Principles of Digital Communications
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Lecture - 35
Line Coding - I

A PCM system converts an analog signal to a digital format by using a sampler quantizer and encoder. The output of the encoder is mostly a binary stream, consisting of digital 1 and 0 bits. Now, for transmission, we need to convert this digital output of the encoder into electrical waveforms or pulses and this process of conversion is known as line coding.

So, we begin our study of baseband digital communication with line coding and we will begin this study with the binary case where the data consists of only two symbols 1 and 0.

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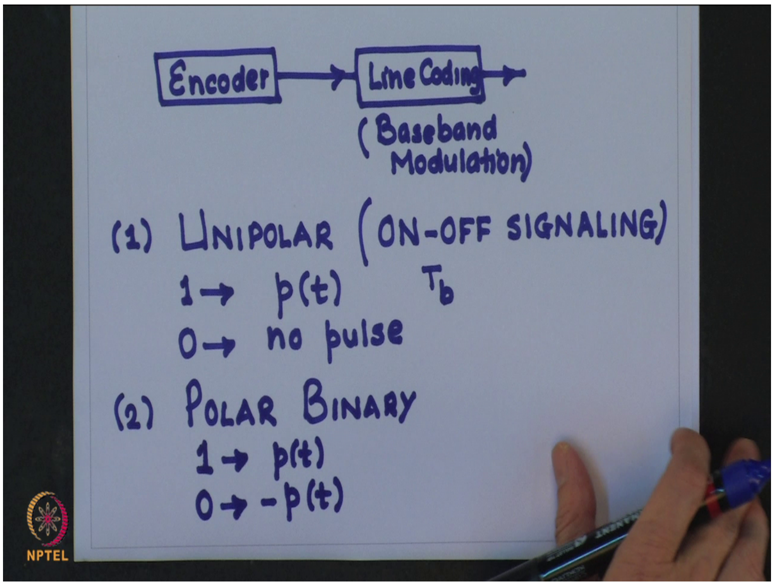

So, we have the output of the encoder which is a bit stream and then this will be converted into electrical waveforms or pulses through the process of line coding.

So, the output of a line coder will be a physical digital signal and then this signal can be modulated using carrier if required and then it is transmitted on the channel. So, this is a form of baseband modulation. We will start with the simplest line code and that is unipolar and it is also known as ON-OFF Signaling.

So, in this format, symbol 1 would be transmitted using a pulse say p t. This p t is a generic pulse and for symbol 0. There is no pulse.

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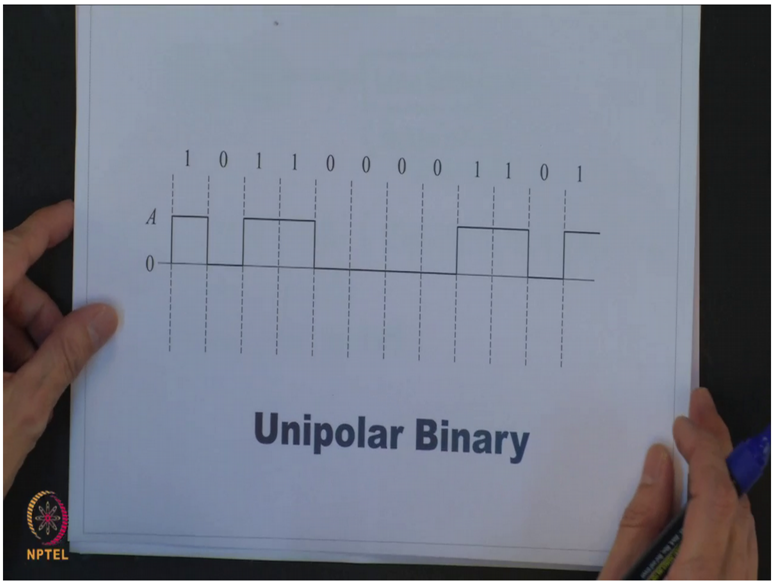

So, let me show you; how the waveform will look for the unipolar binary case. We have this bit streams and for that bit stream, we generate this waveform the p t which I have chosen here, waveform is a rectangle pulse of duration T b.

So, from here to here each binary digit is existing over the duration of T b ok.

