Digital Communication

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Lecture – 15

Binary Baseband Digital Modulation Techniques

We are going to talk about digital modulation techniques today, okay you are all familiar with the process of modulation you have done it in the case of analogue communication whereby you understand by modulation the process of embedding the message on to a carrier that is what you understand by modulation so far in the context of digital communication, the definition is slightly different and more general.

We define the function of modulator to be a essential one of converting a stream of data into a stream of pulses which have to be put onto a what we can call a waveform channel right because the waveform the channel does not work with data, the channel finally works with or excepts a waveform for transmission over a physical medium, whatever that physical medium be right.

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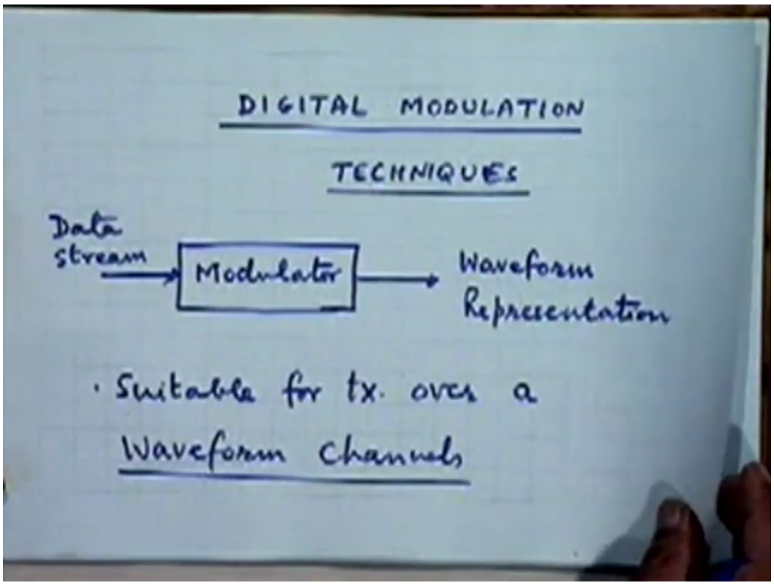

DIGITAL MODULATION TECHNIQUES

Data stream → Modulator → Waveform Representation

- Suitable for tx. over a Waveform Channels

So broadly speaking I can represent the function of the modulator like this, you have this modulator which accepts a data stream input and produces a waveform representation of this data right, that is a primary purpose of a digital modulator to convert a ripple this data stream become in the form of an abstract representation of data right whereas this has to finally be put in the form of waveforms and this waveform representation is suitable for transmission over a what I will call waveform channel.

And all physical channels that we work with trough which we transmit signals message signals or waveform channels right because they support the transmission of analogue waveforms, now waveform on channels are those channels in which the input as well as output functions of continuous functions of time as well as continuous functions of amplitude as (())(04:17) what I mean by a waveform channel right that is it accepts a continuous function of time and a continuous function of amplitude as its input and produces a similar continuous function of time and amplitude as its out, right. And most channels are, can be thought of to belong to this category

Student: What I continuous function over amplitude?

Professor: That is you do not have to, you are not having a discretization in amplitudes like quantization or anything, even we do the quantization before you do your encoding before the data comes through the modulator right but as far as the channel is concerned the quantization does not mean anything to it right, it accepts the continuous waveform as its input and produces a continuous waveform in amplitude as well as in time at its out okay.

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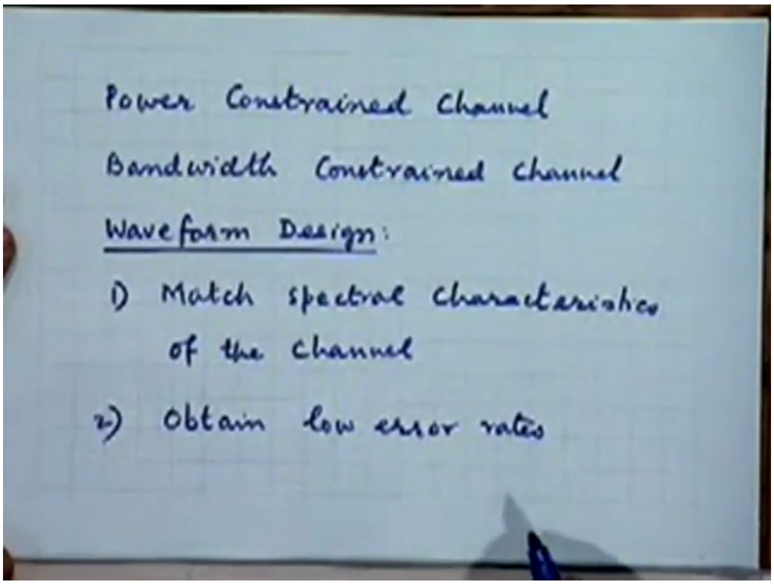

Power Constrained Channel

Bandwidth Constrained Channel

Waveform Design:

1) Match spectral characteristics of the channel
2) Obtain low error rates

So on this channels also, before I come to digital modulation again before I return to this paradigm because I am talking about channel briefly let me talk about that aspect of channel which is important from the point of view of waveform design and that is almost all channels for the purpose of digital communication can be thought of as either of a power constrained type, so you may have a channel which you may call to be a power constrained channel or you may call it a bandwidth constrained channel okay.

