Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Optical Communications

Week – IX
Module-I
Optical communication:-Pulse shape & BW

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Hello and welcome to the moke on optical communications. In this module we will discuss pulse shape and bandwidth issues. Before we talk about pulse shape and bandwidth issue, let us pause a little bit to consider where the data for optical communications come from, you know data might originate from various places. For example, what I am speaking is speech and this speech if it has to be transmitted for example, you are viewing this video, lecture on a video on you tube channel.

So before this you were able to view this channel, the speech that was coming out of my mouth which, you know represents the pressure wave form or the acoustic wave form, because of the varying pressures in my throat the corresponding acoustic wave forms would come out and this acoustic wave forms the pattern of which would be the speech wave form. So this entire lecture is one speech wave form which is more or less a continuous function of time and this wave form had to be first converted into an electrical form.

Because you are going to use an electrical wave forms such as a current wave form or a voltage wave form that would capture whatever the speech that I am speaking right. So it would essentially also be a wave form that would typically be continuous in time, but its modulation, its changes would actually be the same as the speech wave form that I am presently for example trying to communicate to you okay.

So this electrical wave form will be the input to the optical modulator right, the optical modulator does not accept unfortunately just a speech wave form. So I cannot just take an optical fiber, you know for example, if this is an optical fiber I cannot say, take this and say my name is so and so please transmit this message, the optical fiber refuses to acknowledge that.

So what the optical fiber recognizes is light and we have to change light in such a way that the changes in the light wave form will, you know in some way represent what the speech wave form is. So this process of making the carrier and one of the parameters of the carrier to change in accordance with what the message signal is, is called the modulation process. It is kind of used as a matching thing, you know my voice is not matched to the optical fiber, but the light is matched with the optical fiber.

So I take light from a, you know DFB laser and then I will modulate the light wave form using the speech as the source. But speech being an acoustic wave form cannot directly modulate there I cannot use it directly to the optical modulators or at least not the ones that we have covered in this course. So what we have to do is to convert this speech wave form into electrical wave form. Consider a different type of communication.

For example, you want to communicate to your friend a certain message on whatsapp okay. So this message that you want to communicate is you were to type that message, the message as you type is actually a sequence of sentences or something, you know sequence of words which form sentences and sentences presumably have some meaning to them okay. Where are these words coming from, assuming that all of us are using only English as the communicating language.

Then these words are coming from the English language and what is so characteristic of the English language or in general any language, a language has a set of, I mean letters which form a alphabet. For example, English has 26 letters, A, B, C all the way up to Z forming the alphabet. Different language maybe the language that you speak at home which may not be English will have a different set of letters okay.

However, the goal of each of these language is to communicate information and how do we do that.

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For example, in English we start maybe, you know for example we start with letter M, with the letter M which is one of the letters that has been taken from the English alphabet, the next letter would have to follow this letter M will form a word. So group of letters form a word, a group of words form a sentence, that is how we construct even in our languages which is not English, this is how we typically construct.

Sometimes in our language we have the ability to take multiple letters and form a single letter out of that one okay, or we will, you know use this individual letters as in when we are forming sentences using English.

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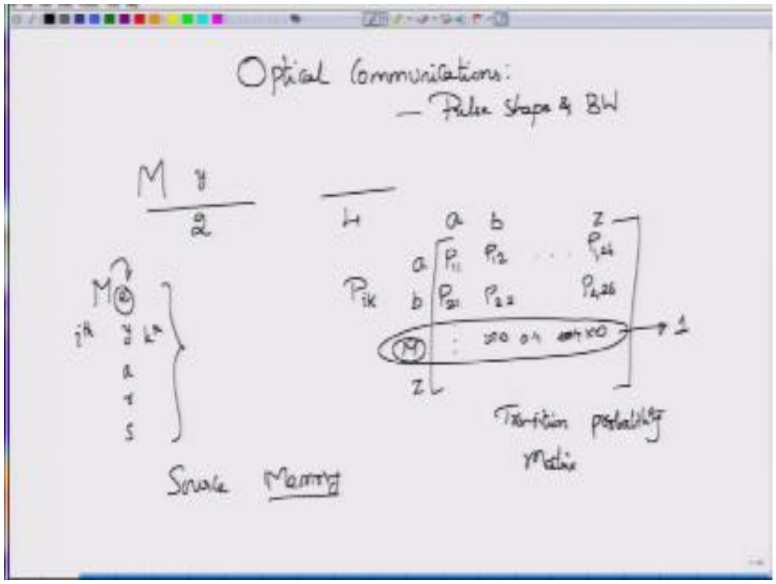

So let us say I am told or you are told that the first word is a two letter word, the second word is a four letter word okay. So once you have put down the first letter M right, then the chances for the second letter to be one of the 26 letters is now distributed according to a probability. In fact even the first letter is a probabilistic occurrence, you know I do not know what the first letter of the message that I am receiving.

