Digital Communication.
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Lecture-6.
Introduction to Line Coding.

Professor: What we have learnt so far is how to represent information which is originally in the analog form to a digital form. Ultimately this information is going to be transmitted on a channel, in the form of a sequence of binary pulses. It could also be sequence of what are called Emory pulses, that is you could have, instead of representing the signal by two-level amplitude, you could also represent it by more than 2 levels, by grouping bits of information together into a single amplitude. Maybe you could club 2 bits into a single amplitude with 4 possible levels and so on.

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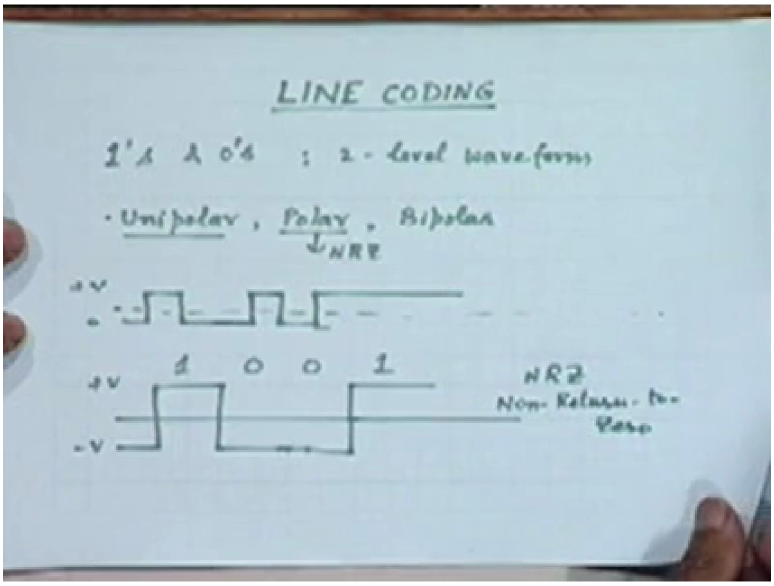

But we will talk more about that later, in general therefore we are going to transmit on the channel pulse sequences with discrete levels, either 2 or more in number, right. So let us at the moment restrict our discussion to binary signals. So in this binary binary system our information is in the form of ones and zeros. And any two-level waveform is adequate to represent this ones and zeros information and you transmit it. However there is an important question, what kind of waveforms to use and what are the implications of using various kinds of waveforms, right.

For example you could have some of the choices that I can just talk about without much Introduction is what are called unipolar waveforms as an example, then we can have polar waveforms, so-called polar waveforms, we could have bipolar waveforms and many others which we will talk about in due course. A unipolar waveforms will be one in which the 2 pulse levels are represented by let us say a 0 volts and a positive voltage, right. Polar one is the one which is 0 represented by a negative voltage and a 1 by positive voltage or vice versa.

A bipolar one would be a slight generalisation of polar in the sense that perhaps you could even apply 3 levels, right, that is positive, 0 as well as negative, right. The polar waveforms sometimes is also known as nonreturn to zero waveforms because they are always switching back between positive and negative voltages and never really transmitting 0 voltages. In bipolar waveforms the difference is that you may see also sometimes transmitting 0 voltages, right. So that is the essential, polar and bipolar are very similar, in the sense that both have positive and negative voltages but in bipolar you may also have some durations over which 0 voltage is being transmitted.

But we will look at the details as to how that comes about in a few minutes. Let us take the so-called polar waveforms because as far as the choice between unipolar and Polar is concerned, it is quite obvious that a Polar waveform will be a better choice. Is it obvious to everybody?

Student: Why?

Professor: A unipolar waveform will always end up transmitting some DC voltage, right, that means you are transmitting some power, you are having some power in the DC component. And by the very nature of information and a constant value signal has no information content, right. So basically wasting a lot of transmitter power in conveying no information whatsoever.

Student: In unipolar?

Professor: Yes in unipolar.

Student: Sir but 0 is (())(5:39) you are not transmitting power…

Professor: You are transmitting power at DC which usually contains no information.

Student: Sir how do we talk about 0 level as transmitting power?

Professor: Okay, I think you are, I thought it is obvious, but perhaps it is not. If you have some waveform which varies between some 0 level and + 5 volts, what will be the average value of this? It will be some positive value, right, you have a finite DC component always sitting on the line which will not be conveying any information, right. And of course it is even otherwise bad to have a DC component for various other reasons which we will soon discuss. So unipolar waveform is very rarely if at all ever used. Right, because of the DC component that is inherently built into such a waveform.