Now this distinction may be rather odd to you because as you will well realise both the constraints are going to be important in every communication system, the power constrained as well as the bandwidth constrained right but this when we say a channel is power constrained what we essentially mean is that the power constrained is more important in this scenario than the bandwidth constrained similarly when we talk about the bandwidth constrained you mean that the bandwidth constrained is more important than the power constrained.

Both are always going to be important but one may override the other depending on the situation we are in for example take a satellite channel right that is obviously power constrained is overriding constrained bandwidth is perhaps important but not the overriding constrained right similarly a telephone channel over which you may like to transmit data is essentially a bandwidth constrained channel right.

Because you have only that much bandwidth to work with so these are things to appreciate when we talk of digital modulations but remember whether we call a channel to be power constrained or bandwidth constrained both the constraints are important, one is more important than the other, other is not totally not important, now when you talk of modulation essentially that as you can appreciate from this block diagram we are producing a waveform representation for the data to be put on the waveform channel.

Therefore really the design of the modulator you can consider as some kind of a waveform design task right you designing the waveform for representing this data to put on the waveform channel, this waveform design that we have to do or the modulator that we have to design must be carried out so as to produce certain desirable properties in our system right and some of the desirable properties that we are looking for first of all the waveform channel that we are working with will have a bandwidth constrained possibly right.

So we should not produce waveforms at the transmitter which the channel cannot support in its bandwidth right so we must match the spectral characteristics of the waveform with those of the channel these are some of the things which are similar to what you might have learnt in the context of analogue modulations as to what is the function of the modulator right so we are considering a similar kind of discussion we are carrying out now for digital modulations.

What are the functions of a, what is a function of a digital modulator right what all it has to take care of, match the spectrum of characteristics of the channel that is the waveform that you produce should be in so matched, the second important requirement is in a digital communication system that whatever waveforms you use should be such as to produce a very low error rate at the receiver end right.

For a waveform design, the overall performance of course depends on both what you are doing at the modulator and what you are doing at the demodulator what waveform design forms a very important part of it, what you can do at the demodulator may be highly limited by what you are doing at the modulator right, so that is a very important thing to worry about that is waveform design when you want to worry about your data error rate.

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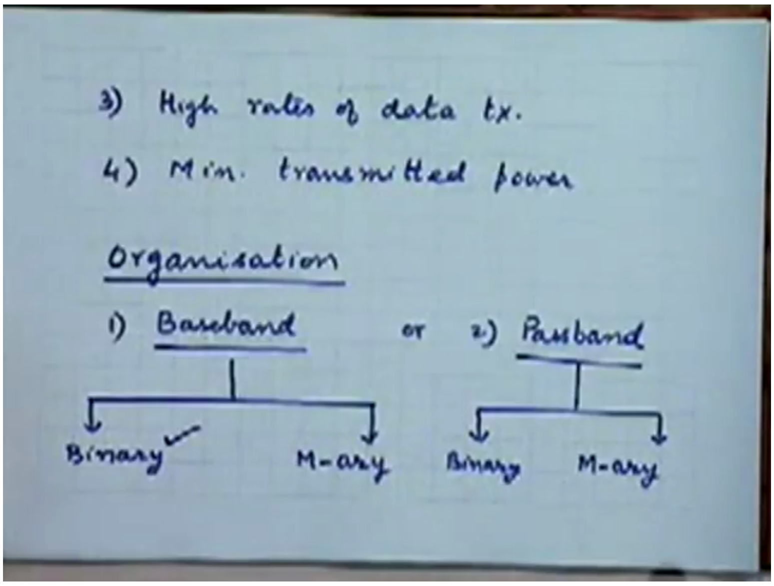

3) High rates of data tx.
4) Min. transmitted power

Organisation

1) Baseband or 2) Passband

Binary ✓ M-ary Binary M-ary

So obtain low error rates or bit error rates whatever, next we will like to transmit this data at as higher rate as possible right so we will prefer that the waveform should be such which permit high rates of data transmission and by high we essentially mean bandwidth efficiency that is we must be able to put in the data rate of as higher value in bits per second as possible in a given bandwidth pack as much data as possible every second in a when you have only given, available amount of bandwidth is limited.

And finally all these things we like to do with minimum possible transmitted power, so these are the four important attributes of a modulator digital modulator so minimum transmitted possible power, now of course there should be associated demodulator which will help us to recover the data from the waveform for any modulations scheme that you may think of, any waveform design that you may think of you must have also be able to think of a corresponding demodulator for it to recover the data back from the receiving waveform that is of course an obvious requirement.

