of your effort. And whether this information is ok, compared to this one is a decision that one has to make depending on the applications. For most speech based applications which was one of the first applications of optical communication systems which they started replacing the telephone wires. This kind of some distortion and some amount of noise in the final waveform that you would receive at the end of the fiber link was more than acceptable for those speech based applications because, human years are kind of not very sensitive to these small amounts of distortion. Of course, it does not mean that you distort it completely, what it means is that you design the system in as much you know bet may efficient manner as possible to keep either the distortion in the final result small or in the digital communication case keep the errors as small as possible ok.

So, that is the motivation for us to go to part 2 because, in part 2, we are going to study light sources, we are going to study detectors and then, we are going to study the amplifiers, which are used. Of course, we will study only optical amplifiers and our concentration would be mostly on the erbium doped fiber amplifier which is the important optical amplifier in optical communication systems.

Now, let us talk about light sources. What light sources can be used, for example, you will be probably viewing this you know video in your room and if you look up or look somewhere else left, right whatever depending on the room that you are in, you would find definitely a light source right. That light source if I might to take a guess would be a tube light or a more common led light source and you would wonder why cannot I simply take that light and then use it for communication. If you did that you are in a good company because, there is an type of communication called as visible light communication whose entire purpose is this. It will use not the tube lights, but it could use the led's which are cheap, which are available very easily and whose electronic circuits are not so complicated. So, you can actually easily make connections to those led circuits and you can use that in conjunction with optical fibers or without optical fibers.

So, one would be the free space communication and the other one would be the fiber communication both are possible with such simple sources of light called as led's. Led stands for light emitting diode and something that we are going to convert you know study later in the in the in this part of the course ok.

But in general, I would not be able to take light from a bulb or from a tube light, the conventional bulb and a tube light and then modulate its property launch it into the fiber. If I were to do that in a standard communication fiber, if you recall the light from a tube light or from some other light source that is visible to your naked eye, that visible light source usually covers the spectral range from 400 to about 700 or 600 nanometers right so, 400 to 700 nanometer let us say.

The standard optical fiber, which is what the subject of this course is not the free space optical communication, but fiber optic communication. The standard single mode fiber has a minimum attenuation of minimum attenuation of around 0.15 to 0.2 dB per kilometer and this minimum attenuation band happens at almost twice the wavelength of the visible light right. So, visible light range is about 400 to 700 whereas, the minimum loss occurs at around 15 50 nanometer and about 100 nanometers of that range around 15 50 nanometer is what is conventionally used for long haul optical communication ok. Most fibers are designed to work at those wavelengths because, that is where the attenuation is small. You could technically take light from any of these light sources and then try to somehow put that one launch into the standard single mode optical fiber, but you would buy in doing so, encounter lot of losses ok. So, therefore, that is not very advisable for you to use the standard telecom fiber.

Because, standard telecom fiber not only has large attenuation at that point, but because it is designed to operate at 15 50 nanometer if you try to put invisible light into it modulated visible light let us say then, at that operating wavelength 400 to 700 nanometer this fiber will be heavily multimoded. Heavily multimoded means, the v number will be much higher than 2.4, in fact, it could be as high as about 20. And then the number of modes that would be present at that wavelength will be easily exceeding 100, which is not at all a good news for us because, we have seen that when you have multimode fibers information will be distorted by a mechanism called as intermodal dispersion ok.

So, it is not a good idea both from the dispersion point of view, as well as from the attenuation point of view to use the room light sources and try to launch it into the standard optical fiber communication system. In addition to these two problems, there is an important problem that the common light sources actually give you. That common problem is that of the diffraction problem ok. The light that comes from of you know light source such as a bulb or an incandescent bulb or a tube light is actually you know has a very large bandwidth, which of course, will again lead to dispersion problem and moreover this light is what is called as incoherent light ok. If you know a little bit of physics, then light emitted by these bulb sources are called as black body light sources or the radiation that comes out of these sources are called as black body radiation. Black body radiation as we know is quite wide, it is a flat radiation and it is highly you know non monochromatic, monochromatic means single wavelength and therefore, larger wavelength spacing I mean spread means that this is non monochromatic and most importantly it is not even coherent.

Coherent light sources are very important because, most of our detection or most of our communication system has to be over a long distance communication and we will be employing some interferometric techniques for detection at the receiver as we will study in part 3 and if you want interferometer then this in coherent light sources are poor choice; moreover their power is actually kind of spread over a wide wavelength and therefore, if you want to obtain higher power, in order to overcome the losses in the fiber then you have to lift the entire spectrum up, which means that the black body or the you know radiation that is coming out from the bulb or an or a tube light would have to be at substantially high you know operating temperature ok, something that we will not be able to work with because, you know it is simply not possible for us to generate temperatures that approximate the surface of a sun, which is what the numbers would actually tell you if you want to use that one for long haul communication.

So, these are the practical problems which means that we cannot use this simple light sources for conveying information. So, if I cannot use these light sources and I can use led's ok, but I am going to talk about led's later in the course. So, what is the other light source that we actually use, we use a light source called as LASER ok.

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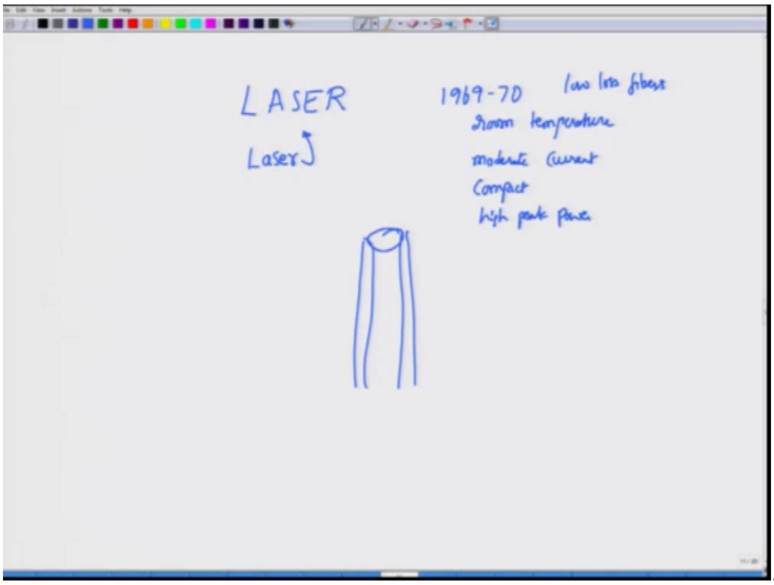

In the olden days LASER was an acronym that was you know, that was written out in this capital letter, but today you can see or you will see people writing laser because, it has now become a word, although originally, it was an acronym which stands for light amplification by stimulated emission of radiation.

The history of laser is something that is very interesting, I would not be able to deal with the history of the laser in this course, but what is important for our purposes is that we were able to obtain a light source in the year 1969 to 1970 ok. Light or lasers which could operate at room temperature requiring the current in a very moderate level so a few milliamperes of amount of current was sufficient and these light sources were also compact and this could produce reasonably high peak power and we could actually take these light source and then efficiently launch into the optical fiber ok.

So, during this time of 1969 70 is when we actually also got low loss optical fibers. So, both the fiber which is low loss, as the channel medium and the light source which is all these nice properties a semiconductor laser were kind of discovered almost at the same time and is very fortunate for us that they were discovered because, they could then combine these two to realize this huge optical network revolution. So, we are going to study lasers in the next module, starting in the next module

Thank you very much.