So really most of the time we are talking about Polar and bipolar waveforms and we shall really consider those in detail here. Take now the case of bipolar waveforms like that. That will be typically bipolar waveforms. For example if you have sequence 1, 0, 0, 1, you, sorry, Polar waveform, Polar waveform, you will be transmitting waveform like that. You will always be switching between positive value, positive voltage and negative voltage, never really going through 0 except for a transition through 0. And therefore this waveform is more popularly known by the name of nonreturn to 0 waveform, nRZ waveform, right. nRZ standing for nonreturn to 0, that is a common terminology used to talk about this waveform, all right.

Let us see what happens if such a waveform is transmitted onto a typical cable system, for example ultimately your all the waveforms are going to go through some kind of transmission line which could be a cable, a pair of wires or any other communication medium. What we see is that such a waveform is not really suitable for transmission on satellites. The reason why it is not suitable is that most of these cables or system will ultimately in between, in fact we may definitely have repeaters in between, right. And at the point at which the cable is connected to a repeater usually, there will be an AC coupling, it will not be a DC coupled thing because you do not want interference, DC interferences or over the DC signal to somehow get in.

So there will be invariably some AC coupling at the point of a repeater, the cable is connected to a repeater. There could also be Transformers in between. It is totally unavoidable to get rid of components like Transformers and AC coupling. And typically because of the presence of these kinds of devices on the line, the low-frequency response of the line is usually poor, right. Because AC coupling will create for low-frequency response, is not it. You have done frequency response of RC coupled amplifiers and there is a series coupling capacitor results in poor low-frequency response. Similarly a transformer, will result in a poor low-frequency response.

Student: (())(9:25).

Professor: That is again to couple, to couple a signal from one point to another point within the repeater somewhere you will require a transformer, typically you will require transformer, right. And therefore the low-frequency response becomes very poor. To see the effect of this for low-frequency response let us look at this pair of waveforms.

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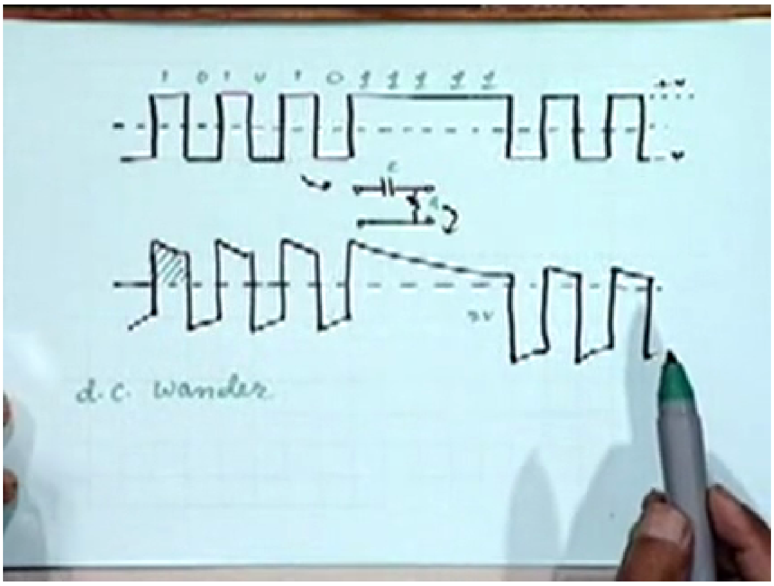

Let us say this is your NRZ waveform that you are transmitting, all right, corresponding to a sequence 101010, typically that is the kind of response that you are going to get, right because of, because of low frequency response you get a droop in the pulse duration, I mean you get, pulse amplitude is not constant, at the output, let us say you are passing through a coupling like that, right, a series coupling circuit like that, some CR, the output of this will typically look like this, I am sure it is obvious to all of you, that is how it will be. Well, what will be the problem of such a waveform?

The problem will come here when we are suddenly having a long sequence of ones let us say, a series of ones, right. So you will get a response like that, right and after that you will get a jump of 2 volts here, right because when suddenly a transition comes, the capacitor shall just respond by creating the same kind of jump in the outputs and you will get now a set of pulses which look the same as these pulses but there is a difference. What is the difference? The DC level of these buses is different from the DC level of these pulses. This effect is called a DC wander, wandering of the DC level, right.