So in (())(11:38) let us see what kinds of digital modulations schemes one can design right which not all modulations schemes will meet all these four requirements adequately some may be good in some attributes and some may be good in some other attributes and we will have to take cognisance of that (())(11:57) but we will not of course start with a proper waveform design approach to the whole problem because we cannot do waveform design with for example with all the requirements simultaneously put in front of this.

We will have to appreciate what kind of waveforms you are working with, how they are demodulated and unless we know how they are demodulated we cannot even think of calculating their performance and if you cannot talk about quantizing the performance, we cannot talk about a waveform design right so as far as presentation of this ideas to use concern we will have to take step by step approach.

What we will do is we will start talking about all possible kinds of waveforms that one can construct for digital modulations and later on I will consider the demodulation of these waveforms and then look at their performance right so the approach that I am going to follow is that in the first go we will just look at various possible waveform designs right without looking at how they are demodulated and what kind of performance can I result it.

Because performance calculation depends on how you demodulate them and demodulation will be just separate kind of subject which you will discuss and unlike analogue modulations the broad mechanism of demodulation is more or less same for every kind of waveform so we can discuss them altogether rather than discussing them one waveform corresponding demodulator, second waveform corresponding demodulator right.

So the approach then is that we will look at all possible classes of waveform that we can use as digital modulations schemes okay so the way I will organise this discussion is something like this I will first discuss, I will broadly classify all possible modulations as belonging to either of the baseband kind or of the passband kind, passband or bandpass whatever you like to call okay.

When I say baseband modulation we are basically referring to the fact that we are using a frequency band between 0 and something and then talking of passband we are talking about the presence of a carrier very deliberately introduced carrier which is present at certain frequency so the information is to be embedded in that carrier right in some way so first of all we will have these two categories baseband and passband modulations.

Then in each of these I separately discuss the binary case first because that is simpler, binary digital modulations and then generalise them to what we call M-ary digital modulations okay similarly in the passband case we will have binary passband modulations and M-ary passband modulations okay so that is the way we will organise our discussion on waveform design from the point of view of digital modulations, obvious kinds of digital modulation techniques.

In fact we have already been discussing digital modulations not so explicitly in what we have been doing so far for example the pulse shaping and the line coding that we are talking about also is precisely performing the function that we are now concerned with that is representing data with a stream of pulses or a waveform right so we have already been therefore discussing binary baseband modulations quite a lot you know quite a lot about binary baseband modulations.

For example the rectangular pulses that we discussed various kinds of rectangular pulse configurations right along with a line coding schemes we could think of them as binary baseband modulations in which bandwidth is not an major constraint right whereas the later kind of modulation pulse shape design that we discussed the nyquist base pulse shape designs could be thought of as binary pulse shape modulations in a strictly bandlimited channel right.

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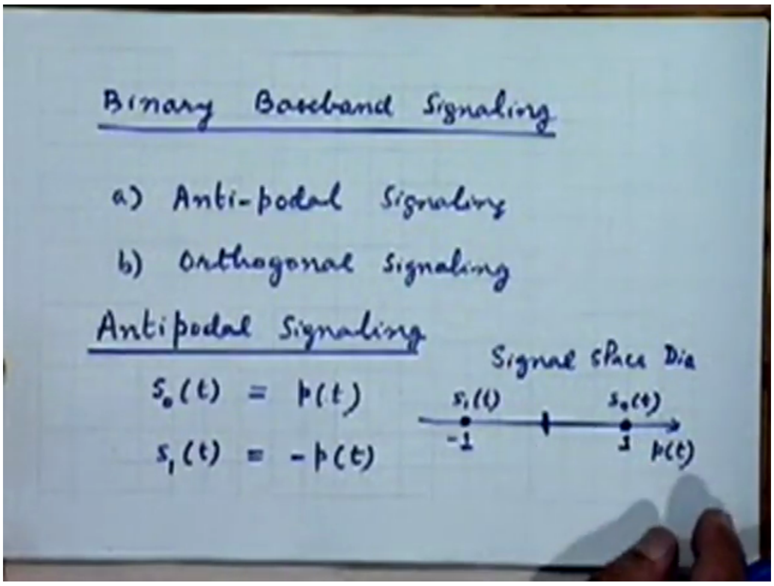

Binary Baseband Signaling

a) Anti-podal Signaling

b) Orthogonal Signaling

Antipodal Signaling

$s_0(t) = p(t)$

$s_1(t) = -p(t)$

Signal Space Dia

So I think it is what we are discussing here is not entirely new to you we already have discussed digital modulations not under this title but we already familiar with it but to formulise what we have done there let me just complete binary digital modulations first for baseband schemes by just generalizing a few concepts that we have discussed okay, so we first take up again very briefly binary baseband modulations, binary baseband signal.