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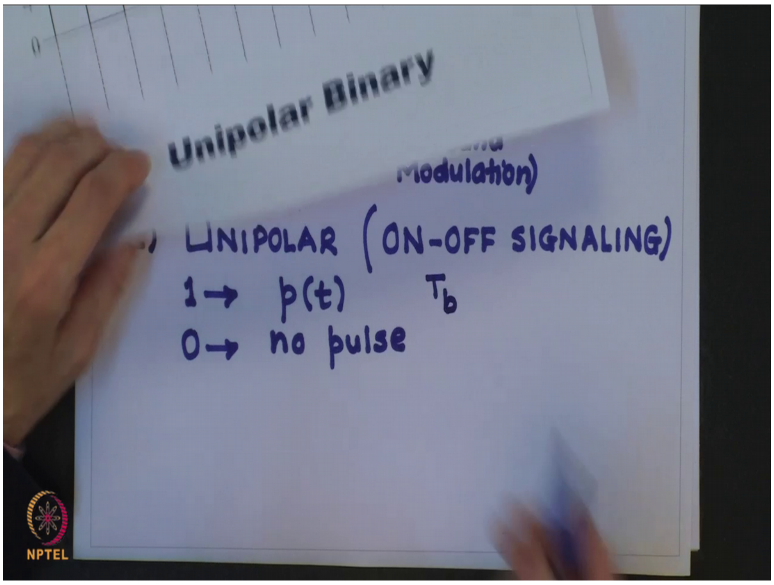

So, for 1 we sent a pulse of height A for 0, we do not send any pulse. So, this is the digital signal of the output from a line coder which uses unipolar format.

Now, we will see soon that this line codes should satisfy certain properties for the transmission over the channel. Now, if you look at this line code unipolar code, here if you have continuous 0's, then this could create a problem or if you have continuous 1 this could create a problem later on and we will see that the problem and that is the problem of what is known as synchronization, correct. But one more thing you can notice from this waveform that this transmitted signal has non-zero mean.

So, what it means that if this signal is transmitted on a channel, then that channel should be able to pass DC, unfortunately, most of the time, you will find that channel has AC coupling which suppresses the DC or in this case, if you have long runs of ones, then also there will be a problem ok.

So, this is the problem with the unipolar binary signal, we have another format which is known as polar and we are considering polar binary in this, again, we transmit two signals. So, for 1 we will transmit say a positive pulse p t and for 0 will transmit a negative pulse minus p t. Now, in this case, the transmitted signal will look something like this. So, for 1 you have plus A and for 0, you will have minus A.

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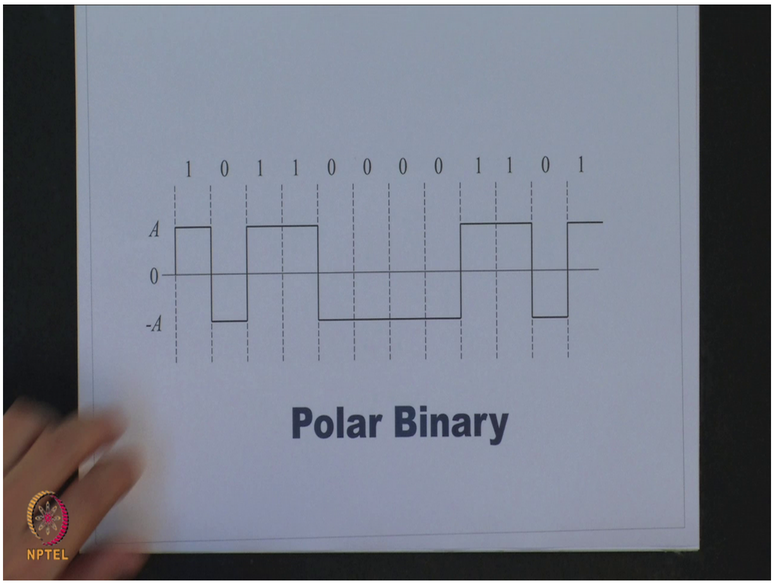

So, this is a digital signal which will be generated and this transmitted signal will have 0 mean provided data is equiprobable, correct. So, but still here also if you have continuous 1's or continuous 0, we will see that this will create synchronization problem, correct.