However, once I receive and I have some knowledge about the word length or the length of the word then if it is a two letter word and if I know what the letter M is then there exists a certain probability for the letter a for the letter b for the letter c and all the way you to the letter z some letters are more likely to occur some letters are less lightly occur.

For example you might more or less rule out this M followed by a Z it is kind of not very common occurrence so I can rule out this similarly I can rule out this M followed by b usually it is not you know does not really make sense M a could be legitimate sentence so you might want to keep that one you can try other letters you can try for example y forming My right so that has a certain probability for it so if you form all the two letter words that began with M in the English language you will see Me My you know Ma could also be another letter.

You probably see Mr as in a short from for mister you might also see s as short form for s so once you have fixed the letter the next letter there is a certain probability for these letters to occur okay we call this so if this instead of occurring at the beginning it had occurred at the i^{th} position and the next one is the i+1 or the k^{th} position we can actually form a transition probability Pik okay and then we can actually look at the we can construct a matrix which tells you that if I start with a and the next letter to be a for a 2 letter word I am constructing this one of course for 3 letter word I have to construct a different matrix right.

Similarly for an n letter word I have construct a different matrix all together for a 2 letter word these are the transmission that I am looking for a to a there is a transmission which we can call as P_{11} a to b there is a transmission which we call as P_{12} and so on all the way to z and z happens to be the 26 letter so you have P1, 26 similarly you start with b you can construct a matrix which we would say P21, P22 all the way to P to 26 and so on for all the letters up to z this is the transition probability matrix what it simply means is that if you start with a two 2 letter word okay.

Such as the letter M some where it would appear here right so if you start with a letter M then the probabilities for these words would be high the probability of these transmissions would be pretty high where as transmission of M x z might be very nearly 0 right probability of M x a might be some number M x b might again be very nearly 0 M x y might be pretty high probability so may be about say it occurs point 4 times where as Me might occur point 4 times so the in a way you once you fix the letter M in a two letter word the next letters will all be according to a certain probability right.

So to properly capture this and you can of course also absorb that the sum of these probabilities should be equal to1 because if you start with M and it is a 2 letter word next letter as to be something from 1a to z right so this process in which or this kind of us behavior in which the letter of occurrence depends on the previous letter if it is a 2 letter or it might depend on previous 2 letters it might depend on previous 2 letters in general it may depend on pervious n letters we have to model this characteristic of the dependents of the pervious letters to pervious letter by modeling the source of this information as a memory source okay.

Sometimes this is called as mark of model okay where in the mark of source represents the dependencies and these transmission probabilities will all come into picture but even if you where to not get into all the details of this source modeling and this is really a subject on it is own.

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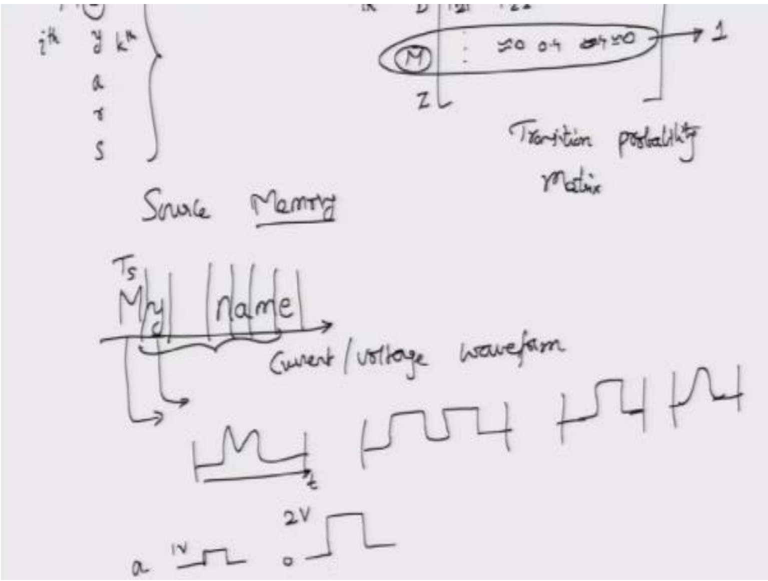

Which is very important what you have just realized is that if I take a word so which would say my name this phrase which is there right this is nothing to do with optical right this my name exists weather it is optical wireless weather it is communication by anything if the transmitter and receiver are pretty close to each other then my name can be congaed over the channeled by shouting across.

So I shout the pressure variations on my through will now generate acoustic waves form these acoustic waves forms will travel to the listener the liners ear will interpreted that is how I will be able to communicate the problem is that sender and receiver are not close by they are connected by an optical fiber of course they are connected by an optical network by we will assume that they are connected by an optical fiber you know not the elements which go through the network.