Actually we have discussed them in sufficient detail but I like to just fill up what we have not done I like to introduce the concepts of binary anti-podal signalling and binary orthogonal signalling, now you will find that these are not really new things I am just introducing some new names to you okay the things that we do in anti-podal signalling generalise some of the things that we have already been doing.

Similarly the things that we do orthogonal signalling also generalise in some ways that we already been doing or discussing under our pulse shaping and line coding discussions but we will now like to generalise this and say that all binary digital modulations essentially can be thought of as belong to 1 or the other of this category okay and let us say therefore to understand that let us understand what each of these terms means.

Let us come to anti-podal signalling first, actually anti-podal signalling is just another name for polar signalling, it is nothing really new so it is you can say it is same as polar signalling in which I have two possible waveforms which I can use this is a notation that I am going to generalise and introduce here now I will write two waveforms S sub o and S sub 1 or S sub 0 and S sub 1 of t to represent, see after all what is the modulator doing converting 0s and 1s in the binary case to waveforms.

So basically it is carrying out a mapping of bits to waveforms and this mapping is precisely represented here that when a 0 comes along it will transmit a waveform S o when a 1 comes along it will transmit a waveform S sub 1 right, so in the case of anti-podal signalling basically you have one basic pulse shape which you may call p t right and you either transmit p t or minus p t which is the same that we have discussed under polar signalling right.

So anti-podal signalling or polar signalling are the same thing that is what you have to understand you may also represent these on what is called signal space diagram, this is a signal space diagram for anti-podal signal what we do is we take now this is a one dimensional space really because both the pulse shapes are really same okay they are not different pulse shapes so we can represent it by what is called a one dimensional signal space representation where this is an abstract representation, this axis is assumed to represent the waveform p t right.

The x axis is assumed to represent the waveform p t this slightly familiar with a (())(21:13) diagrams in which you take your reference axis to be cosine omega t and sine omega t right similarly you are taking the reference axis here to be the waveform p t so in this, on this axis on this one dimensional space we can represent S o with a pulse of amplitude 1 which shape p t right so this point on this line therefore represents S o right, it does not matter whether it is S o or S 1 here and slowly this point will represent.

Actually yes this is right normally we would have done the other way around S 1 t equal to p t and S o t is minus p t but it does not matter, it hardly makes any difference so this point represents S o t and this point represents S 1 t okay and we will return to these signals these diagrams wherever it is possible to do so, so nothing new here.

It is just a representation of this binary signal set, we used a signal set which consists of two signals S o and S 1 these two are being represented as two points on this signals space whether signal space is just a one dimensional space in which this dimension represents just some skilled version of p t right any point for example if I have taken this point which is half of this that is what represent half p t right somewhere here.

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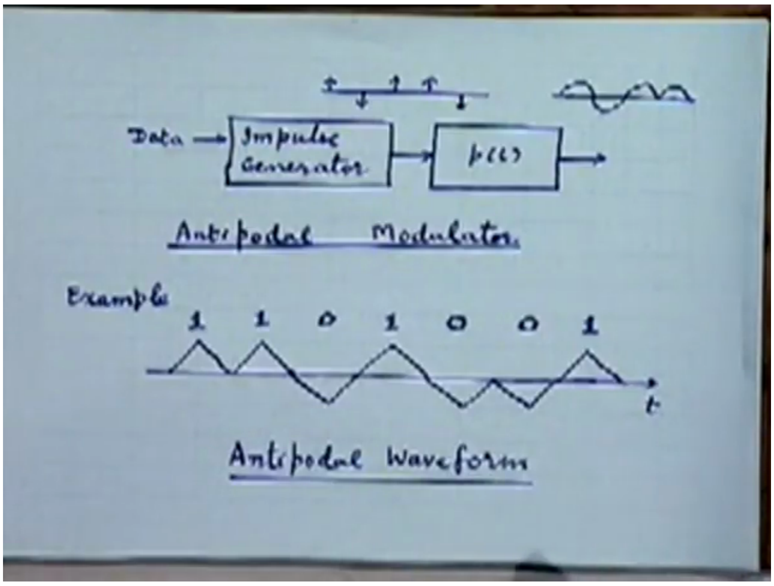

Antipodal Modulator

Antipodal Waveform

If I had chosen a point here which is twice this amplitude that way I represented it two way, yes I will write 1 and minus 1 or whatever you like this 1 represents a co-ordinate right okay so an anti-podal modulator is really basically we can realize it this way you have data coming in which is represented eventually by a sequence of positive and negative impulses by using perhaps an impulse generator, that impulse generator, that sequence of impulses is fed to a pulse shaping filter p t and depending on what p t choose here you will get a sequence of positive or negative pulses right.