So, there is no guarantee of transitions for timing regeneration which will shortly study, correct. So, though this polar binary signal does not does have 0 mean, if the data is equiprobable, we will see that this still has a high power spectral density at low frequency and therefore, still a problem with channels which do not pass DC.

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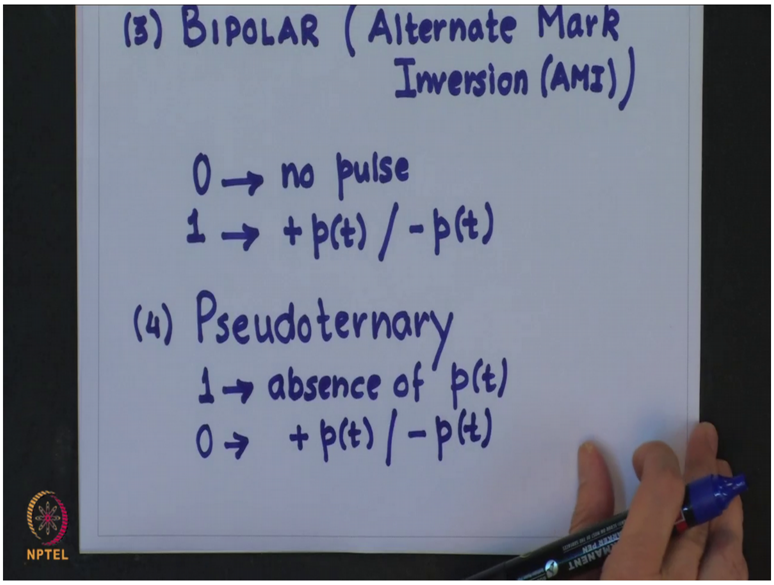

Now, other form of line code is what is known as bipolar format or it is also known as alternate mark inversion. So, here totally or three level symbols are transmitted. So, for 0, we do not transmit any pulse and for 1, the pulse will be transmitted either as plus p t or minus p t and this will happen alternatively. So, the waveform will look something like this.

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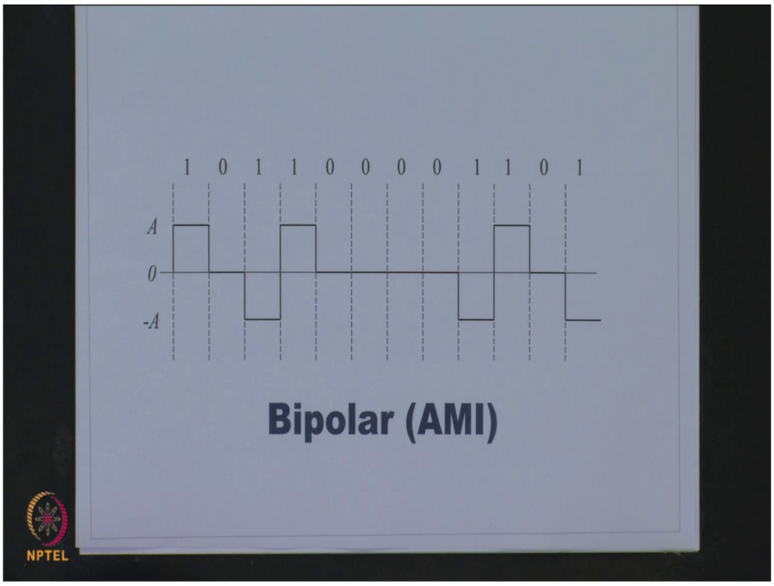

So, let us start with the first one. So, I send the positive pulse here and then for 0; no pulse, then next time when the one comes, I will switch the polarity compared to the earlier polarity. So, it was positive. So, this will become negative, I have 1. So, again the polarity will switch over to plus and then there is no transmission here and then again here at 1 from positive, it will become negative and here it will become from negative to positive, this will continue here, it will again become negative. So, this is known as bipolar AMI form.

Now, again here also there is no guarantee of transitions for timing regeneration in the sense that you could have continuous string of 0, then there will be problem, but if you have equiprobable 1 and 0s, then maybe you should be able to recover the timing information there is a spectral null at dc. So, there is no longer a problem if channel does not pass DC correct and we will see basically that this bipolar format requires lower bandwidth and you can carry out the error detection, we will come to this little later on.