So how do we convert this first of all I cannot take my name and then try to modulate the optical transmitter I cannot, right. Because this is an English and modulator does not understand English, so I have to convert this into a current or a voltage waveform, okay in order to do that one I have to specify waveforms corresponding to each of these letters that are occurring, so for example if M might be specified by a waveform that looks like this, why might be specified by a waveform that would look like this okay and N might be considered as a waveform A might be considered as another waveform.

So I can do this, this is one arbitrary way of setting up the waveforms I can also do this, A might be of 1 volt know I am now going to the voltage representation these could for example be current and this entire duration might be representing one letter, okay so this entire duration represents one letter and let us assume that these durations are all going to be the same, so the durations of each letter in this representation is all going to be the same.

And if you imagine there is a time access running through this then the first letter M was typed then letter YY was typed there is a space then N, A, M and E if you call each unit as some Ts unit so you can have any kind of a waveform representation the simplest requirement that the waveform has to satisfy is that the waveform have to be unique, you cannot have a single waveform representing two different letters.

Then it would not really match correctly you cannot reconvert the waveforms into symbols so you can do symbol to waveform but you cannot do the waveform to symbol okay you cannot de-map is as been call, so you have to choose that know you take that criteria then you can choose this waveform to represent A you can choose a 2 volt to represent B similarly if you come up to the end you know then you will be choosing a 26 volt to represent Z, okay.

This might be possible the only thing is there are so many levels and you are electrical circuit will really be complicated while it is trying to generate this multiple levels, okay. So this is not something that is efficient so here is a second characteristic you want to choose the representations which are efficient and easy to generate, the universally accepted you know technique to transmit information is in digital optical communications is to convert.

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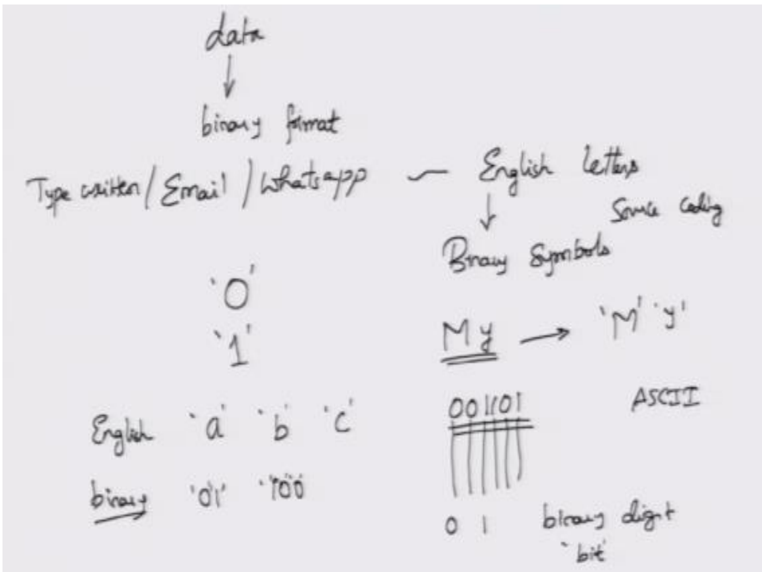

Every known form of the data into binary format okay, the type return sheet or the email that I would write or the message that I am going to type on a what's app application they are all in English assuming that this is the language that we are working with there all in English there are sequence of letters that are coming out but these symbols so these are English letters these letters will have to be converted into binary you know format.

So we call this as binary symbols, okay. The primary binary symbols are symbol 0 and symbol 1 so I am putting this inverted comma or codes to indicate that these are symbols these are not numbers, this is not a 0 number this is not a 1 number this is actually 0 symbol a 1 symbol there has abstract as the English letters, okay. If you technically want to write this one either where it My should be written as the symbol M and the symbol y in much of the same way we have written 0 and 1.

Now what the source coding does for us is that when this conversion from English letters to binary symbols happen each letter in the English alphabet or each knows in the letter in the English alphabet will be represented by a group of binary symbols, okay.

May be you can call this as a symbol a group of symbol or a warred or something like that, okay. So the binary representation for this A might for example include symbol0, symbol 1 in sequence, okay. For B it might be 100 okay please note that these are not efficient these are not the way in which actually you would be doing the source coding I am just giving you an example of how you might do it, okay.

These are not very efficient at all this process of going is called source coding and this is something that is a very important subjecting communication theory all together we are just giving the idea of what goes on here. So you start with English letters and then you get to binary symbols, now My might have a binary symbol representation of this one, okay it need not be this but just taking an example, if you want to be little more technical you can try a ASCII code or something these are efficient representation or they are good representation not a very efficient representation out there.