A DC level is constantly changing depending on when you get a sequence of one, long sequence of ones you will get a drop in the DC level, if you get suddenly a long sequence of zeros, - this, you will get lifting of the DC level and depending on what is the length of the sequence the amount by which wander takes place will keep on changing, right. now this will create a lot of problems for us when he eventually at the receiver or as a visitor we are interested in finding out when we transmitted a 1 and when we transmitted a 0.

Remember we talked about matched filtering for that purpose, right, but let us forget about matched filtering. What is the common sense way of intuitively appealing way of deciding whether in a particular bit interval a 1 or a 0 was transmitted? For such a waveform in the presence of noise?

Student: The 0 (())(12:39).

Professor: The best way would be look at the area of each pulse, right. The most intuitive of this way would be, because you do not want to get affected by spikes of noise. So best thing is to stick average of the noise by looking at not by instantaneous values of the pulse but by looking at the area of each pulse, area under each pulse. If you get a positive area, I mean in this sense, if the area which is largely positive, you can declare that the 1 was transmitted. If on the other hand you find the area is mostly under this thing come under 0 or negative area, you will declare 0 was transmitted.

So this is required to be done at the repeater, repeater after the repeater and finally also at the receiver. Well actually we do not, this is a very simple intuitive we have suggested, but a better way to do matched filtering, we will talk about matched filtering later.

Student: We will be looking at the area of for integrating…

Professor: Basically that. Any kind of method for calculating the area will be fine. Right, so we will not go into that. Yes?

Student: You mentioned the problem of DC wander, it is like, before that (())(13:58) DC components in the signal, right?

Professor: Right.

So therefore any variation in that, from that point of it, it should not affect because only the AC part is getting coupled, however, I mean the only thing that it can affect would be that the threshold can come down.

no, there are 2 ways your, the problem will crop up, I will 1st describe the 1st problem and the 2nd problem is still the one which we discussed earlier. namely because there is a constant change DC, therefore effectively there will be always DC at the other component which is a waste of power. So eventually we end up transmitting more power for the same performance, power is being wasted here and there, right. So that problem stays but in addition to that problem I am referring to a more serious problem here which am talking about, we will just talk about that 1st.

Student: (())(14:44) generating the positive and negative 1s, how will it assure that you will not be transmitting any power?

Professor: I did not get your question.

Student: What I mean to say is that, I mean it is not very intuitive that you will be transmitted, it depends on how you are generating the positive and negative… And what are the voltage current relationships?

Professor: For finding the area?

Student: Yes.

Professor: Now, I am asking you how exactly do you transmit the positive and the negative levels. This is what we are transmitting, this is the transmitted waveform.

Student: How do you generate them?

Professor: Oh come on, does that require any elaboration how do you generate such pulse train?

Student: no, how do we say that the power is given as per the voltages like this? What we are arguing out is that since the voltage signal is like this the power, the power signal…

Professor: I have not talked about power in general, I am only talking about DC component.

Student: You bring power to the DC components, indirectly hinting that…

Professor: Okay, if there is a DC component, that DC component will contain some power or not, that is the point.

Student: Are you mean to say that in ideal case you will not be using any power at the transmitter?

Professor: If I do not have a DC level, that means I am, means all the power that is there in the signal is not being used for transmitting a non-varying component. If you have a DC power, that means some power is being transmitted for conveying a non-varying component, a DC components which is of no use to us, right. That is all that I am saying, that is the, you are referring the old DC problem as to why DC is not a desirable thing to have.

Student: It basically means that in the transmitted signal the DC signal is 0 but now because of that decay, some DC pops up.

Professor: That is right, that is right, the DC level is in fact not only cropping up, it is constantly changing. There are 2 things, it is cropping up and it is changing, it is not constant, at least in the unipolar case, if this problem was not there, even then this problem would be there. We were talking about a constant DC level but here this level is even changing with time.

Student: If it is varying then how will it deteriorate…

Professor: You have not let me complete what I wanted to say, you will know if you would let me complete, right. So let us come back to what I was trying to say, detection of ones and zeros, that is what you are talking about, intuitive way of finding out at the repeater or at the receiver whether in a particular bit interval the transmitted bit value is 1 or 0 and we decided that one intuitively appealing way of carrying out this decision would be, making this decision would be to look at the area under the pulse in the bit duration. For positive area larger than a certain value, you can always declare safely that 1 was transmitted, similarly for negative area larger certain value you could declare that 0 was transmitted.