There is another format which is known as pseudoternary, this actually is a subclass of bipolar, there is not much difference between this and AMI except in this 1 is represented by absence of the signal and 0 is represented by alternating positive and negative p t. So, no specific advantage or disadvantage over bipolar AMI correct ok.

Then there is another format which is known as non return to zero, invert on ones and this is known as NRZI.

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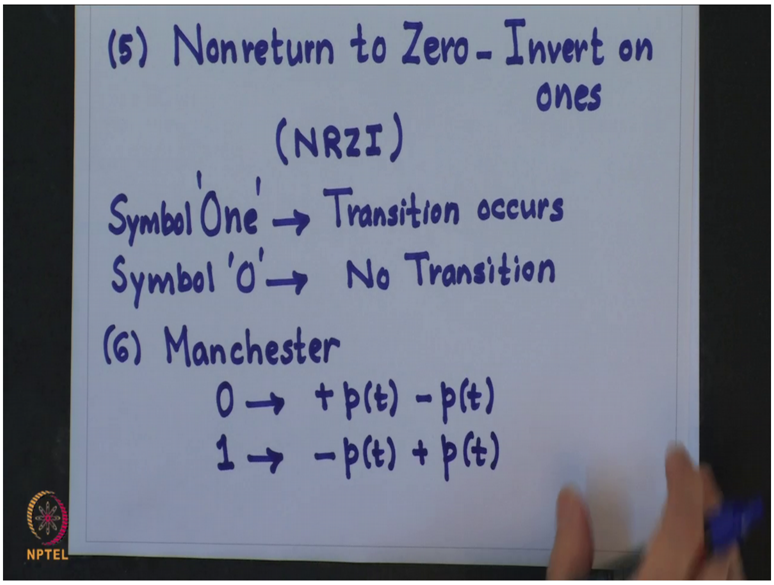

So, here what we do is that constant voltage pulse for duration of bit is transmitted and data encoded as presence or absence of signal transition at the beginning of bit time. So, data is based on transitions low to high or high to low level change takes place. So, what we could do is something like this for one symbol one, let us say transition occurs and for symbol 0 no transition.

The signal would look something like this. So, let us take this is a data stream.

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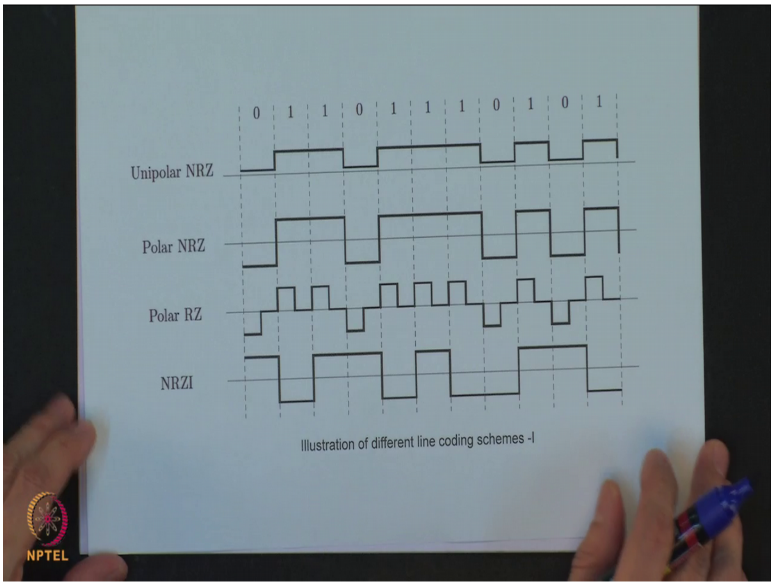

I have here, ignore other waveforms, look at the last raw out here. So, I start with 0, let me say, I was transmitting a positive value for this, then when 1 comes the transition takes place. So, this will get change the polarity again 1 comes. So, the transition takes place changes the polarity 0 comes; so, no transition. So, it continues; 1 comes, transition takes place, again 1 comes, transition takes place, 1 comes, transition takes place 0. So, I continue 1 transition 0, no transition and then 1 transitions, this is known as NRZI.

