Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Optical Communications

Week – III
Module – I
Digital Modulation-II

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Welcome to this course on optical communications in this module we will continue the discuss of optical transmitters we have looked at the representation of signals both in continuous time domain as well as we have introduced the geometrical view point of visualizing the signals in the last modules we will unutilized that theory here to discuss digital various digital optical modulation techniques the word optical is used because are talking about optical communication otherwise this material is essentially.

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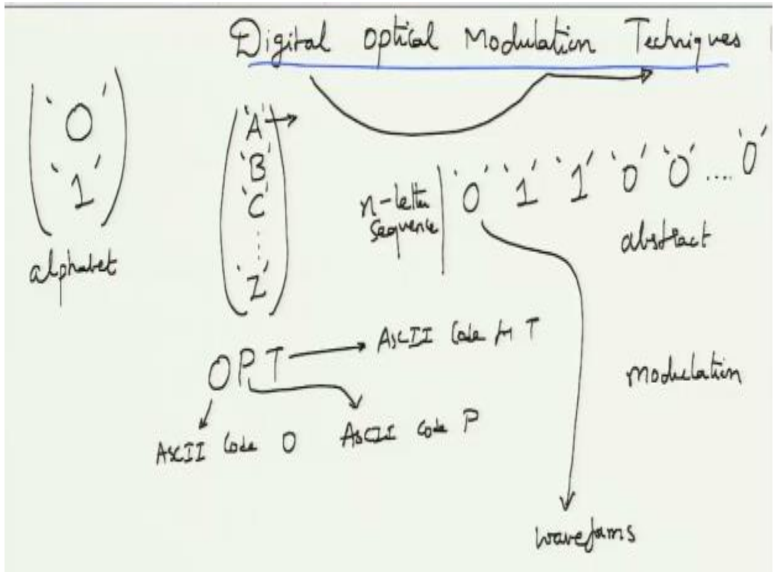

Digital modulation techniques now it is always possible or at least in most cases it is possible for us to communicate by means of digital data that is we can think of the simplest communication wave is that of communicating where symbols 0 and 1 so let us say for some reason some magical reason our alphabet is reduced to two symbols these symbols can be denoted as 0 and 1 so let us say I denote these symbols as 0 and I put this inverted comma here to show that this is the symbol this is not the number that I am representing this is the symbol okay.

And then 1 is a symbol I mean a familiar example would be the English alphabet you have in the English alphabet a total of 26 letters right so from A to Z similarly we have in our you know hypothetical source we have 2 letters o and 1 together with this, this forms an alphabet okay so this is not English alphabet this is some sort of a binary data alphabet which has two symbols 0 and 1 just like the regular English alphabet has 26 letters.

These letters are essentially those symbols A, B, C up to Z we do not put the inverted commas because we can of understand what alphabet and letters are so this is the analogy by which we want to proceed so we will assume that pour alphabet consists of 0 and 1 and whenever a transmitter communicate some information to the receiver it will communicate by sending a sequence of such symbol 0 and1 right so for example in some message this sequence of symbols might be 0, 1,1 0,0 and so on let us say the last symbol is 0.

This is let us say n such letters where used and since each of these letters we will eventually see that they can represented in terms of binary digits this is called as an n bit sequence or an n bit string okay of course it is not yet become a string it will become a string when we assign this 0 to the number 0 and 1 to number 1 okay so far this kind of a letter sequence so it is possible in most cases to reduce nay complicated information or any general kind of an information it could be speak for example it could be the video that you are actually viewing now right now.

It could be the text that someone as written so all these different kind of sources you know they are all coming from different sources they can eventually be represented or they can be represented by this sequence of 0’s and 1’s a familiar example is how do I represent this letter A in ASCII code ASCII code consists of 7 or about 8 I am not very sure but it consists of a sequence of 0’s and 1’s though number 0’s and1’s or the symbol 0’s and1’s which will then allow you write down all this different letters.

So if I want to send you know OPT from the transmitter to the receiver I will substitute this O with the corresponding ASCII code for O I will substitute here the corresponding ASCII code for P and here will be the ASCII code for T so I can substitute each letter which is actually originally in English by that particular sequence which is made up those 0’s and 1’s okay so in this way I can reduce in any information that I want to transmit into a sequence of binary symbols these are all the symbols these are the binary letters.

