**Indian Institute of Technology Kanpur**

**National Programme on Technology Enhanced Learning (NPTEL)**

**Course Title**
**Optical Communications**

**Week – I**
**Module – III**
**Digital Modulation-I**

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Hello and welcome in this short module we will learn digital modulation we will look at amplitude modulation or intensity modulation of optical signals and we will look at the simplest modulation in terms of phase called the binary phase shift keying so we will began by looking at the transfer characteristic.

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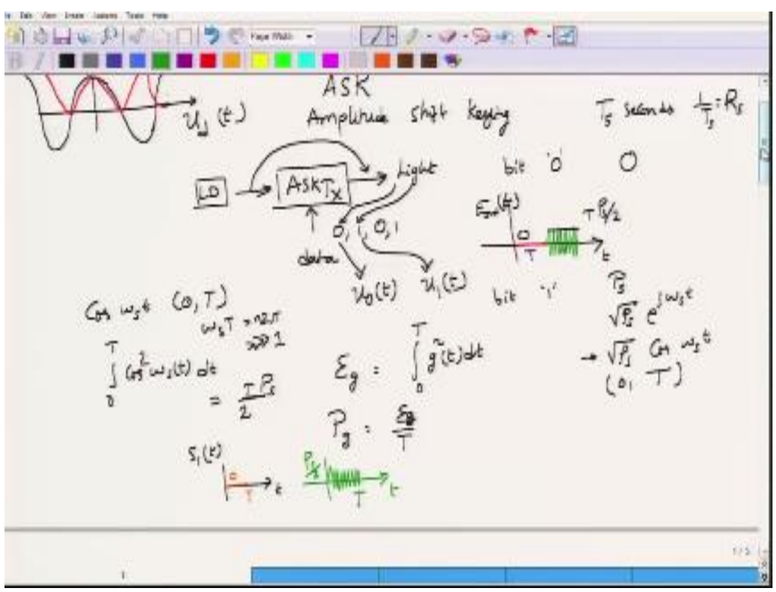

Which we called you know of the modulator that we studied earlier this modulator was the mach zehnder modulator and we know that the electric field input and the electric field output of this modulator was related by this cosine transfer function the electric field output to the electric field input of the modulator if I plot that against the different signal ud (t) that I was applying to mach zehnder modulator then you would see that there is a electric field relationship written in the black color this is the cosine form and the red one is the power transfer function which is the ratio of output power to input power as a function of ud(t).

We have already seen the use of this mach zehnder modulator to generate pulses optical pulses out of continuous wave optical input signals we will now look at how to implement basic digital modulation technique using this modulator the technique that we have mind is called amplitude shift keying so this A stands for the amplitude S stands for shift keying as I remarked in one of the earlier modules this shift keying you know is a older terminology for talking about digital modulation something that has been persisting even now.

So this ASK simply means that I have to switch my amplitude between two levels why two levels because to this ASK transmitter okay let us now functionally label this as ASK transmitter there is of course the optical source which is coming from the laser or the laser diode and then output would be the light wave which could be coupled or it will be processed further and then coupled to the fiber okay pulse shaping and everything as one of the other inputs to the ASK modulator is the message signal that you want to transmit.

This message signal will be in the form of 0’s and1’s okay this 0 and 1 is an abstract quantity but if I want, what I want to obtain is this light wave to represent 0 and this light wave to represent 1 this 0 and 1 is my information or data which is coming in as one of the inputs to the amplitude shift keying in a real transmitter this data would not be the form of 0, 1’s but this 0 would be represented by a wave form u0(t) this would be represented by the wave form u1(t) we will see how all these things are related in amplitude shift keying.