Even in the presence of noise we would be reasonably sure to make correct decisions if we do things like that. Because we will not be affected too much by occasional largest groups of noise, right, which typically will occur for very short durations, right. So therefore in this kind of situations things are fine, whether positive and negative areas are clearly equal. And the thresholds are completely fixed, let me complete please, right. now what happens here, vertically towards the end of this? You have a very small positive voltage in a particular bit interval, let us say this bit interval.

You are trying to decide in this interval and it will well be, if the area here maybe below the threshold value which we have decided for a proper decision, right. It may be, this may be in fact because of noise may look like a negative area because noise may be largely negative in this region and may, the net area will turn out to be negative when you may take your own decision, make your own decision. Therefore your tolerance to noise becomes very very small in this particular region. And what is worse, it is unpredictable overtime where it is going to happen advises is not going to happen, right. So this is going to create a lot of problems for us. Is it clear?

So if you have a high-frequency channel…

Student: The channel has a lot of bandwidth, in fact because we have a lot of bandwidth we are transmitting digital signal.

Professor: If you have a very high, number of, rate of bits is very high, then this decay problem may not be as prominent because the amount of time…

Student: So, when we have a large bandwidth, we also have a fairly, series of ones you could have for fairly large duration…

Professor: These 1s occurring are very less. There could be very long series.

Student: Not only that (())(19:59) but as the frequency increases the degrading effect of series of 1s will decrease.

Professor: no, it is like this, it basically depends on the time constant relative to the duration. That is, we have to examine that, more importantly it is important to realise that this is not a very uncommon occurrence, reason is suppose we are talking, right, particularly its talk about a series of zeros, right. There could be if zeros are representing silent intervals for example, typically there could be long silent intervals in between your words, in between your spoken words. And that could be sufficiently long to cause this DC wander, right and affect your performance.

And mind you, remember that at the receiver we are not talking of a very strong received signal or at the repeater, we already have undergone a lot of attenuation, right. So the signal and noise levels that we are looking are fairly similar to increase. Signal-to-noise ratio not infinity, it is, it is more like 10 to 20 dB or 30 dB, right, not much more than that maybe even down to very close to 0 dB sometimes depending on the situation. So that is how this problem becomes very prominent. Any other questions or any other discussion you want to have in this?

Student: If width is increased (())(21:32).

Professor: If width is increased.

Student: Pulse width.

Professor: But if you are pulse width is increased you are sacrificing your data rate, that is a trade-off between your data rate and…

Student: (())(21:44) DC wander.

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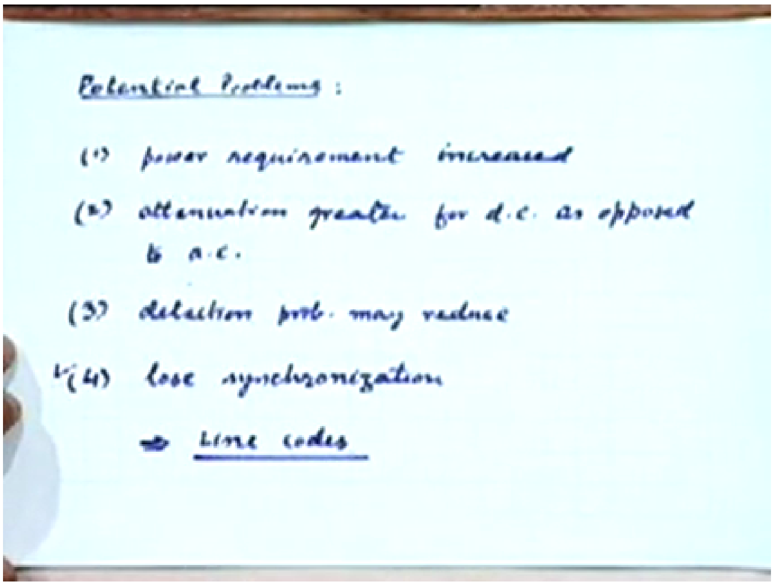