Something that we already know nothing new about it, so that is what anti-podal modulator looks like this is an example of an anti-podal waveform right corresponding to p t being a triangular pulse right, a chosen p t to be triangular pulse so when you transmit the positive triangular pulse that represents a 1 when you transmit negative triangular pulse that represents a 0 okay, 1, 0.

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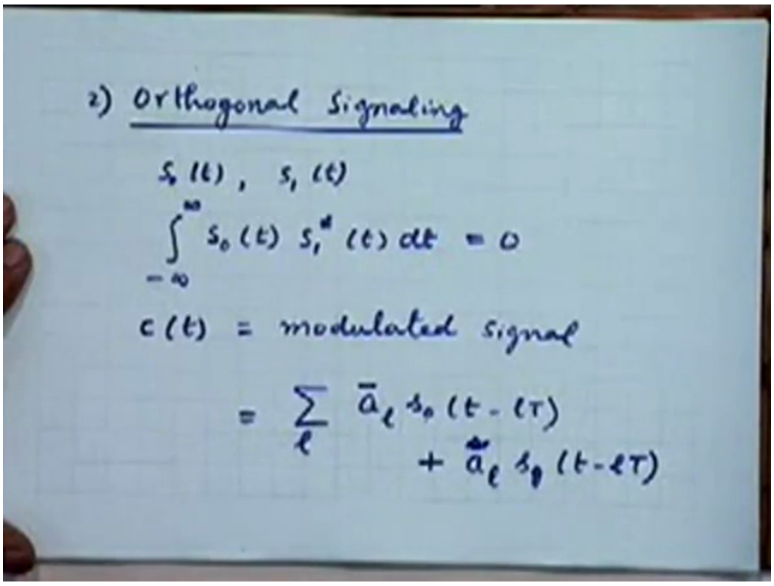

2) Orthogonal Signaling

$s_0(t)\ ,\ s_1(t)$

$$\int_{-\infty}^{\infty} s_0(t)\, s_1^*(t)\, dt = 0$$

$c(t)$ = modulated signal

$$= \sum_{\ell} \bar{a}_\ell\, s_0(t - \ell T) + \tilde{\bar{a}}_\ell\, s_1(t - \ell T)$$

So as you can see there is nothing new here I have just introduced a formal terminology which is used in digital modulations, binary digital modulations to complete the discussion, no new concept has really been introduced okay, can I go up next thing okay, we now take up the case of the second kind of signalling I mentioned which was that, orthogonal signalling right, orthogonal set of waveforms so when I say orthogonal signalling I am essentially referring to the fact that according to some definition of orthogonality, the two waveforms S o and S 1 are orthogonal to each other right.

And just to keep my discussion as general as possible we will see the usefulness of doing that a bit later we will consider the, we will permit the signals to be complex valued in nature from now onwards okay for example you could use two pulses shapes S o and S 1 which are both complex valued that is at each point in time the value amplitude is as a real part as well as an imaginary part right.

We will just keep that discussion general for the time being, without worrying about why that is important but I think you already haven’t introduce the introduce to the notion of complex representation of signals, that is right we will return to that in the context of digital modulations later, so we say two signals are orthogonal or a set of binary signals are orthogonal when this property holds okay.

That is you multiply the two signals in time and integrate the product from minus infinity to plus infinity the average value or the value of this integral turns out to be 0 and therefore the modulated waveform now consists of pulses which are of this kind they are no longer anti-podal right, they are different pulse shapes unlike the anti-podal case S o t and S 1 t maybe different pulse shapes in the anti-podal signalling you are basically using one pulse shape positive amplitude represents 1 and negative amplitude represents 0 or vice versa right.

But here S o and S 1 maybe physically different pulse shapes okay, different kinds of waveforms and your overall modulated signal which you put in the channel let me represent that modulated signal by c t so c t is the modulated signal you can represent it as it will be either a sub l s o t minus l t this will be true if a l is, when I use a s o when l al is 0 right when the data corresponding to that is 0 or it will be s 1 excuse me al bar s1 t minus l T right.

That will be the case when al is 1 and al is 1 will be using this waveform, (())(29:04) this is the final wavefrom which is a superimposition of this pulses right, this pulses whether you will be transmitting 0, s 0 or s 1 will depend on whether al is 0 or should be other way around, it should be al bar here al here I am sorry okay, where is this condition comes from this condition of orthogonality can you guess why do we require, no that is okay those are examples which I am going to discuss very soon

No we have to discuss this in the context of digital modulations why do you think such a thing would be required?

Student: Sir we can (())(30:00)

Professor: Okay that is closer to the answer but I am more, the important thing is you require some attribute by which we can distinguish between the two signals right in the case of anti-podal signalling that attribute was a sign of this pulse, same pulse right now we have a more general attribute and that is the shape, different shapes representing different messages can we distinguish from each other through the property of orthogonality right.