So this My which was in English has now been converted into a group of binary symbols, okay it turns out that these binary symbols can also be made into binary digits, okay a 0 symbol can be a 0 binary digit, 1 symbol can be a I binary digit, okay. This binary digit is in short called bit, okay so eventually what you have done is to take the data.

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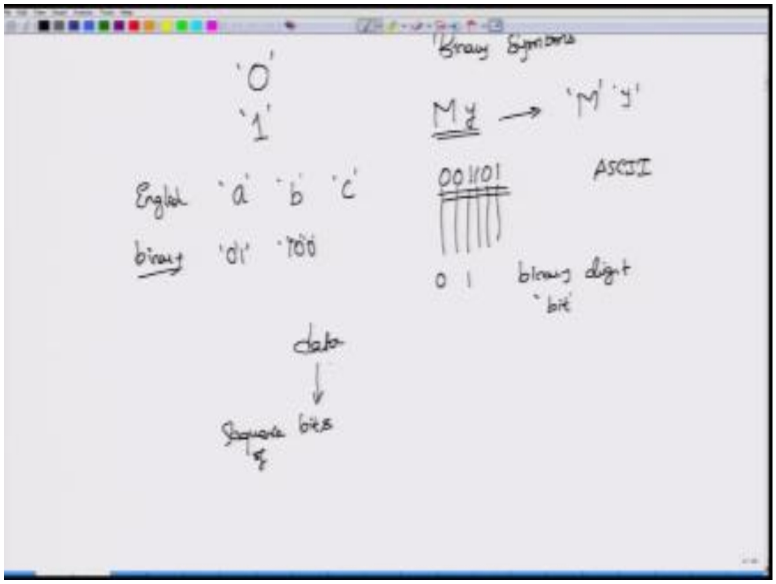

And then convert the data into bits or sequence of bits, okay sequence of bits form a symbol, right. There is one aspect which will left out, we said that speech wave form is a wave form but that would be converted into a current or a voltage waveform, right.

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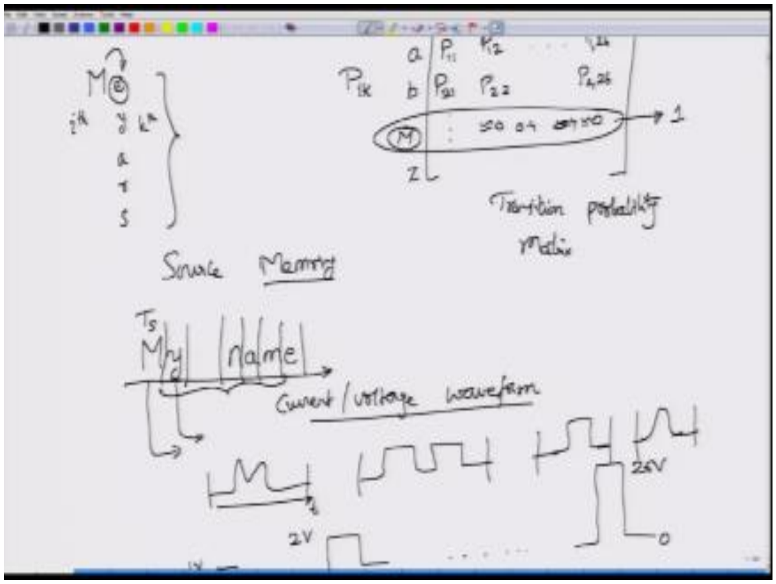

So if this was the speech waveform that has to converted into a current or voltage waveform, if this is not a speech waveform but this is just something that you have written here or it could be an image then that has to be first converted into a current or the voltage waveform, right. So there are certain devices which perform this conversion of non electrical data.

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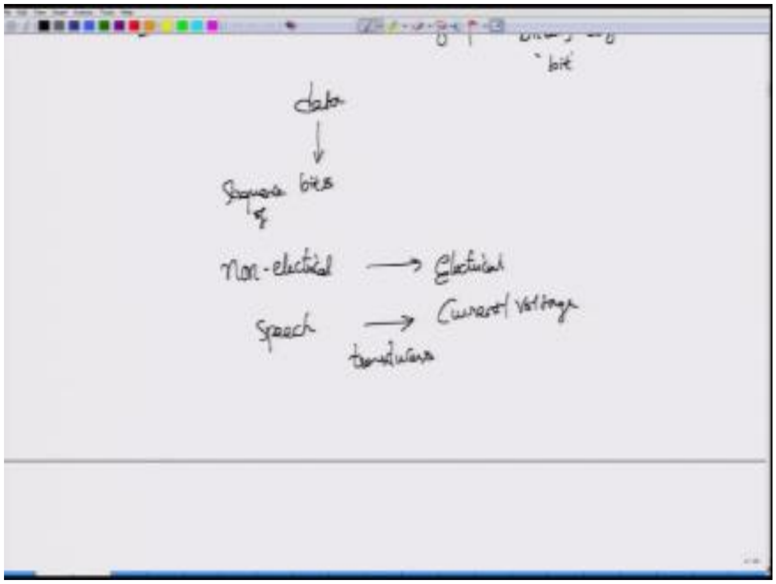