Now, in this figure, you will also notice there is something what I have written here, polar RZ. This NRZ means Non-Return to zero. So, what it means that for the big duration of T b, the pulse exists for the full duration. So, example take unipolar NRZ; if I use a rectangle pulse, then the rectangle pulse exists for the full duration of T b in this case for 1, I am transmitting the signal.

So, it will exist for the full duration out here, here also; it exists, correct. Similarly, for the polar case for 0, I am transmitting minus A and for 1, I am transmitting plus A, but it exists for the full duration.

Now, the same case of polar NRZ you could have, what is known as polar written to 0. So, in return to 0, what I do is that I use the pulse for 0 which is negative minus p t. So, in this case, a rectangle p t is rectangle, but the duration has been reduced and in the way, I have shown here in this figure the duration is half of my T b.

So, what happens that the pulse exists only for the half duration and then it goes back to 0 and then when it comes to 1, it is a positive pulse, but will exist only for half the duration and it will go to 0 and then for 1 I have positive pulse and then again it goes to 0.

Then for the negative similarly, I repeat. So, I have this. So, I could have unipolar return to 0 case also and the duration of the pulse need not be half the bit, it could be anything else, but lower the bit; you have the bandwidth of the digital signal will also and there is a one more format of what is known as Manchester format. So, in this case, what happens like example signal 0 would consist for half duration as plus p t and for other half duration, it would be followed by minus p t, correct.

Whereas for symbol 1, it would be just the reverse of it, we would have for half the duration minus p t and other half duration plus p t. So, if I take my p t to be a rectangular case, then I get this digital signal.

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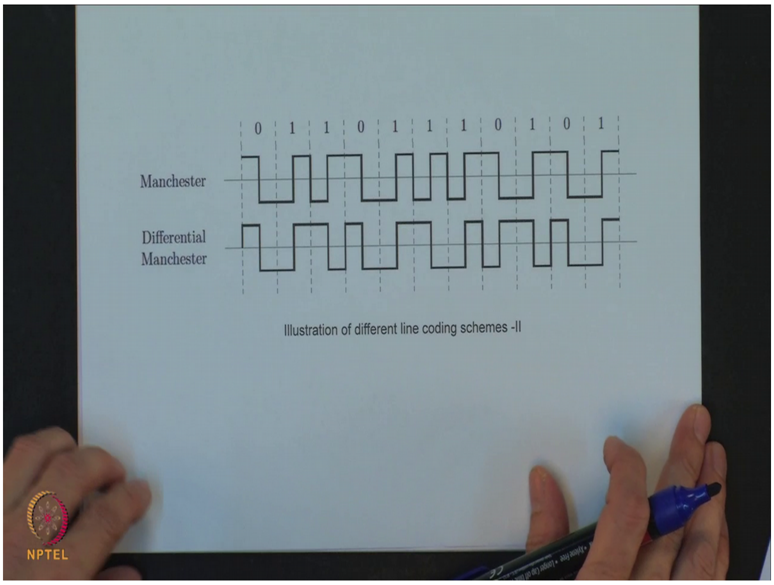

So, let us take a case for 0 1 1 bit stream and the Manchester coding for this is shown here for 0, it is positive negative and for 1, it is negative positive, again 1 negative positive, 0 positive negative and this is the way, we get and then in Manchester coding also you can have another form of coding what is known has differential Manchester.

So, in differential Manchester, what we do is basically is that whenever 1 comes depending on the polarity of the earlier transmission of 1; the polarity of the current transmission of 1 will be decided. Take a simple case here. So, for 0, I am going to transmit plus t and minus t; for 1, basically, I have minus t plus p t, but when other 1 follows, I am going to make it switch the polarity it is going to become. So, when I start with 0, it is plus p t minus p t for 1 as usual minus p t plus p t when I get another 1 it switches the polarity compared to the earlier 1.

So, it becomes plus p t minus p t for 0, again it will become plus p t minus p t when 1 comes compare to the earlier 1, this will switch the polarity. So, it will become minus p t plus p t and this is the way, it continues and this is what is known as differential Manchester. There are different forms of line codes, we are not going to do all those details. But whenever you decide any line code, it is important to see that this line codes have certain properties for the transmission onto the communication channel.

So, what are those properties; let us quickly look at those properties.