And if we, it so turns out that this is very closely linked to it how we demodulate waveforms at the receiver right because at the demodulator we require to carry out a correlation operation right and therefore this concept of orthogonal signalling is linked with the kind of demodulation we do at the receiver and we will return to that discussion again when you do digital modulations okay.

Let me take a few examples now of orthogonal signalling, now I would not consider cosine omega not T and sine omega not T for minus infinity to plus infinity why, that will be a useless signal for us we want to transmit data the signals have to be pulses of finite duration or at least apparent finite duration so I cannot consider cosine omega not T and sine omega not T as we know from T minus infinity to T plus infinity to be the right kind of waveforms in this context.

Yes they are orthogonal but we cannot use them in any digital modulation okay, the most trivial example of orthogonal signalling is one that you have already done what is that in the context of binary modulations it is the On-Off signal right, it is a very trivial example of orthogonal signalling right because the two pulse shapes are p t and 0 right, so the product is always 0 and therefore they are orthogonal, that is trivial so I will not discuss it any further.

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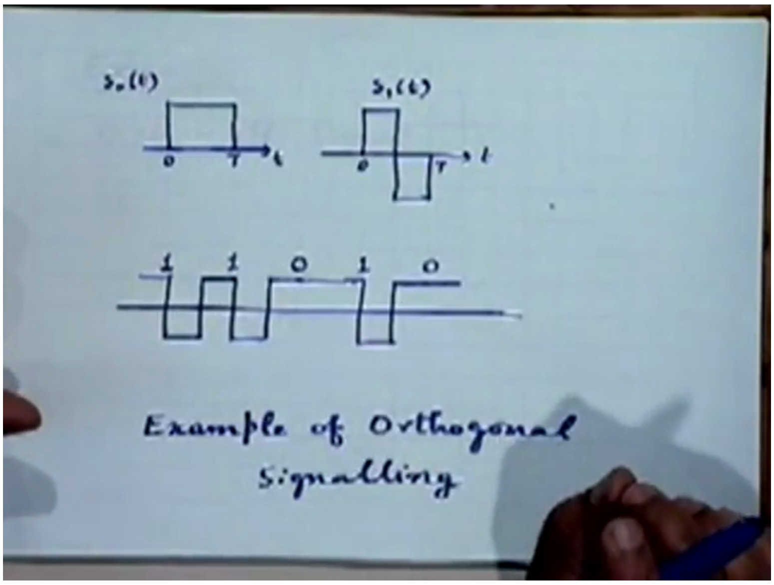

There is another example, I think I have it drawn here so I will just show it to you, S o maybe a pulse, rectangular pulse of this kind or a rectangular pulse of this kind right as you can see if you multiply the two the product will be this right and the integral of this will be 0.

Student: Sir Manchester coding

Professor: No Manchester coding is (())(32:52) okay what is a Manchester coding it is anti-podal, it is anti-podal right, all waveforms we discussed so far were anti-podal or On-Off right but this is a different kind of wave, there are different pulse shapes one is this kind of a pulse, other is a different, see Manchester coding basically the pulse shape is same just change the sign right now this is just to illustrate to you that sometimes looks can be very deceptive.

Here is a waveform that will result from the modulator corresponding to a specific sequence when you use these two signals for example you transmitting your 1 that means I am transmitting this right, first 1 is a 1 so that corresponds to a pulse shape like that right next is again a 1 so you get this, next is a 0 so you get the constant value here a 1 and a 0 again right this represents the sequence 1 1 0 1 0 alright.

Now that may look to you if you just look at the waveform without looking at where it came from or how they were generated how this waveform was generated you might be led to believe that this is a polar waveform, anti-podal waveform right but it is not, it corresponds to an orthogonal signalling set so it is an orthogonal signalling example so by just looking at the example we cannot always say whether the incoming waveform is of this or that kind.

That may be true a DC 0 maybe true because on average you may have equal number of positive and negative pulses from 0 and 1 pulses and okay may not be true, may not be true right so in that case you will have to do some line coding and all that in addition to this or another thing we can do to take care of DC problems which we have not discussed I like you to read it to yourself is scrambling of the data signal right so

Student: What do you mean by line coding?

Professor: That is you can reintroduce certain desirable features like

Student: The 1s when we have we decided upon this (())(35:27) What do you mean by line coding, we do the pre coding

Professor: Now that is a good question I am just thinking about it

Student: Sir there is no need of, because we are doing orthogonal so other things are, the line coding will not (())(35:43)

Professor: Let us put it this way that if DC level worrying is important in the context in which we are going to use it we will have to do something about it right and there are various things we can do one thing that we can do is we can redistribute 1s and 0s in such a way that the average value is 0 right

Student: Sir because the average of 1 is always 0 but

Professor: I know I know but if I have let us say more 1s and less 0s

Student: Sir we can do one thing, and then you can have 1s and 0s distributed so that (()) (36:27) for the shape of S0 T

Professor: Okay I think you raised a very important point which I cannot immediately answer, can we control the discussion a little bit, it is an important point that you have raised and I cannot immediately answer it perhaps the reason is that not everything can be mixed with everything else perhaps I will return to this later I do not think I can react to it immediately I will have to think a little about it as to what you do about DC in this kind of environment okay.