That is non electrical format to electrical format, okay for example the speech signals or the speech waveforms will be converted into current or voltage by appropriate transducers, okay so you find an appropriate transducer to connect I mean convert a speech or a current, speech into current or voltage waveform, okay. However, if you are looking at a message on the text then would be internally converted into a group of symbols, okay that is also non electrical but there is again the type that you are going to press the switch will activate a certain waveform which will then be a representation of what you have typed, okay.

So there are without going into details that also is non electrical but that is converted into electrical form, okay.

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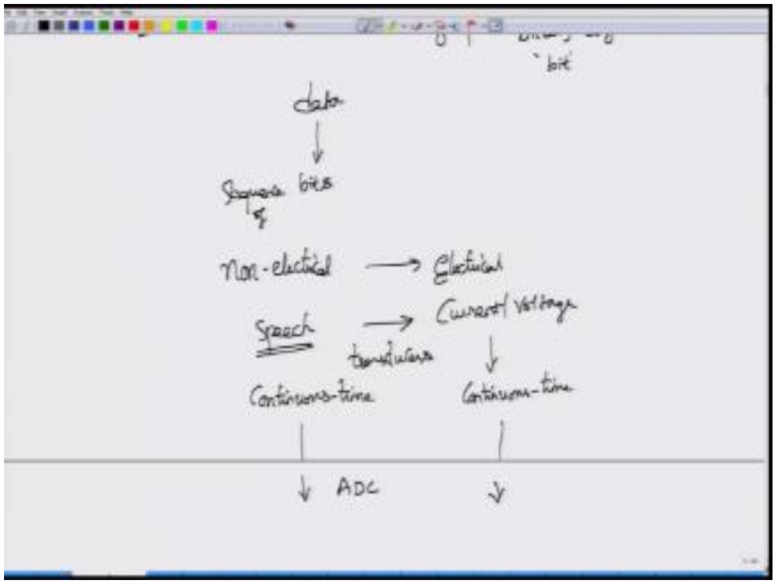

One difference is that a speech signal is inherently continuous time signal, okay which means that it has a value for every time variable, okay it is a kind of continuous in time and the corresponding conversion is also continuous in time. But you want to capture a discrete time version of this, okay so you convert this continuous time signals into discrete time signals by a process known as sampling which is usually implemented by an analog to digital convertor.

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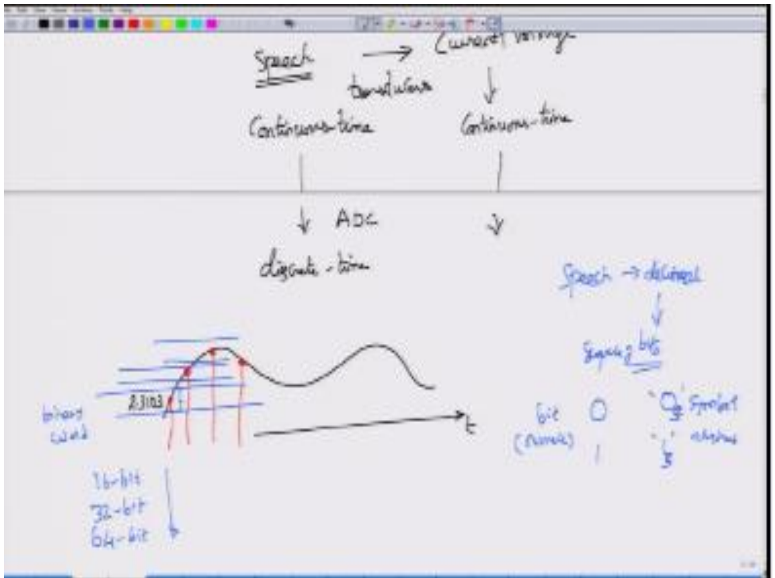

So an analog to digital convertor samples the continuous time waveforms and generates a discrete time waveform, okay an example would be let us say this is the speech signal or this is some other signal which is varying continuously with time what analog to digital convertor does is, it looks at this sample value, right records it, looks at this sample value records it, it samples here records the value, samples here and records the value and so on.

However, these are actually numbers they can be any number so this for example could be 2.3103 in the decimal format this could be the number. However, what we do is we consider certain ranges, okay we consider a certain r5ange and then so we divide this one and then consider a certain ranges and if the sample value falls anywhere within that we associate a binary word to it, okay so we associate a binary word to it.