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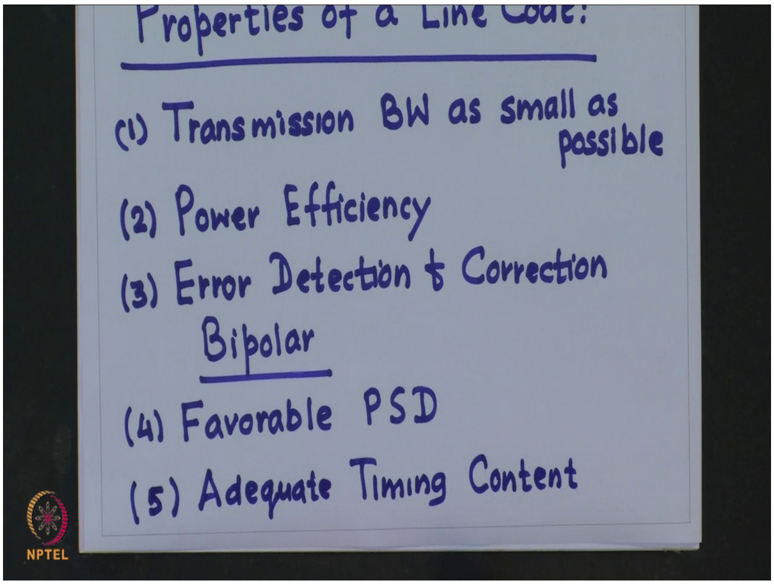

First, transmission bandwidth should be as small as possible and we can obtain this bandwidth by calculating the power spectral density of a line code and we will see later on; how to do this. So, this is the important thing, another thing basically; what we desire is the power efficiency.

So, just to go back on the transmission bandwidth, it is important to know that NRZ version of the unipolar polar or bipolar will make more efficient use of bandwidth, whereas, the return to zero formats of this line codes unipolar polar or bipolar will require higher bandwidth ok. Power efficiency means that for a given bandwidth and a specified error rate the transmitted power should be as low as possible. Now, the we will see that polar scheme is the most power efficient because it uses two signals plus p t and minus p t correct whereas, if you take a unipolar case, it uses 0 plus p t.

So, the distance between the two symbols becomes lower in the case of unipolar compared to the polar. The third property is that; it should have some kind of error detection and correction property. Now, we will see that the bipolar signalling can detect single errors because what will happen when you look at the digital waveform the polarity will help you to decide whether the error has occurred or not, correct.

So, if only one error occurs, then you can easily find out by looking at the polarity of the signal transmitted whether there has been error or not, but this will not be error detection will not be possible with say unipolar or polar case, then the next is basically link to the first one is what we should have is a favourable power spectral density, what is desirable that it should not have any impulse at DC. So, that on the channel if there is a AC coupling the DC will be suppressed and then the whole line code structure would be changed.

So, we do not desire; we desired that DC is should not be a DC impulse should not be there and as far as possible the power spectral density at the low frequency should be lower. So, whenever a AC coupling is there, it does not create a problem and because of the low pass nature of the communication channel we would also desire that we should not have power spectral density of a larger magnitude at high frequency also ok.

Another important concept is of adequate timing contained what this means basically is that we should be able to extract out the timing or clock information from the signal itself. Now, if you look at the digital communication channels, then on this channel you will find that there are regenerative repeaters which are placed at regularly intervals and the tasks of this repeater is basically, to detect the incoming digital signal and create or regenerate new pulses or new digital signal for onward transmission; by this process what happens that the noise gets diminished.

So, there is no attenuation of the noise and the distortion in the signal also decreases, but to do this efficiently we require that timing information. So, it should be possible for us to generate the timing information from the line code itself for example, when I am transmitting my line code pulses at a rate say R b pulses per second, then I should be able to extract out of clock frequency at R b hertz. So, this clock frequency can be used for detecting the incoming signal and regenerating new signal for onward transmission.

Now, some of this line codes which we have seen may not have this property, for example, if you take a polar signal and if you pass it through a rectifier then and if you take a polar RZ return to zero, then you will always be able to generate a timing signal out of this correct.

But this is not true for example, if you take a unipolar cases correct because you could have string of 0 or you could have string of 1 and in that case; whether you will not be able to generate it. But still on of signal can be modelled as composed of two components; random component and periodic component.