This is how we start we say that when the bit 0 arrives so this is how the bit 0 is there and at each of these simples last T seconds so the symbol rate is basically 1/T okay so this is the symbol rate which is denoted by this $R_s$ T is the duration of 1 symbol if you want you can also put a s here to indicate that this 1 symbol the inverse of this Ts or 1/Ts is called as the symbol rate and that is denoted by Rs here okay the mapping between that abstract data 0 or the abstract bit 0 and the corresponding light wave is that if I get a 0 then the laser light should be modulated or the laser light should be changed in such a way by this case get transmitter block in such a way that it produces a signal which has a peak power of 0 light wave, okay. Thus if I were to graph as a function of time a bit 0 is characterize by the laser light being blocked off for a duration if t seconds.

So this the duration t seconds and for this duration the light wave is simply blocked off and e out must be equal to 0 during this particular time, okay. When I get a bit 1 this bit 1 is characterize by sending an average optical power of Ps, okay. An average power of Ps is what we want to send in okay and this is equivalent of having an electric field of duration T but then having an amplitude of √Ps.

Remember that $E_{in}$ is actually given by √Ps x $e^{j\omega st}$ or equivalently in terms of its real value this is √Ps Cos $\omega_s$t correct, so this is the signal that I would like to transmit over the direction t, okay. So when I get a 1 I would be transmitting and remember that this ω is this quite large, okay. This is the electric filed remember electric field can be negative but if you want to look at the power then this power would essentially be a constant power because what you would be transmitting is the average power contained in this waveform, okay.

So we already know how to calculate this average power contained in this waveform because in the previous module we have learnt that if I have Cos $\omega_s$t which last a duration of t seconds and I assume that $\omega_s$t is either some multiple of 2Π or integral multiple of 2Π or the this is very larger compare to 1 then if I want to perform this integral in order to find out what is the energy contained in this.

Or what is the power contained in this I have to take this $Cos^2$ $\omega_s$t and integrate this fellow over dt, right? So this was what I have done and this would have given me d/2 in this case what signal I have is √Ps Cos $\omega_s$t which would last a duration of T seconds from say 0 to t and this fellow would be given by t x ps / 2, okay. So this is how I would be transmitting so when I have a bit 0 I will be transmitting 0 powers.

And when I have bit 1 I will be transmitting Tps/2 but this particular quantity which may have written is actually the energy of the signal, remember that the energy of the signal is given by s(t) if s is the signal then the energy is given by integrating $s^2(t)$ over the duration t, if I were to divide this energy Π time what I get is the power, so let us write down this as a different one, so let us use a different signal symbol.

Because we have already used s here, so let us say eg(t) where my signal is g(t) and this if I divide the energy of the signal g(t) by the duration t what I get is the power Pg so in this particular case I have two signals, one signal which will last from 0 to t, right? So this is your signal so we can call this signal as s 0(t) or will case this as s1(t), s1(t) is s signal which last for a duration t seconds and it is given by the value 0 whereas you have another signal which will last against the same duration t, but it has a power of $P_s/2$, okay this 2 because this is the average that you are calculating this is the average power that you are calculating, so therefore this is a $P_s/2$, okay.

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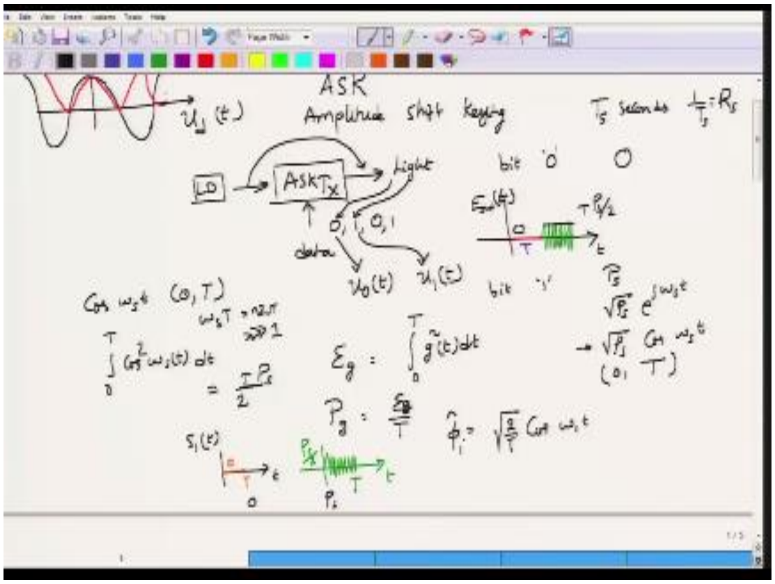


