Optical Fiber Sensors
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Lecture 04
Optical Sensor System

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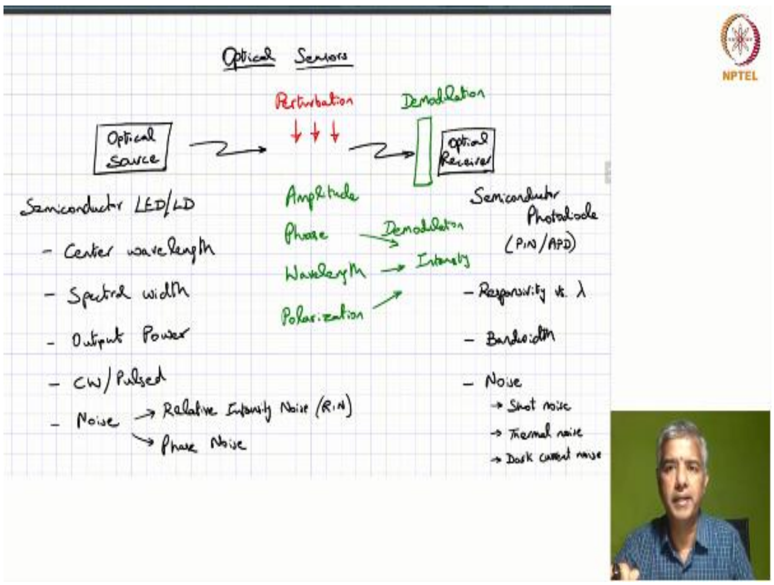

Hello friends, so far we have been looking at the overview of optical sensors through presentation mode, so I was actually trying to motivate you why optical sensors, specifically why optical fiber sensors and then we went on to look at different types of sensors amplitude, phase, polarization and wavelength modulated sensors and then we went on to look at a very unique type of sensor which is a distributed fiber sensor and we looked at examples of Raleigh, Raman and Braun scattering based sensors.

So, that hopefully gave you overview of what we are going to be discussing as far as this course is concerned, so it is time to actually move in and try to go into a little more depth on some of these topics, so that is what we are going to do today.

So, let us say we are looking at an optical sensor, we are looking to design an optical sensor, so where do you start? Well, you for any optical sensors you need an optical source. So, you draw a box here and say this is my optical source, so the question is what type of optical source would you pick? So, typically we see that for a lot of practical applications we need a very compact package, so you need a compact light source and from that perspective typically the optical sources tend to be semiconductor, LED or a laser diode.

So, we typically try to, you know use one of these sources, then the question is how do you characterize the source, so what are the typical characteristics that you would be interested in? So, clearly you need to start with what is the color of light that you are going to use for your sensor, so when you talk about color, the first thing that we are talking about is the center wavelength, so it could be say a blue colored light source or a red color light source or something in the infrared also maybe some applications require light in the mid infrared or real infrared, far infrared region as well.

So, the center wavelength is something that you need to start picking up right away and when you talk about the center wavelength, you also start looking at what should be the spectral width of your light source, so that is the other characteristic that you are interested in, what is the spectral width of your light source, so whether it is in the order of 100 nanometers, 10 nanometers, 1 nanometer maybe even down to a picometer for certain applications, now we talked about for example, Braun distributed sensors and we said we wanted to have close to a monochromatic light source for such an application.

So, maybe you want to have something in the order of a few picometers as your spectral width so but you need to define your spectral width. And then of course, you are also interested in how much power you have from the light source, so what is the output power from the light source, so that is something that we interested in if it is relatively short distance application where you are conserving the photons or you are localizing the photons and you are picking up photons with very high efficiency.

Maybe something the order of mill watts of light would be fine. But then, there may be applications where you need to shine the light over a very long region and then try to pick up whatever photons are backscattered from that region and in that case you may actually need very high power, maybe in the order of watts or maybe even more than that, so the output power is another characteristic that you would be interested in.

And along with that you would also want to know whether the light is going to be cw, continuous wave or it needs to be pulsed, so that is another property of the light source that you are interested in, whether it should be continuous wave light source or a pulsed light source.

And of course, you are also interested in since we are trying to do a measurement where signal to noise ratio is very important, so from that perspective you are also interested in the noise issues. So, what is the noise of your light source and when we talk about noise you can talk about two types of noise typically, one is called relative intensity noise or in short it is called RIN and there are certain applications where you are trying to pick up the changes in phase of the light and in that case the phase noise of the source imposes a fundamental limitation in your measurement.

So, in those sort of cases phase noise is also going to be quite important and of course, you can go on to talk about other sort of derived parameters to describe your light source. For example, you may want to look at the temporal coherence or spatial coherence of the light source, so temporal coherence corresponds to how narrow is your spectrum.

So, in certain way the temporal coherence is determined by the spectral width itself, so we do not have to define it separately but the spectral, sorry, the spatial coherence is something that you may have to define in certain applications where you say, is the light highly directional or whether it is going to be a diffuse light source.