The length of the binary word which determines that so called quantization levels, okay is dependent on the ADC you can have a 16 bit word, you can have a 32 bit word, you can have a 64 word, okay with the increasing number of bits you are better able to represent this decimal numbers, okay. So you actually have a speech waveform converted into decimal numbers and this decimal numbers are converted in turn into bits or sequence of bits or binary words, okay.

We unfortunately use the same symbols for bits which is 0 and 1 as the same symbol for symbols 0 and 1 as well.

So this is the symbol here, okay whereas this is a bit, this is the binary digit, this is numeric while this one is more or less abstract a symbol of course we would have been better to take this 0 and 1 as say 0z and 1z and then this would have been sorry 1s and 0s maybe to just indicate that these are symbols but eventually symbols have 1 to 1 representation with the bits. So we simply call both of them as bits itself okay.

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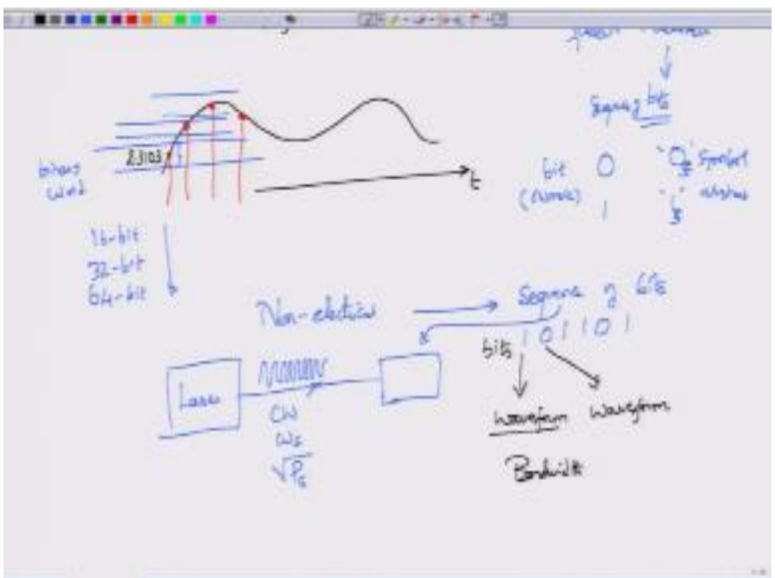

So that is the goal of the source coding problem so any non electrical data will be eventually converted in to sequence of bits has our problem have been solved yet unfortunately our problem is not yet been solved why is that our problem has not been solved yet well go back to the optical transmitter you have a laser here okay which is producing nicely a continuous wave signal of frequency Ωs having a certain amplitudes √Ps.

So this is nice carrier with a very high frequency up there but then you have to modulate this carrier right you have to modulate the carrier according to some data and this data in this time is actually a sequence of bits so let say the sequence of bits is 101101 how do I know take this sequence of the bits which are still even though they might be number but I cannot do just numbers and then modulate an optical transmitter right for that I have to do an interesting thing I have to represent this one by a wave form okay.

And represent this 0 by a wave form okay so I have to represent the bits in to wave form and this process you know is the bit to wave form conversion and here is where we are going at the pulse shape because the way you convert bits in to wave forms has a tremendous effect on the band width of the system what would be the band width of the system okay so you chose your wave forms efficiently such that you are well within the bandwidth that is magnate by the regulation.

So if the regulation say that you cannot use more than 50gHz band width all your optical energy must be within that 50gHz band width okay if your outside then you are not just interfering with the next band you might also have a commercial penalty you know you might also have a penalty for going over your band so if you have been allotted a 50gHz band you better chose pulse shape such that the optical energy at least in 99% of the optical energy 90% of the optical energy as regulated by the regulation regulator commissions you have to have all the energy within that okay.

Of course unfortunately there is no universal definition of a band width I just said 99% could be a cut of 90%could be cut of some other commissioner might come and say no I do not like 99 I do not like 90 let me make 98 and there is nothing you can argue about it because band width is not uniform all though if you take it 10% then you will be in trouble okay because the energy is considerably spilling over and your either wasting it or causing it to cross talk with other bands okay.

So there are some trade of set are involved all though band width is not defined you do know that what happens if there energy goes or occupies a certain range of frequencies okay so whit that let us look at pulse shape as I said the bits have to converted in to wave form.