So we can reduce them to binary letters why do I call this as binary because there are only two possible letters so by corresponds to two so binary stands for 2 and there are these two symbols which are labeled as 0 and 1 okay now what we do is this is of course the letter this is how you would for example write on a piece of paper but if you want to transmit or you know on a computer you would type OPT and internally the computer converts this OPT into sequence of 0’s and 1’s.

But remember this sequence of 0’s and 1’s are just the symbols or they are the sequence of letters they are not the number they are not something that can be transmitted directly over the transmission medium for example I cannot take a symbol 0 and then transmit directly this symbol on the optical fiber I have to convert this 0's and 1's into an appropriate form that is suitable for transmission over the fiber channel, okay.

And this process of taking this symbols which are essentially abstract in nature and converting them into forms which are suitable for transmission over the fiber optical cable or in general any transmission medium is called as the modulation so you can think of modulation as some sort of a matching mechanism wherein the symbols which are abstract and they cannot be communicated directly over the channel are being matched to the form in which they are suitable for transmission over the channel, okay.

So this is the binary communication and what we will be looking at today is how can we consider this sequence of symbols and then come up with waveforms which will be transmitted over the fiber optic channel, okay.

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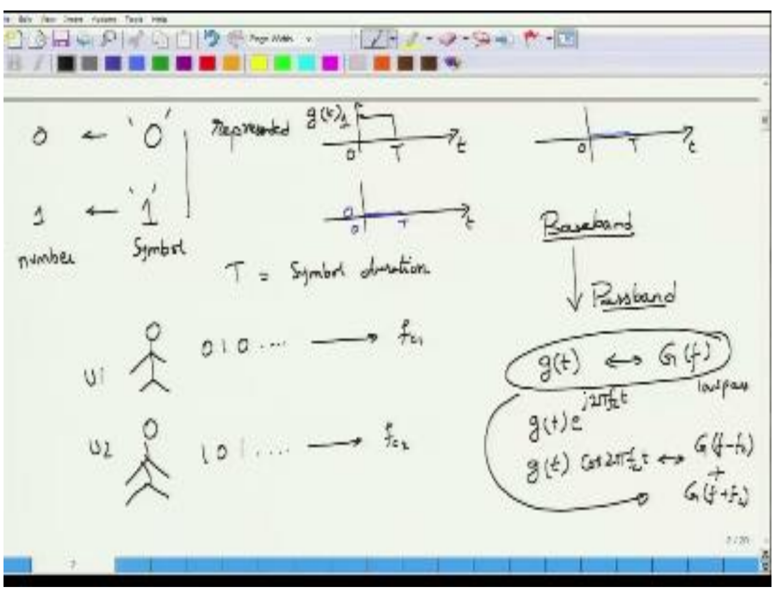

So to do that let us first give some waveform representation for the symbols, okay. So I have a symbol 0 and let us say I denote this one by sending a pulse an optical pulse for example of duration t seconds, okay. So this is the optical symbol so we do not have to name what this one this so or we want to name let us call this as some g(t) so this g(t) waveform actually having an amplitude let us say 1.

Will be transmitted over the optical cable, okay. So waveform g(t) would represent the symbol 0 so we say that this 0 is represented by this waveform so if you are someone who is looking at the time varying waveforms the moment you get this pulse you can say that Oh! The transmitter is trying to send a symbol 0 to me, okay. So this is how you would know the mapping from the symbol to waveform, okay.

So this mapping from symbol to waveform is of course is decided by you, you could for example go in the conventional way and say I do not want to transmit a pulse but I will transmit nothing during the duration for a duration of t seconds in order to represent the symbol 0, so this choice of whether transmitting a pulse or it the pulse need not even be of this shape because if someone might actually say I will transmit this pulse, right?

So the kind of waveform representation that you give for the symbols is determine entirely by you, of course you have to be consistent you cannot give the same waveform to represent two different symbols then there will be problem, right because you look at the waveform and you would not be able to tell whether you have transmitted a 0 or a 1, so you avoid that simple pit fall and you are completely free to choose whatever the waveform that you want to transmit.

So let us for simplicity set in this course or at least until this module at least call this rectangular pulse you know the pulse which is equal to 1 having an amplitude of 1 for a duration of T seconds as representing bit 0 or the symbol 0 and then this symbol 1 will be represented by transmitting nothing, okay. So we will represent 1 by transmitting an amplitude 0 over the duration of the symbol this 1, okay.