Most of the applications that we are going to be looking at, we will look at fairly directional light source, so we are typically looking at light from a laser diode but even when we use a light emitting diode we try to capture part of that light which can actually be sent in a particular direction, so you are typically looking at fairly high spatial coherence. So, those are the typical characteristics of your light source.

Now, what is happening to that light source? Well, it is going to undergo a certain perturbation, so which is what we are trying to sense in our case so we have a certain level of perturbation and now we want to actually figure out what that perturbation, what is the magnitude of the perturbation, what type of perturbation it is and so on. So, we typically have to collect this light, this perturbed modulated light and then we send it to an optical receiver.

So, before we go into the characteristics of the optical receiver, let us just spend a little bit of time understanding what this perturbation does. Well, the perturbation could now cause changes in certain properties of the light, so it can generate changes in either the amplitude or the phase or the wavelength or the polarization of the light.

So, you may have changes in one of these properties of the light and if that is the case, if it is amplitude modulation then that is directly picked up by the optical receiver but if it is something like changes in phase or wavelength or polarization, we said the optical receiver which is typically a semiconductor photodiode is going to be agnostic to changes in phase wavelength of polarization.

So, in lot of these cases what you actually need to do is you cannot send it directly to the optical receiver, you may have to include a box here which does the demodulation. So, what is the demodulation we are doing? Well, we are essentially taking changes in phase, wavelength or polarization into changes in amplitude or the intensity of light. So, this is what we are talking about as this demodulation process. So, that is typically the scenario that we are looking at.

Now, let us look at the receiver. So, what should be the receiver that we use for these applications and what are the characteristics of the optical receiver that we are interested in. So, typically for the same reasons that I mentioned why we use a semiconductor LED or a laser diode, you also want to use a semiconductor photodiode.

So, a semiconductor photodiode at your receiver, at the front end of your receiver, so when we talk about semiconductor photodiodes it could be either a PIN photodiode or a avalanche photodiode. So, these are things that you might have learned in one of the basic optics courses, photonics courses before.

So, I am not going to go into too much detail about them but I will try to give you a little bit of background so that you can or more of a refresher about some of these photodiodes, what are the concepts related to that. But in terms of the properties of the photodiode, what are the properties that you are typically interested in?

Well, the first thing that you would be interested in is the responsivity. Responsivity as a function of wavelength which is typically expressed as lambda so, you want to know whether the photodiode is going to respond to visible light or near infrared light or a mid infrared light and so on.

So, what do you use if you want to capture say visible radiation, what type of photodiode would you use? It will be a material typically made out of silicon that is one of the most common elements that you use for capturing visible radiation. So, silicon has high responsivity for visible wavelengths.

Similarly, if you want to go to near infrared wavelengths, say 1 micron and above, then what photodiode would you, what material would you use? Well, the most popular material for those sort of applications, especially from a communications viewpoint is indium gallium arsenide.

So, each of these would have their own responsivity curves as a function of wavelength, so that is clearly one major aspect that characterizes these semiconductor photodiodes and the corresponding optical receiver. The other characteristic is your bandwidth, so what are we talking about as far as the bandwidth is concerned, we are looking at how fast the optical receiver can respond to incoming, to the changes in the incoming light.

So, if you want to capture events perturbations that are happening in a nanosecond time scale. For example, what sort of bandwidth would you need? Well, you take the inverse of that and you say roughly it is going to be requiring bandwidth in the order of gigahertz, whereas if you have events like typical strain or temperature events, these are, these tend to be relatively slower, so those are millisecond or even slower than that.

So, what is the bandwidth you need from your receiver to pick up that sort of slow changes? Well, you may not need much more than a kilohertz of bandwidth for that. So, bandwidth is another important characteristic that you would have to be vary about.

So, let us now say and of course, there is also another important characteristic of the optical receiver which is how sensitive your receiver is going to be, how well can you capture the modulated light and that is going to be limited by noise and when we talk about noise from a receiver context, you typically look at a short noise, so short noise which is because of the random arrival times of photons at the receiver, it is typically characterized by a Poisson process, those arrival times, so that actually causes certain noise at the receiver or the other typical noise that you get to see is thermal noise.

So, what is thermal noise? It is because of your resistors that you have in your optical receiver those do not actually allow propagation of the current or the flow of charges in a very uniform manner and because of that there could be some temporal changes in the current that is flowing through the resistor, so that which is what we characterize as thermal noise.

And of course, you could also have another noise term which is typically sometimes wrapped into the short noise itself, which is actually called the dark current noise. So, what is dark current noise? Even when no photons are falling on the semiconductor photodiode you may have thermally excited carriers electron hole pairs in your photodiode and that might actually give rise to certain current in your photodiode and that actually would be converted to a voltage and it will show up as some background noise in your measurement. So, dark current noise could be another thing that is very important.

So, we will come back and look at all these in a little more detail but before we do that, let us actually go in and try to understand what is happening as far as semiconductor light emitting diodes and semiconductor laser diodes are concerned.