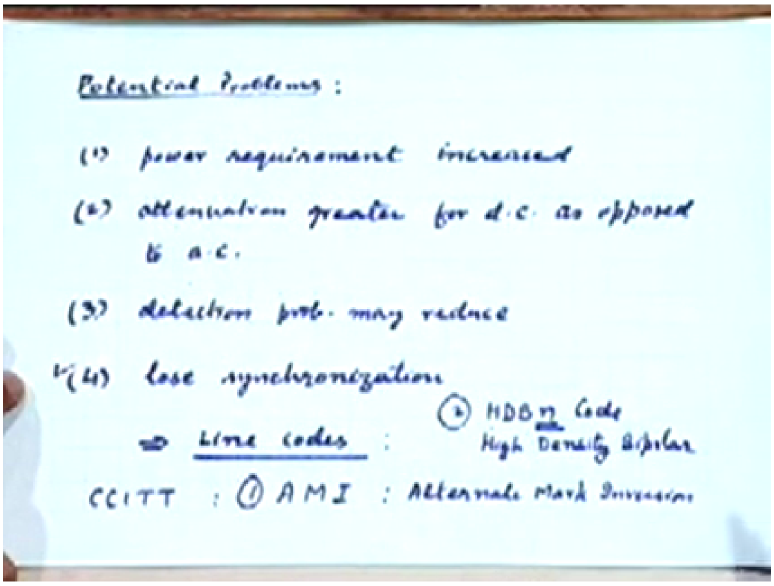

Professor: DC wander will not be stopped, in fact it will become more serious. Alright, this point is understood, what we can conclude from this discussion is that there are a lot of potential problems in transmitting nRZ kind of signals, that is according the ones and zeros in the form of n RZ waveforms on a transmission line, particularly when there is a long string of zeros or a long string of ones, right. Because line would appear either permanently on for some time or permanently or for some time and that will create problems, that creates a DC condition which is undesirable.

So net effects of this DC condition are, we have discussed this now, I am just summarising what we have discussed. Our overall power requirement will go up, right, that is one effect and usually because of poor low-frequency response, DC components also get greatly attenuated, attenuation is greater for DC as opposed to AC. And detection probability or correct decision probability will be reduced or performance may go down, right. Finally one more effect that I should have bought about, I will just 1st mention it and show you the picture again. We may also have the possibility of losing synchronisation, let me talk about this also, this effect.

If you get a long string of ones, it is also bad from the point of view of, you have synchroniser at the receiver. The synchroniser at the receiver or at the repeater is going to look at synchronising information, that is your bit period from the 0 crossings of the received waveform, right. How often ones are changing to zeros and zeros are changing the ones, that is going to give it some ideas to where, how to adjust itself so as to be in synchronising with the received bids rate, received clock, right.

And when you have a long string of one's or a long string of zeros grid is not going to get those big transitions for adjusting itself accurately enough. You may be slightly not very confident about what I am saying here because we have not looked that how a synchroniser really works. But obviously whatever be the exact mechanism of the synchronisation that we will probably study later, it has to derive the information about bits by looking at bit transitions, right. Because that is related to clock transitions, right. If it does not get any transitions, it does not get any information and if it may lose a generation, then that is again bad.

That means your local clock may get disadjusted with respect to the received signal clock, then we are not even looking at the correct bit interval. You may be slightly offset, instead of looking at this area, you are looking at this area, area under this direction, right which is even worse because your local clock got disadjusted after such a long string of ones. Does it make sense what I am saying? Everybody?

Student: Yes.

Professor: So that is another possible problem, source of problem from a long string of ones (())(26:28). And obviously the problem gets worse as the length of this all 1 sequence or all 0 sequence (())(26:38). The solution to all these problems is the use of properly designed line code. Okay. That is used waveform to represent your binary sequence in such a way, such that these problems are minimised if not totally eliminated. Ideally we would like to eliminate them but at least we will like to minimise them. And the number of line codes we discussed (())(27:14), let me 1st talk generally about 2 important classes of line codes which are coined and standardised by CCITT.

And these are, one code is called AMI code, stands for alternate mark inversion and the other one is called HDBn code, this is one and this is the 2nd. H DB stands for high-density bipolar, high-density bipolar and n is the parameter of the code, okay. Basic name is high-density bipolar and n is the parameter of the code which we will talk about. For example we can have H DB 3, H DB 5 and so on. Let me talk about these codes and appreciate how the use of these codes avoids or possibly reduces the effect of some of the kinds that we have discussed just now.