You can also define these two in terms of its peak power this would be peak power of 0, this would be peak power of $P_s$ okay, in some sense you can talk of this as 0 or $P_s$, okay. Now what is the geometric interpretation of this well, you have two signals here and incidentally these two signals can be defined by a single signal which is $\cos\omega_s t$ I also know that I have to do this division by 2/T as per the previous module I have to define this multiply this one by cos√2/T so that this would form $\phi S_1$, right if remember $S_1(t)$ was cosωt, in this case there is only one signal so let me just remove this S here and then call this as $\phi_1$, okay.

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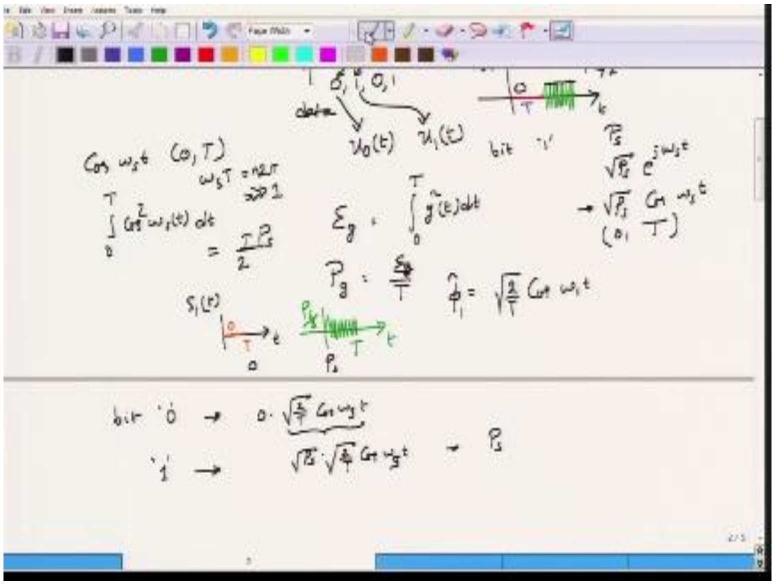

So with respect to $\phi_1$ I can represent bit 0 as $0.\sqrt{2/T}\cos\omega_1 t$ this is my vector having and magnitude of 0 and I have a vector 1 which can be defined as $\sqrt{P_s}\sqrt{2/T}\cos\omega_1 t$, so if I want to send this $\sqrt{P_s}$ signal change the amplitude of this signal $\sqrt{2/T}$. $\cos\omega_s t$ so this is $\cos\omega_s t$ by multiplying it by $\sqrt{P_s}$ I know that the power here would be $P_s$ because, this 2/T will get multiplied by T/2 when I take the power so that would be gone, okay or when I take the energy so that would be gone here, okay.

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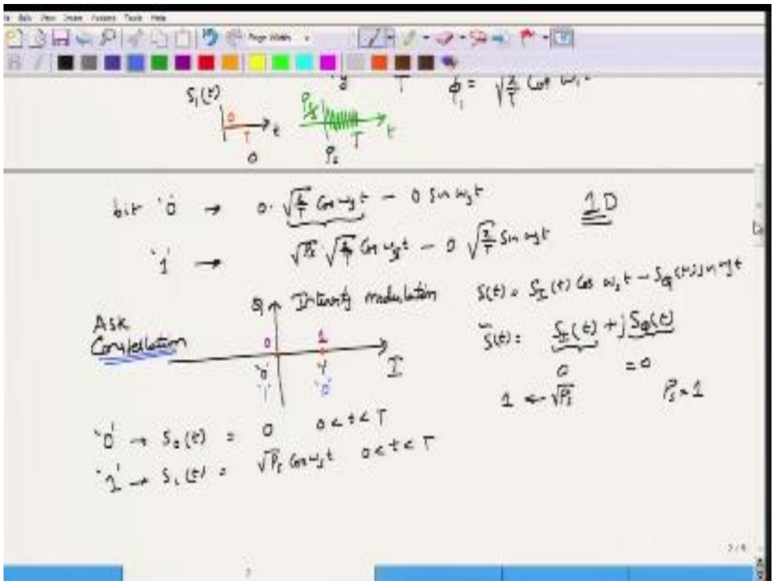