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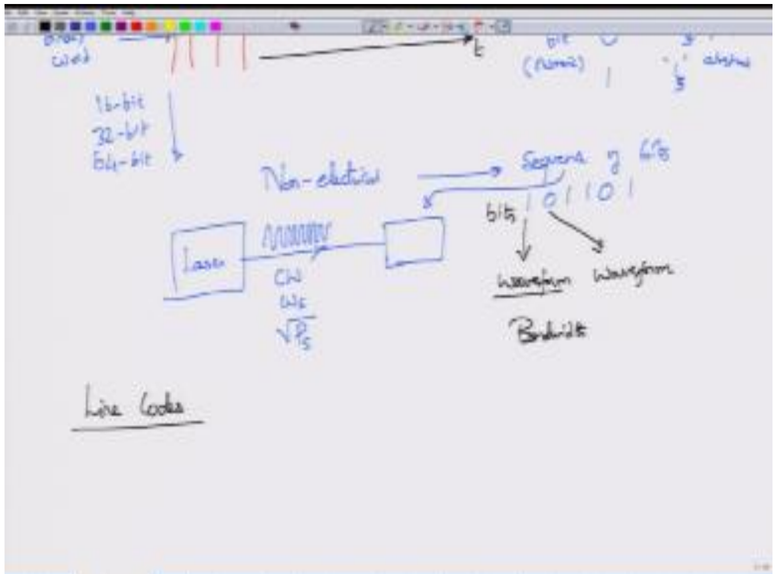

And there are various choices okay so let us look at some common choices these choices are called as line codes okay if the goal is to just be there in the electrical format these are called as line code so you take the bits and then convert them I to electrical wave forms it is a voltage or current wave form. One popular coding technique is what is called as the polar coding technique.

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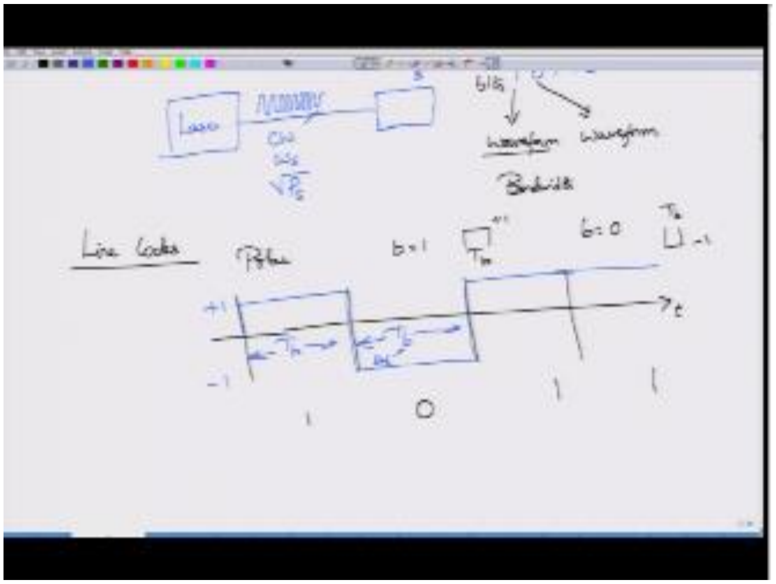

In the polar coding technique you assume that the bit b you know if the bit b is equal to 1 then you represented with rectangular pulse of amplitude of duration tb and an amplitude of +1 if it is current it would be one ampere ort normalize is to one ampere or normalized value there if it is voltage it would be some voltage but it would a positive pulse okay of duration tb and more or less rectangular for our analysis.

We will assume rectangular if the bit b -0 then you represent that one by a pulse of the same duration tb but it amplitude is -1 at the same time let me remove all this one here so the tails or there the 0s are not the part of definition okay so this is what it is, so this is the polar format you have let us say the sequence which we looked earlier so the sequence are 101101 so I have the sequence first let me take the time access and section it okay.

Now the sequence has to be 1011, I don't have space to write the other one, so I am going to live it, at these four symbols, lets also draw a line showing that this is the time axis, okay and now these symbols have to be written. What is the symbol for 1,it is a , +1 which would be occupied by the entire duration, a 0 is something that could be occupied as an entire duration but it would be amplitude -1 so here the amplitude is +1 , here the amplitude is -1, the duration here is Tb, the duration here is Tb, the subscript B indicates that this is a bit time or a bit duration.