So this T which is the duration over which the waveform is representing a particular symbol is called as the symbol duration, okay. If this 0 is mapped to a binary digit that if numerical 0 and if the symbol 1 is mapped to a binary number 1 okay, so this is the symbol this is a number, okay to denote the difference between the symbol and a number I have used the inverted commas, so if we use 1 to denote the symbol 1 and 0 number to denote 0.

This 0 and 1 is the binary digit, okay. Each of them is called as a binary digit or short for bit, okay. So a bit 0 is represented by a waveform which is rectangular pulse having a duration T seconds and an amplitude of 1 and bit 1 is represented by an amplitude of 0 for a duration of T seconds, okay. So this is what my waveform representations look like, now these waveforms are they ready to go on the optical fiber?

Well not quite yet because we have these waveforms in what is called as the baseband domain, okay. In the baseband domain the frequency content is mainly concentrated at the 0 frequency, okay. But you want to transmit this symbols you know or this way forms over optical fiber what you would have to do you should transform this base band into what is called as pass band or band pass sometimes okay so you want to transmit this into pass band the immediate question who might ask is why should I do that there are various reasons first fall by transforming them into pass bands right you can along more than one user to transmit symbol in the optical fiber at a same time right so I have user one here who wants to transmit a sequence of 0 once and so on.

Remember now this is a bit sequence which I have written which means that you have to mentally substitute for each bit here the corresponding symbol that is shown here okay so there is user one and there is user two okay and both want to transmit information if the both are allow to transmitting the base band then the information gets jumbled up right you cannot separate them out rather than allowing such a possibility what you do and you got nothing what you do is you assign a certain a frequency to this person to attain another frequency to this person okay.

So to this person who is transmitting U1 you assign a frequency of fc1 to the person to you to you assign a frequency of fc2 that way you are allowing more than one user of course you can continue this provided that fc1 fc2 and all the other frequencies are sufficiently for apart okay, now the simplest way of transforming this base band into pass band is to recall a theorem in Fourier transforms right, if g of t is a signal which had a Fourier transform of g of f then if I multiply this g of t by $e^{j2Лfct}$ or equivalently by cos 2Лfct so this is a real way this is the complex way so if I multiply by.

Cos2Лfct you know that this has a Fourier transform components which will be centered at fc and – fc right, so this will result in the Fourier transform being centered at fc and – fc so clearly what you have done is to take this low pass signal okay or the base band signal and convert this into a pass band signal whose frequencies are now centered at plus fc and – fc is that okay right.

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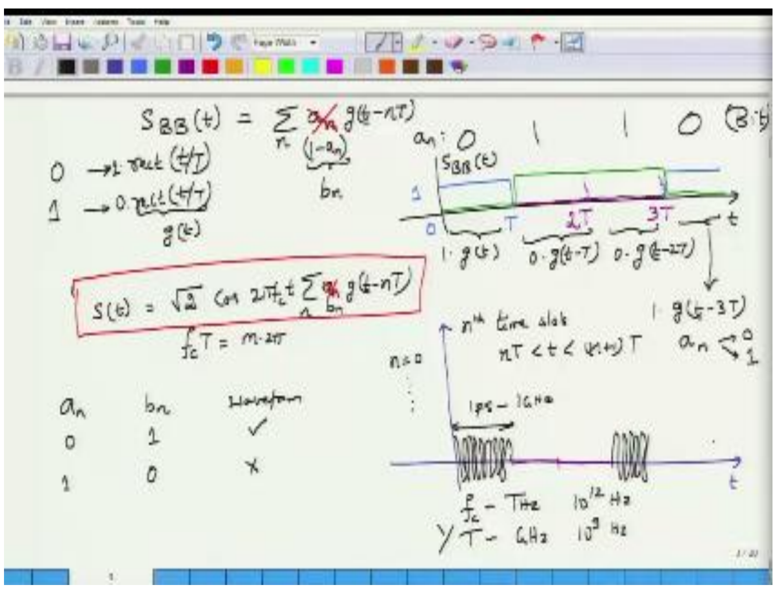

So we know that we have to transmit not in the base band but in the pass band but how can we even represent this signal this sequence that we are no someone is transforming how they are represent that sequence okay so I can represent that sequence by writing down the signal in the base band domain and I will call this as SBB of t this would represent the fact that a sequence of 0s and ones are being transmitted okay with the basic pulse shape of g of t right, if you go back to what this symbols are what this bits equivalently were represented by 0 was represented by a rectangular pulse of duration t seconds right.