We will talk about it separately later on to that okay another example of so this was a second example in which you use pulse shapes of this kind and right or basically to illustrate to you the fact that you have different kinds of pulses now a third possible example is can we limit the talking please, third example is this cosine and sine that you refer to but with a difference, the difference is, these are now pulse shapes with limited duration and therefore you have to careful about something.

S1 t would be, actually I am not talking about cosine and sine I am talking of two signs of different frequencies okay, not always, not always, now to ensure that sine 2 pi fo t into sine 2 pi f1 t is 0 between we are integrating between 0 and t what you need is that fo and f1 should be integer multiples of 1 by t right so either actually 1 by t or 2 by t and so on, so in general we will choose fo to be some m by 2 t and f1 by some m prime by 2T where n m, m prime are suitably chosen integer right.

Of course if fo and f1 are very high frequencies as compared to 1 by t then more or less you can see that they will be always orthogonal if these two frequencies are very high then more or less approximately one can say that they will be orthogonal right.

Student: Sir why do you have to introduce the concept of having a very high frequency and (())(39:32)

Professor: This is always true but this condition can be relaxed that they have to integer multiples of 1 by 2T right provided the two frequencies that we are talking about of very high frequencies right is it clear obvious to all of you fine okay if it is confusing you do not worry about it too much all I said was that if you want to relax these two conditions for these two frequencies to be integer multiples of 1 by 2T you can do so provided you choose these frequencies to be very large.

Because in that condition it is both of them right in that condition the average, most of the time, for most of the value between 0 to T the average value will be sometimes positive and negative equally and the product will average out to 0 possibly there will be a small cycle of 1 or the other waveform that will be non-zero or something that will contribute to non-zero correlation anyway that was just by way of illustration.

So here is an example of this kind here your S o t is like that and your S 1 t is like that right as you can see both integer multiples of 1 by 2T the frequencies right or a time periods are the multiples of T by 2, what multiples, what should I say 2T by m, we have of the kind 2T by m right actually that does not matter we just have to worry about the frequencies, look at the frequency that is easier to visualize.

You have chosen here how many cycles in T? Three, that means so what is f not in term of, what is m here, m is 3 right yes sir and here m is, m prime is 2 by 2T right and this is what the final encoded waveform will look like modulated waveform will look like, so that is an example, second example of orthogonal signalling. That is a, (())(42:27) yeah I have been doing that okay this will be 1 0 0 1 1 sorry, yes thanks for pointing that out, good to know that you are not sleeping okay.

One mistake is enough alright incidentally before I go to the next thing this kind of, this kind of the two comments here, one is you can see that as you go from a 0 to 1 or a 1 to a 0 what essentially you are doing is changing the frequency of the some kind of a carrier that you have over here okay it is not really the concept of a carrier it is more like that you are having two waveforms with different frequencies right, two waveforms with different frequencies.

So for this reason such waveforms are also called FSK waveforms, frequency shift key waveform such binary waveforms are also called or such signalling scheme are also called FSK signalling schemes and the initials standing for frequency shift key in fact the general class of orthogonal binary signalling is sometimes loosely referred to as frequency shift key class for example even the previous example the on off and this kind they all belong to the general class which is something just loosely called FSK.

Although strictly speaking they should be called orthogonal okay, because the reason is the most commonly used orthogonal waveforms is the FSK waveform okay so that is the reason for this special name taking over a general name okay, this is frequency shift key that is for representing a 1 you are using a waveform S1 t which has this frequency which contains one cycle in this duration whereas here is a sine wave with a larger number of cycles in the same direction right so the frequencies of these two sinusoids are different right.

Student: Sir the first case is something like this (())(45:01)

Professor: That is right, therefore there is a reason for clubbing all of them as FSK waveforms right or calling all of them loosely as FSK waveforms right but this will have a advantage other than DC problem that we had spotted there we no longer bear problem here okay.

Right it can be there, because there is a net positive area here, yes you are right absolutely fine so as far as binary baseband waveforms are concerned this is all I have to say, the second comment I wanted to make was 1 was regarding the FSK, the second comment I imagined to wake in this context was a fact that the FSK kind of signal can be a baseband signal or a pass band signal depending on what frequencies are we talking about.

For example the kind of situation I have depicted here is a typical baseband situation right where you have very small number of cycles of this sine wave in your pulse duration in your symbol duration when you choose a very high frequency for example higher frequency and you may represent the two bits by different values of the other frequency but both are very high then it becomes a passband modulation.