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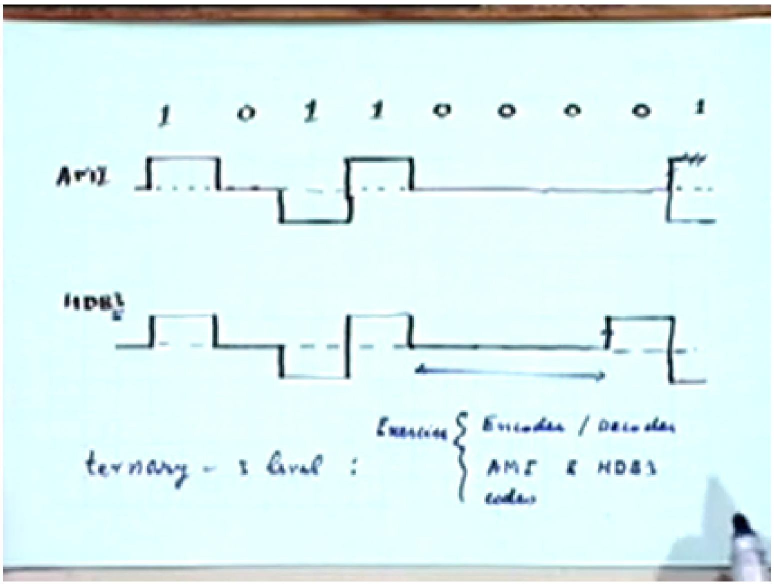

This picture shows what we do in this situation. AMI approach takes a simplistic view that if I have a long string of, okay, before I come to the details, one common feature of both these codes is that they are actually both bipolar, that is they are actually transmitting not only + voltage level and negative voltage level but also 0 voltage level. So in a sense we can call them as ternary codes rather than binary codes, right, they are ternary codes, they are both ternary, ternary means 3 levels. And both these codes, a 1 is represented either by a positive level or by a negative level, right.

Positive and negative levels now are not representing ones and zeros, they are both representing ones and zeros are being represented by a 0 level in both these codes, that is one difference, right. So this is one thing which is common to both. now in the AMI one gets a simplistic view that if we get a long string of ones to ensure that there is no long string of ones, you just alternately invert the 1s, right. Alternate marks or alternate ones are simply inverted.

That is 1 is represented by a + voltage, positive voltage, the next one will be negative voltage, the next will be positive voltage and so on and so forth and obviously that will avoid a long string of ones. A long string of, actually what you are not worried about is a long string of ones, what you are really worried about is a long positive voltage, a long duration of positive voltage or a long duration of negative voltage, which is what you are really avoiding, want to avoid, which you can avoid by doing things like that. So this is an example, you have this possible sequence in which I have a long string of zeros which I want to avoid. Right.

Actually AMI will not take care of long string of zeros, it will only take care of long string of ones, that is disadvantage of AMI which is obvious now. Right. 2 ones it will take care of, 1st one is like that, 0 is like that, next one will be like this because this was a positive one, this will be represented by negative voltage, again by positive voltage, long string of zeros goes as such.

Student: (())(31:37) last one.

Professor: Yes, this is wrong, thanks. It should have been like that.

Student: What happens when there is a long string of zeros? (())(31:51).

Professor: What is that?

Student: A long string of zeros…

Professor: This is better than, this is better than a long string of negative voltages, right. But it is bad for series of zeros, if you want to avoid the DC wander problem, but it does not totally eliminate the loss of synchronisation problem, right.

Student: You cannot rely on the clock one starting on the common frequency and then do synchronisation?

Professor: Unfortunately no because there will be clocks at various interval and they will have their own stability equations, right, they will not really be. In fact every time you start transmission one does not know that your clocks are fully synchronised or not. Even a 1 hertz difference in clock can be crucially affecting your performance and it is bad, right. So one has to be very, that is the cost you are paying in all digital systems. Your complexity is much more than in analog systems, right. You see this picture is totally not required in analog receivers, there is no concept of a clock pair, or the clock being synchronised with the transmitter clock.

Whereas in digital transmission it is absolutely crucial, right. And there is nothing we can do about it, except to make sure that you satisfy the requirements. All right, is that okay? What is your question?

Student: (())(33:30).