So if you are slightly confused do not be this what it means is that I have only one dimension that is sufficient for me to represent both bit 0 and 1, and if you look at in a slightly different way this signal that we have written can also be rewritten by writing 0 $\sin\omega_s t$ or and then also write down this as +0 -$\sin\omega_s t$, right because this is the real signal which I am writing so this can be written as -0$\sqrt{2/T}$ $\sin\omega_s t$, so it can be considered as a two dimensional vector except that the second value would always be equal to 0.

But since I have already written down the I and Q plains, right the corresponding I and Q values here that I have, remember if I have $S_I(t)$ $\cos\omega_s t$-$S_Q(t)$ $\sin\omega_s t$ as the real signal S(t) the I and Q in terms of I and Q the complex signal can be written as $S_I(t)$ so this would be $\bar{S}(t)$ which is a complex envelope on this one as $S_I(t)+jS_Q(t)$ and in this case $S_I(t)$ is constant $S_Q(t)$ is constant luckily for us $S_Q(t)=0$, $S_I(t)$ can take on two values 0 and $\sqrt{P_s}$.

If I normalize these signals by saying $P_s=1$, then $\sqrt{P_s}$ will become 1 and I can now represent bit 0 which is given by $S_I=0$ coordinate and bit 1 given by $S_I=1$ coordinate by writing two points here, so this would be my 0, this would be my bit 1, okay. So this is bit 0 this is bit 1, these are the actual values that I have used 1 and 0 okay so 1 maybe this is m/w 10m/w would correspond to the physical variables okay and if I do not really worry about what this m/w is then I can eliminate this units here okay but whatever that is there you have to distinguish between two points right one is that on this iq play and I have actually condensed two way forms one way from corresponds to 0 which is s0 of t which is actually 0.

For 0 less than t less than t and then s1 of t which you would be transmitting cause ωst which would last over another duration 0 to t so I have actually written down s0 of t which corresponds to bit 0 s1 of t which corresponds to bit 1 in this geometric representation by choosing this √2/t cause ωst as the unit signal so in terms of that signal this component is 0 this terms of that this should one so the coordinates of those in the iq coordinate plane is given by this 0 and 1 incidentally this is called as the amplitude shift keying constellation or simply the constellation corresponding to ask.

Okay so this amplitude is going from 0 and some value okay intensity is equivalently going from 0 and to some non zero value therefore this is also called as intensity modulation okay one final point I have arbitrary chosen to send 0 when I get a bit 0 and the 1 when I get a bit 1 I can switch around okay there is no harm I can consider this as bit 1 and this as bit 0 after all 0s and 1s are abstract what we associate with the way forms is something that is real this associate can be anyway that you please so you can choose 0 intensity value that is 0 m/w for example 0 power value.

0m/w power to bit 0 or bit 1 similarly say a 1m/w power to 0 bit or the 1 bit so this is all up to you this kind of representation of the way forms which are actually being transmitted to represent the corresponding bits that you are receiving in terms of some geometrical pattern in the iq plane is called as the constellation diagram let us move on from this intensity.