One was represented by the same rectangular function of duration seconds except that it is amplitude was multiplied by 0 right. However for 0 the amplitude was multiplied by one so you have the same basic pulse shape this rectangular function of t by t is what we had called as g of t we will assume that this is the case for this module then if you have this g of t and multiplied is g of t by one your allow your transmitting bit 0 if you take g of t and multiplied by 0 amplitude become 0 and then your transmitting bit one or equivalently symbols 0 sense symbol one so how can I write down the sequence of symbols.

Well let us just consider a hypothetical sequence that has been transmitted or that we want to transmit 0 1 1 0 to transmit 0 at the beginning of the transmissions you might we will have to transmit a pulse of duration t seconds right it will last from 0 to t at the end of this pulse you have to begin transmitting the next pulse okay for the next bit the next bit will be 1 so where this bit ends the or this way from m the next way from starts which would represent bit 1 or symbol one and this will also last for a duration of 2t seconds.

Next you want to transmit one again so the amplitude for one is in our representation 0 so you simply continue although you know that this actually have ended the transmission for this symbol you continue this because the way form is the same way form for the next bit as well so it was o0 this pulse one this amplitude 0 next with also one therefore the amplitude to continue is to be 0 at the end of this starts from t and ends at 2t the symbol starts from t and ends at 2t the third symbol starts from T and ends at 2T the third symbol starts from 2T and ends at 3T.

These dotted lines are simply used to show the boundaries, okay they would not really exists as part of the wave form and finally when you want to transmit 0 you start the transmission at this point, right with an amplitude of 1. So what you have is essentially this signal g(t) and what about this signal, this signal will be 0.g(t)-T would that make sense, yes because g(t)-T corresponds to a signal which has shifted in time by t seconds, right.

And what about this third symbol that would be 0.g(t)-2T and finally the fourth symbol is basically 1 into, so let now also put a 1 up there, 1.g(t)-3T, okay of course they could be a sequence and that would never end in general you get the idea, right. In the n^{th} time slot, okay in the n^{th} time slot where n stand starts from 0 and goes all the way to the infinity the time durations are from n^T to $(n+1)T$, right.

You can check that this is true for this particular example, for example n=0 the time duration is from 0 to T which will then have the bit corresponding bit will be represented as say a_n, okay a_n can be 0 or it can be 1, right. So by this way you are actually able to represent this wave form so this would be the base band wave form that I have been transmitted and this base band wave form can be represented as a sequence of pulses, okay whose basic pulse shape is g(t) but then this basic pulse be shifted, shifted, shifted by every t seconds and at every time slot it gets multiplied the amplitude of g(t) gets multiplied by this sequence a_n, right.

So this is how would I represent the base band signal, but as I said I am not interested in the base band signal I am interested in the pass band signal, so for the pass band signal I will not use any subscript to denote the pass band signal and use s(t) this can be written as if you go back to the modules earlier we had shown how to represent the pass band signal, right. So you can represent this as $\sqrt{2} \cos 2\pi f_c t$ this would be the carrier and this $\sqrt{2}$ is used just for normalization purposes, okay to normalize the energy of pass band signal as well it is complex envelope representation something that we covered in the previous module.

So this is the basic carrier and then to this basic carrier you need to multiply this pulse sequence, okay and there is a relationship that you have to satisfy with respect to f_c and t you want f_c and t to be some multiple of 2π, is that okay. So this would be my pass band signal s(t) you can see that the sequence a_n, right multiplying the time shifted pulses g(t) will determine the overall envelope of the signal, right. If you actually look at how the signal would look like you know if this for example would represent a voltage signal, okay or it could represent the electric field coming out of the optical transmitter, right.

It would be this one, so you will have for you know initially because a_n for the same sequence 0110 you will have a fast varying carrier wave form then followed by 0, followed by another 0 then again you will have the fast varying wave form, of course you have to understand that this cycles which I am showing would not even be visible if you were to kind of measure the electric field which you will not be able to, but if you were able to measure the electric field you would not be able to see the cycles, because the frequency for optical communication is around tetra Hz, okay which is 10^{12} Hz.