Professor: Yes, we can have all those things but I think we will discuss that in a different place. A Universal worldwide clock, right. Yes, those things already exist but we are talking of digital transmission in a variety of situations by a variety of people and everybody wants to do things in his own way, right. In this (())(33:58) kind of situation will be very difficult to do that. When you talk about different languages, then therefore this is a slightly let say utopian kind of thing to ask for this kind of application.

Coming to HDB 3, it is very simple to alternate mark inversion, with one difference, you also take care of long string of zeros because that is bad, right. What you do is, in fact the significance of this number 3 or number n is, this is the maximum number of, maximum length of zero string you will permit, after which you will change the nature of your 0 from 0 to 1 in a manner that at the receiver you will know somehow that 0 was transmitted, actually a 0 has to be interpreted, right.

And the way to do it is, if you get a long string of zeros, follow it up by a mark but follow it up by a mark of a different rule than the one that you are using in AMI because you do a violation of that rule, right. Violation being, this mark should have really been of this sign but you transmit a mark of the same sign. So when you get 2 consecutive marks which are of the same sign, the next one is to be treated as a 0, right.

Student: (())(35:30) then you will again come back to 0.

Professor: Yes, at anytime you can permit 3, transmit a mark in between, then again at the most permit 3 and so on. So as long as you keep getting marks of the same polarity, that means they are all zeros, right. And basically what we are getting is additional 0 crossings, additional bit transitions to take care of your synchronisation problem. And in HDB n, you can permit up to n zeros but obviously the smaller the value of n the better, right. Therefore HDB 3 is in fact the most important code out of the HDB n class. So as far as these 2 important classed of codes is concerned…

Student: As far as structure is concerned, would HDB 3 will be different than (())(36:40) radically different?

Professor: By construction you mean the encoder and decoder?

Student: Yes.

Professor: Maybe similar in class but the details will certainly be different.

Student: (())(36:52).

Professor: That is right, that is why we only use HDB 3. The reason is not from the (()) (36:59) point of view but from the point of view that you would like to have as large number of transitions as possible, as frequently as possible. So n equal to 3 is the most popular HDB encoder, right. And of course you require certain amount of delay here at the encoder, you have to see the 3 zeros have come, only then we will do that, right. So coding delay is implicit in (())(37:24). It will be good exercise for you to do, try to design the encoder and decoder for both AMI and HDB codes. I would like you to do that as an exercise.

Student: In the lab?

Professor: Well, do it on your own even if you are not doing it in the lab. All of you please do it, there will be more exercise in both your digital logic (())(38:02) as well as, or you can use it in the lab or you so desire as a project. Any further discussion you want on this? So basically what we are saying is that data can be transmitted onto a, onto a digital line or a cable by using different kinds of line codes, right. Polar, bipolar, on-off, on-off and unipolar are the same kind of things and it will be useful also to study their spectral properties. There are a lot of lines, lines, things you can learn by looking at the spectral properties, looking at their power spectra, power spectra signals using different kinds of line coding schemes.

So let us spend some time on doing some maths or looking up on the power spectrum of such coded, line coded signals. How much time we have, only about 10 minutes. I will just start some basic idea about it, how to go about it, then we will complete the exercise next time. All line courses are special cases of a pulse train of the following kind.

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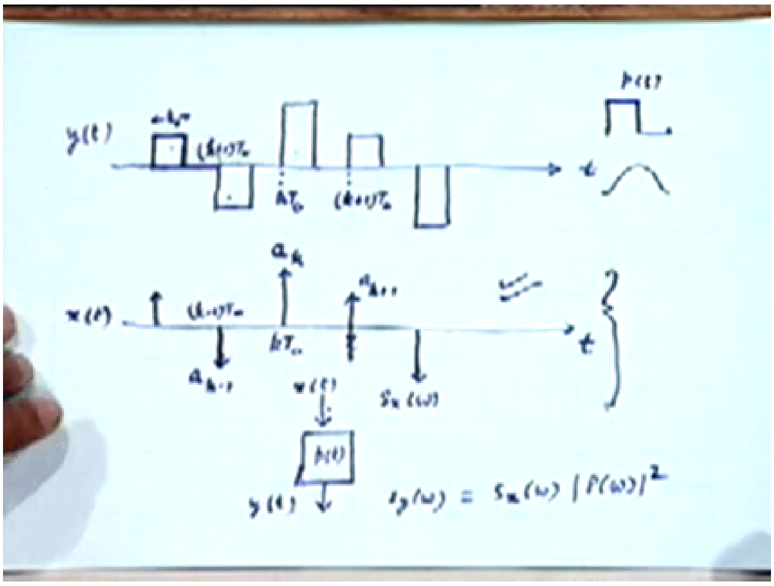