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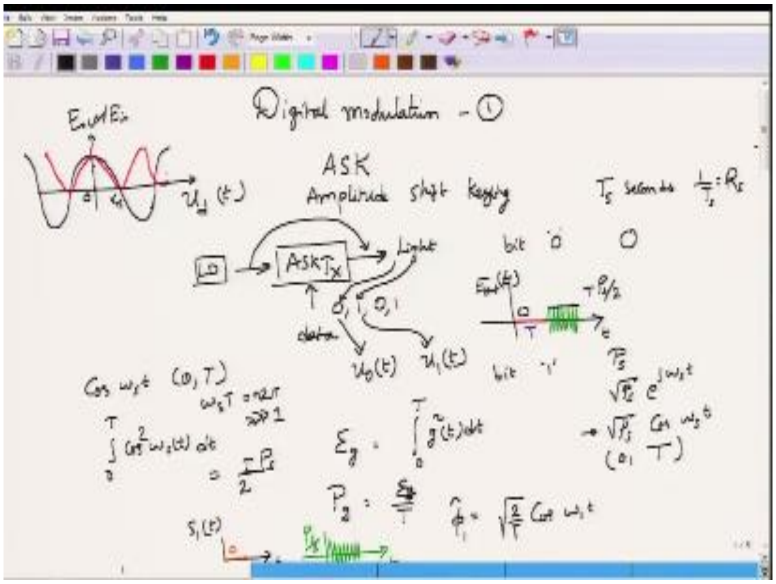


Modulation now before moving on let me ask you what should be the corresponding value in terms of the implementation of this one well we have already seen that one if my ud of t = VЛ then the mug center modulator output would be 0 when it is = 0 the Mach zehnder modulator output would be equal to 1 so if I want to actually realize this.

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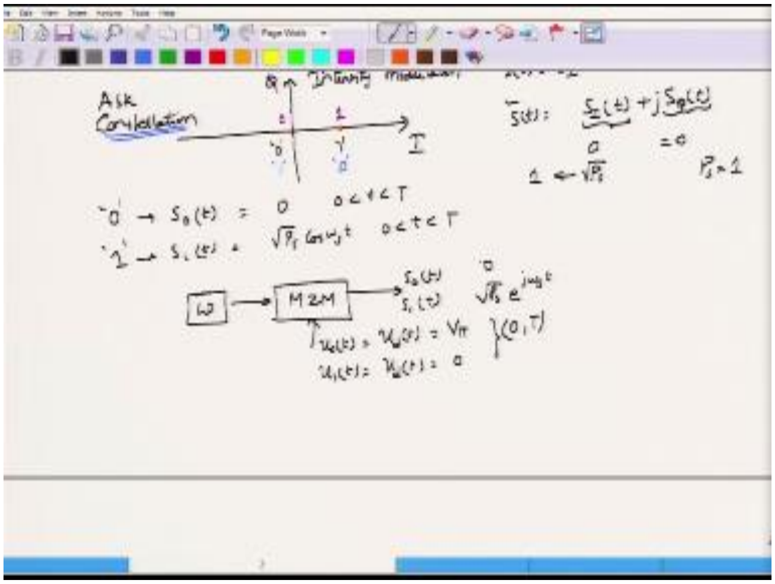

$S_0$ of t and s1 of t in terms of the you know in terms of Mach zehnder modulator then I take in light from the laser diode and then send u0 of t which is equal to the $u_d$ of t whatever that value it ud of t would take and this would be equal to 0 or u1 of t as $u_d$ of t which is the you know which is what ud of t should be when you want to transmit of bit one and this would be equal to VЛ and it could be equal to VЛ both over a duration 0 to t and what you get is s0 of t and s1 of t why should it be 0 and VЛ I have switch these two because I associated 0 with 0 right so I have to make this as VЛ and this as 0.

So when ud of t is 0 the Mach zehnder modulator will simply act like a at will be bias at the maximum transmission point and s1 of t will be equal to square root PS $e^{j\omega st}$ here it would be equal to 0 so this essentially what amplitude shift keying or intensity modulation is all about okay now let us move on to another simple modulation.