So every Tb seconds you are going to output one wave form this wave form would represent either a bit 1 or a bit 0, but it could output one bit wave form, okay then going back to 1 you have a +1 here, and then going back to 1 you have a +1, so the amplitudes are +1 so this is the wave form representation for your polar format, okay let us look at one more popular format, this is called as,

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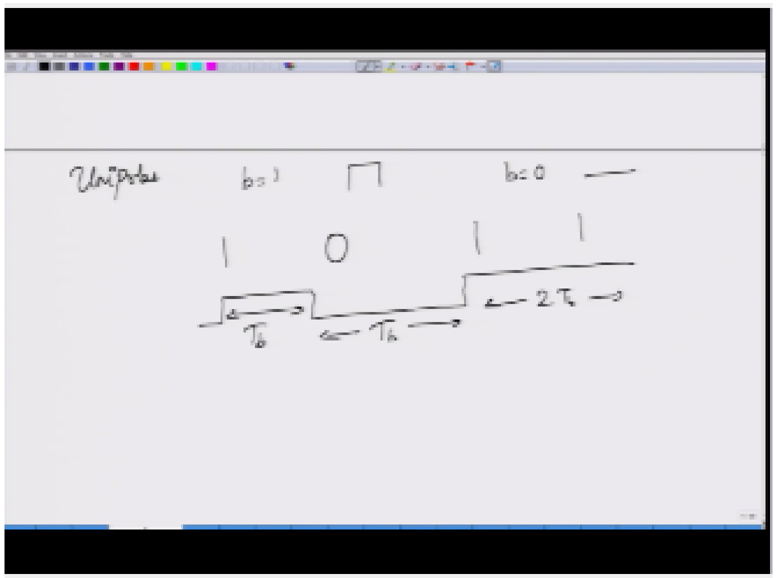

Uni-polar format you do of course realize that there is nothing optical about this one, at least until we specify that it cannot be optical, these are just regular line course, okay how you represent bit with a wave form, however for optics is nothing like a minus power, for example you want to represent optical power right as in the intensity modulation systems, I can’t have a -10whatt optical power.

Because optical power is always a positive quantity, okay so I can’t really use this polar format which will give me +10whatt and -10whatt , so I have to find other means, however with electrical signal is possible the current could be +10 amps, or current could be -10 amps, okay.

Now with uni-polar you overcome this problem uni-polar actually as its meaning its suggest a single polar quantity so here a bit b=1, will be represented by a positive quantity bit b=0, is represented by transmitting nothing, okay so if you go back to the same sequence 1011, this would be your transmitted sequence, okay.

Each occupying a duration Tb, it doesn't really look like that and then you have 2Tb over here , because you have taken to 2 bits of time to transmit this one, okay so this is polar, this is uni-polar, in addition to this you also have two formats,

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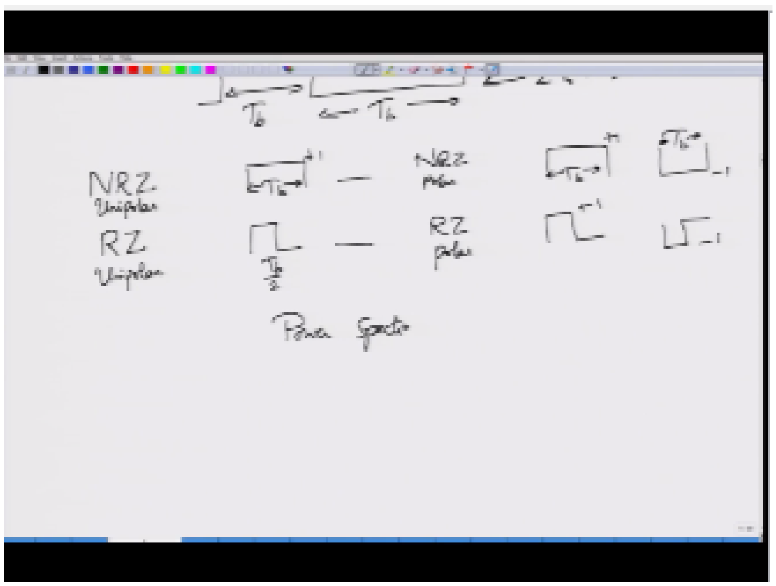

Which are even used at the optical live, these are called as RZ and NRZ in the NRZ the pulse occupies the entire unit Tb, for example I am doing NRZ uni-polar, then the pulse occupies entire Tb, okay if I am doing NRZ polar then this would be slightly different, so I will have for + signal I have positive one for a bit B=1 I have Tb here for bit B=0 I will have for that entire duration with an amplitude of -1, okay this as an amplitude of +1, this is +1 but it would continue to be there for the entire duration Tb.

However if I am looking at RZ uni-polar RZ stands for return to 0 and NRZ stands for non return to 0, okay I might actually have a duties cycle which is only 50%, so this would be for bit 1 and 0 for bit 0 but note that this duration is only Tb/2, its only occupying half the bit duration.

For RZ polar I have a return to 0 pulse here for +bit 1 so this is for bit 1 and then I have a, -1 pulse that would look like this okay, so you will have these different ways in which you can represent, but which one would you want to choose? What you want to choose is determined by what is called as power spectral density something that we are going to look at in the next module, okay so we will stop here and continue the discussion of power spectral density of this various formats in the next module, thank you very much.

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