Basically the frequencies is what matters, the absolute value of frequencies if the number of cycles in the waveform of the sine wave is small right for example of the kind I have depicted here, 1 cycle, 2 cycles, 1 and a half cycles, 3 cycles right these are all because basically your first duration and your frequency of the same order right basically that is our, the order of magnitude of a twist so we call it a baseband FSK waveform whereas if we have a set of frequencies which are very high as compared to the time period here that is the large number of cycles of this waveforms then we say they are passband modulations. One question at a time, yes Vivek.

Student: Sir in short that if the frequency is high then it is passband,

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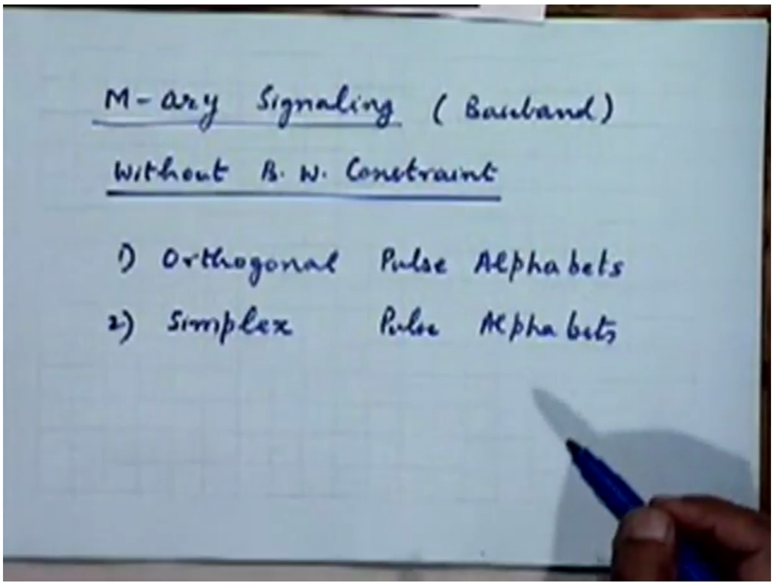

M-ary Signaling (Baseband)

Without B. W. Constraint

1) Orthogonal Pulse Alphabets

2) Simplex Pulse Alphabets

Professor: That is all I said, that is it (())(47:39) what is your question Vivek, no synchronization is a separate aspect and I think it is best to postpone it for the time alright as far as binary waveforms is concerned that is all there is to it let us go now to M-ary signalling, again first we will take the case of baseband in fact we have discussed we are so far discussing only baseband modulations, baseband digital modulations right okay.

Again I will discuss first the case of power limited channels not really, in which bandwidth is not a major constrain let us first talk about those signalling, M-ary signals in which bandwidth is not a major constrain and when bandwidth is a major constraint I think you already know what to do, let me ask you the question we do not have to discuss, suppose bandwidth is a constrain how do I go to M-ary signals? How can I, we have discussed the bandwidth constrain binary signals.

For example a pulse p t, anti-podal signals can be used with p t shape by the nyquist criterion or whatever you see typically the important point to note is the essential difference between waveforms that we will use for bandwidth constrain and non-bandwidth constrain channels is this, in non-bandwidth constrain channels you may use pulse shapes of different kinds but in bandwidth constrain channels you typically use one basic pulse shape whose bandwidth you will restrict according to what is in the nyquist criteria right.

So in the binary case the only kind of waveform, only kind of modulation that makes sense in the bandwidth constrain situation is an anti-podal waveform with p t chosen to be a nyquist pulse or a duo binary pulse or whatever right, in the M-ary case we can generalise it to a multi amplitude modulation scheme with pulse amplitude modulation scheme with that basic pulse used with different amplitudes right.

So we will return to this later but I just wanted to bring it here at the moment let us consider when bandwidth constrain is not important so without bandwidth constraint is the case we are discussing now and primarily here again there are two important classes like in the binary case these are essentially generalisations of what we have discussed in the binary case, what we discuss there was anti-podal and orthogonal right.

I will first talk about orthogonal here, orthogonal so now we are going to talk about M-ary orthogonal schemes okay and then corresponding to the anti-podal case in the binary case we have the more general what are called simplex signals in the M-ary case okay so we have two kinds of pulse alphabets these are also called signal sets, pulse alphabets you know there are number of different names which are used to say the same thing okay.

Basically a dictionary waveforms that are used for but what is the basic idea of M-ary schemes? The basic idea is that instead of using 1 bit to map on the waveform, you get a group of bits and represent this group of bits by a single waveform right so for example I may use two bits at a time and the 4 possible values which can take, I will have a dictionary of 4 possible waveforms right, alphabet of 4 possible waveforms.

So instead of having only the waveforms S sub o and S sub 1, I will have a waveform S sub o, S sub 1, S sub 2 and S sub 3 right and I will have a mapping scheme by which I will say when 0 0 comes go to the first waveforms 0 1 comes go to the second waveform and so on and the modulator we will essentially be a device which carries out this mapping okay. Now okay I think we will start from this point next time, thank you.