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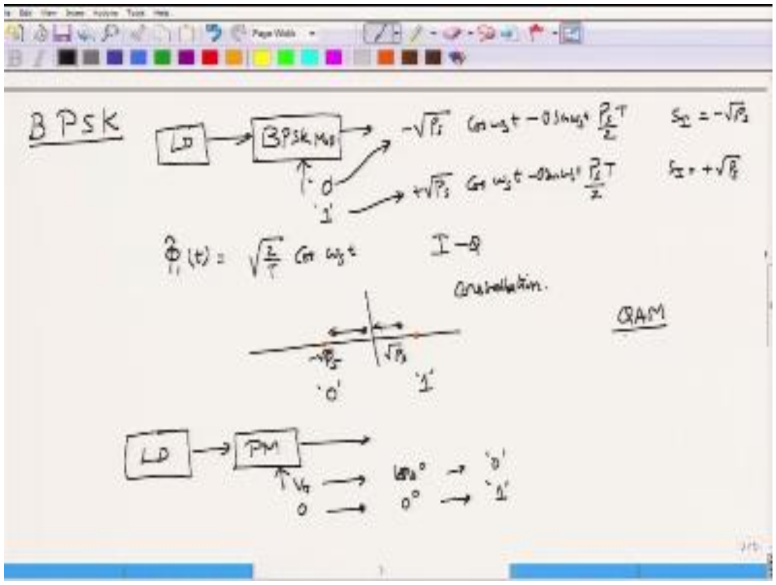


And we will stop at this point because we want to come back and then combine these two in the next module okay so in this module we will look at one of the simplest modulation in terms of the phase called as the binary phase shift keying the idea of BPSK is quite simple if I have a BPSK modulator or a BPSK transmitter I have to consider the light coming in from the laser divot, and I have to again have bits 0 and 1 I am denoting them with this quotation marks so I have to emphasize you that these are bits 0 and bit 1.

What is should get is if I get a bit 0 I should get $-\sqrt{p_s}$ cos **Ω** $s_t$ okay if I get a bit 1 my electric field output should be $+\sqrt{p_s}$ cos **Ω** st okay what is the corresponding energy is associated with these two to obtain the energies if you simply square them and integrate the over the time so that would be $p_s$ t/2 the same energy is associated with this $\sqrt{}$ $p_s$ cos **Ω** $s_t$ as well, however if I define $5_1$(t) which is which we have define as $\sqrt{2}$/t cos **Ω** $s_t$.

Then or equivalently in terms of the iq plan I can write this as 0 sin **Ω** st-0 sin **Ω** $s_t$ then I can easily see that corresponding to this $s_t$ should be equal to - $\sqrt{}$ $p_s$ corresponding to this the coordinate $s_i$ should be equal to $+\sqrt{}$ $p_s$ right so geometrically they are actually opposite of each other having the amplitude values of $\sqrt{p_s}$ and you know and the value here is $-\sqrt{ps}$ therefore the length of these two are essentially equal $p_s$ okay.

So in terms of the energy or in terms of the envelop nothing changes they are called as the constant envelop what will change is this particular phase, phase goes from $0^0$ sent $180^0$ remember we have define this has bit 0 and has bit 1 so this is your basic BPSK modulator how do I realize this optically you remember the phase modulator that we talked about in order to obtain $-\sqrt{p_s}$ what I have to do is to send in $V\pi$ if I have to obtain 0 phase shift send in 0.

So this $V\pi$ will be equal to – this $V\pi$ will give you phase shift of $180^0$ this would correspond to bit 0 this 0 will give you $0^0$ phase shift and this would correspond to bit 1 okay so this would be the realization of the BPSK modulator using optical means and this is the corresponding constellation for the BPSK signal we will now combine amplitude and phase shift in order to form what is called as the quadrature amplitude modulation and we will begin this discussion on quadrature amplitude modulation in the next module. Thank you very much.

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