Whereas the time durations are typically in the order of time durations or equivalently the data rate is in the order of about say giga Hz, so there is giga Hz is 10^{9} Hz, so which means that in this time slot if you assume that this is 1 Pico second corresponding to 1 giga Hz, right there would be about 1000 cycles here so you would not be able to even see this particular carrier cycles. I have used it just to show a kind of an excoriated version of this, okay.

So coming back you now have a equation for base band signal s(t) and what you can observe here is that the amplitude of the carrier is getting changed or it is getting modulated by the sequence a and this rectangular pelf g(t) correct more importantly when a n =0 you have a carrier full carrier field and when a n = 1 you have the carrier frequency and when an = 0 you have nothing right or we have taken the convention that a bit 0 would represent a non 0 signal.

Right so when an = 0 I do not want the amplitude of the signal to go to 0 but rather I want the way form to be present so I cannot directly if I call this sequence as an then I cannot directly use an her right rather than that I should be using so her I will make a correction to this what I should be using is 1-an so that when an = 0 the amplitude $1 – a_n = 1$ and that gets multiplied to the pull shape and you get this sequence form 0 to t.

And when an=1 bit a_n=1 1-1 will be 0 and then you put the representing the bit 1 okay so there is couple of points that you have to remember the bit or the symbols are 0110 and the corresponding amplitude are 100 and 1 okay this was a convention which I have followed in this module you can of course follow the more natural convention that when an= 0 the amplitude of the pulse will be 9 and when an= 1 the pulse will be equal to 1 okay.

In that case you will get signal which would look like this it would be 0 here followed by a 1 1 and a 0 the reason why I have flume to have chosen have very different kind of a way to represent this signal is because in the optical transmitter is natural to realize a 0 to a signal and 1 2 no signal okay so for that reason I have use this format but you are free to inter change the format as well as what you want.

So going back to this one 1-an is again a sequence so when an = 0 1-a_n will be 1 when an =1 this 1-a_n will be equal to 0 so I can very well call this as some b_n right so in place of an and now going to use the sequence b_n so let me make that substitution her as well I will be using b_n what is the nature of b_n when an is = 0 b_n =1 and this corresponds to in the way from being present. Whereas when an =1 remember these are the bit sequences of the symbol sequence b_n will be 0 and way form will be absent okay. So that put correspond to the notation that we have been so fare using.

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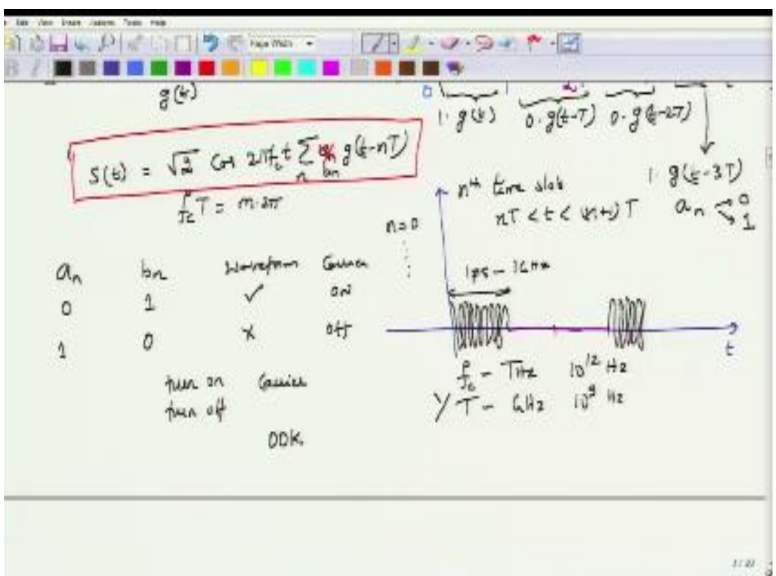

So I can write down the pass bands signal s(t) as the carrier that is getting multiplies by a number or a sequence b_n for every n^{th} times lot this carrier gets multiplied by this number b_n and this b_n decide whether the carrier has to turned on turned off so in a sense what you are doing is with this b_n you are turning on or turning off the carrier right the carrier being $\sqrt{2}\cos 2\pi f_c t$.

So you are choosing to turn on or turn off depending on b_n =1 or 0 here carrier will be on carrier will be off in some sense right it is kind of a switch you are taking and then doing enough turning a switch on and turning the switch off you turn the switch on carrier will be connected to the input line y turning the switch off the carrier will be disconnected to the output line to the fiber line such a modulation technique in which the carrier will inform abruptly changes from on to off, is called as on off keying, because the amplitude is the one changing, the amplitude G(t) or equivalently this square root of 2 cos 2лft is getting changed to 1 or 0 or root 2 and 0, because this amplitude is the one which is shifted, this kind of a modulation is also called as amplitude shift keying.