I am taking a fairly general situation here, where I am permitting even amplitudes to be variant, multiple amplitudes possible, right. So I am permitting positive values, positive discrete values, negative discrete values and also 0 values, right, in this general scheme of things, this is your time axis. Let us say the Pulse width is some T0 and let us say your this, these are your new pulse intervals, right. So this may be time interval, this may be time k T0, where T0 is your interval between successive bits, right. So I am now having a general situation where even your pulse width may not be equal to T0, it would be less than T0 and this will be K - 1 T0, this is K T0, this is K +1 T0, right.

So one can look at what data is being transmitted, that data will decide the amplitudes of these pulses somehow, either directly or indirectly and then one can complete the spectrum of this pulse train. If I take a rectangular pulse train and do this analysis, I can do it by some kind of Fourier series or autocorrelation analysis. But doing it that way only for rectangle pulses adds a disadvantage that if you change your pulse shape from rectangular pulses to some other pulse shapes, you will have to redo the calculation all over again, right. Therefore it is more convenient and more useful to do 1st a spectral analysis corresponding to an impulse train like that. Okay.

So this was your XT, this impulse everything represented by a sequence XT, then at K -1 T0 you have this impulse, as K T0 you have this impulse and so on. Let us say the strengths of these impulses are AK, so it is A K here, AK -1 here and some AK +1 here, where the values of A sub K -1, A sub K +1 will depend on the data sequence you are trying to transmit which could be a multivalued data sequence, multiple amplitude valued data sequence but discrete.

Professor: You have removed 2 impulses.

Student: Have I?

Professor: This corresponds to this, this corresponds to this.

Student: Why would coming down and coming back to 0?

Professor: No, I am representing this whole thing is by this impulse, right. That means in this waveform the pulse shapes being used is this over this duration. The waveform that you are using for one bit duration is not a constant voltage level over the whole duration but more general situation like that, this is a waveform being used, pulse waveform. Is it okay? If you say wish, you could have a waveform coming in the whole duration. So this would be the most general situation which would permit you all kinds of, in fact not most general, for a rectangular pulse cast would be the most general.

But you could have nonrectangular pulses, right, nothing that says that you must have rectangular pulses. In fact you will see later that in reality we will not be using rectangular pulses, we will be using other pulse shapes but we will come to that by and by. Okay. So what we would like to do is compute the power spectral 1st of a simple sequence which would be really a random impulse sequence of some kind, is not it? Whose amplitudes are some discrete valued random values, discrete random values, because we do not know what the amplitude might be, they are going to be covered by the nature of the data that is modulating these impulses, okay.

So if you know the power spectrum of this, one can derive the power spectrum of this very simply, how? By saying that I will pass this simple sequence through a filter whose impulse response is, let say this pulse shape is PT, so obviously the 5 past this impulse sequence through a filter whose impulse response is PT, what would be the output of this? YT, YT will be precisely this because every impulse that comes along with produce an output of the filter whose shape will be governed by the impulse response PT, right. So this impulse will, suppose your impulse response was this, it will create this response, the next impulse will create this response coming like that and so on.

Student: So will not it multiply (())(45:47) train of PT.

Professor: (())(45:53) A convolution of this impulse train, more the impulse response, right. And if your, duration of the impulse response is less than this period, each impulse response will die out before the next impulse comes, right. And therefore really you will get this kind of situation, right. That will be the case for our application, impulse response duration will always be less than T0, right. This impulse response PT will have a duration which is less than T0, it could be more but at the moment we are considering situations where it is less, any doubts?

So therefore 1st do a spectral analysis of this, then realising this relationship between this and this, given xx omega, the power spectrum of this, I can obtain xy omega, the power spectrum of this multiply Sx omega with, magnitude square of P omega and that is how you can derive this. So this is a more general approach and we will follow this approach because this does not depend on pulse shape. You compute this, any pulse shape you just have to compute the corresponding Fourier transform and multiply with that filters, right. So we will take that approach, I think we will start that next time, thank you.