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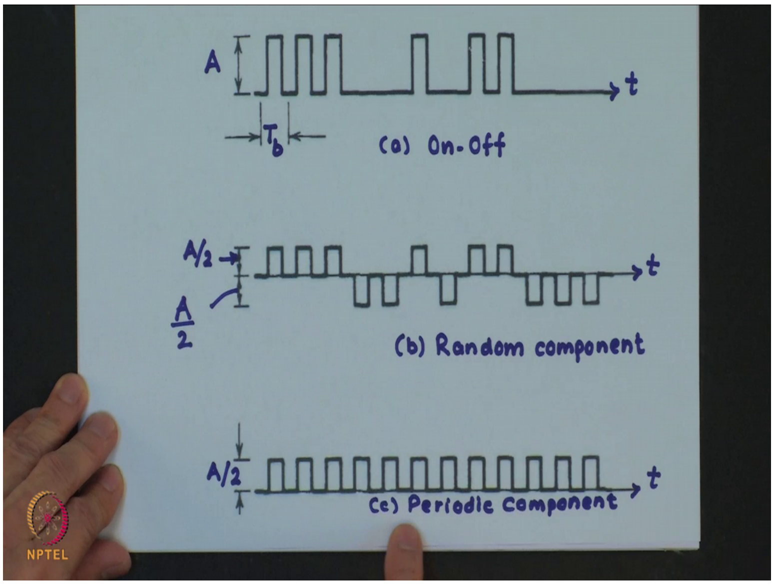

So, what this shows basically that there is a periodic component available in on-off signal, but there is no guarantee of this correct because if you have a string of 0's or 1's and this will not be valid ok. Other interesting property which we would like to have is that; it should be robust against polarity inversion because it is possible that on the channel the digits get swapped.

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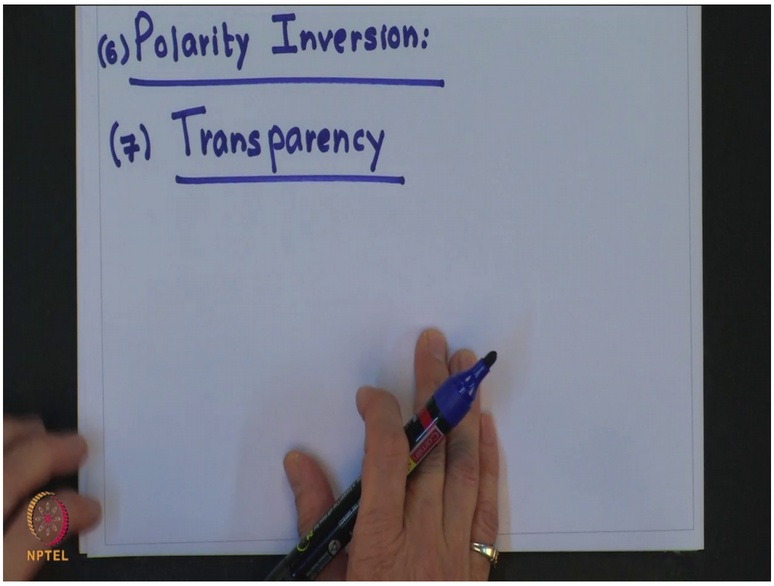

Now, if you have this for example, in unipolar case, you will be in problem because once will become plus A; A will become minus A. So, you again a problem again in the polar case, you will have a problem because 1 and 0's will get swapped, but polarity inversion problem will not be there for example, in a bipolar case because your information is coded in the inversion, correct.

So, whenever the inversion takes place we know; what is the transmission taking place, for example, we had said that whenever 1 is transmitted will have the inversion, right. So, now, in this case even if you have polarity inversion, it will not affect the detection process and the last is what is known as transparency, correct, it is more of a term which is defined classify a line code which withstands some kind of distortion. For example, like if you say that bipolar codes, they are transparent to polarity inversion because even if you have a polarity inversion; then I will be able to detect whereas, unipolar and polar codes line codes are not transparent to polarity inversion correct.

So, that is what we mean by transparency. So, transparency is really could be included as part of polarity inversion. Now, if you want to go into the detail of the study of this line codes properties, then we would be required to find out what is the power spectral density of this line codes; which is an important concept in deciding which line code to choose and this we will study next time.

Thank you.