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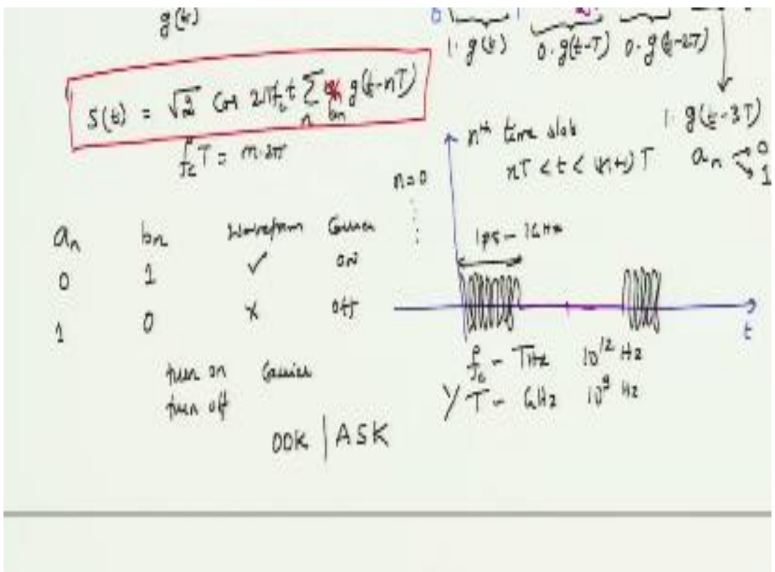

The keying should tell you know, the key is kind of a thing, piano kind of a thing so you press that key down, your connecting the switch and the input carrier is connected to the output line, you remove your hand from the key the switch is disconnected and the carrier is turned off from the connection between carrier 2 and output line. So this is the so called on off keying or the amplitude shift keying, modulation formats, so these are the modulation formats, called on off keying or amplitude shift keying.

You can think of this on off keying and amplitude shift keying as a general transmission, as a general amplitude modulation, modulation is basically changing the characteristic of the carrier in order to represent the data. In our case data is a bit sequence 0 or 1, so for 0 you will give some amplitude, for 1 you give some amplitude, so essentially you do amplitude modulation. In general it is the waveforms that you want to communicate, ok this the waveform that you want to communicate.

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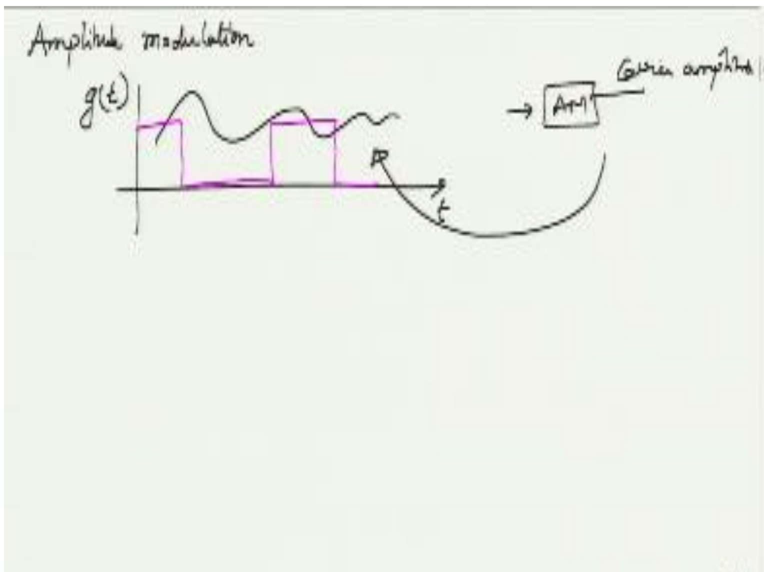

Call this waveform as some G(t), this would then be given to a optimal Am transmitter whose carrier output or carrier amplitude will be changed according to this signal, o instead of having any general variation, our digital modulation have a very strict variation of zeros and 1's. So that's all the connection between the amplitude modulation and Ask, ASK is kind of general or a special case of amplitude modulation.

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