Digital Communication
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Lecture – 12
Partial Response Signalling: Duobinary & Modified Duobinary Pulse Shaping

Let us get back to the discussion we were having yesterday if you may recollect we were talking about pulse shaping from the point of view of eliminating inter-symbol interference and we have introduced now a set of pulse shapes or family of pulse shapes which are appropriate for this purpose which satisfy the so called Nyquist First Criterion okay, this family of pulse shapes, if you may recollect is basically an extension of the idea behind the sinc pulse itself.

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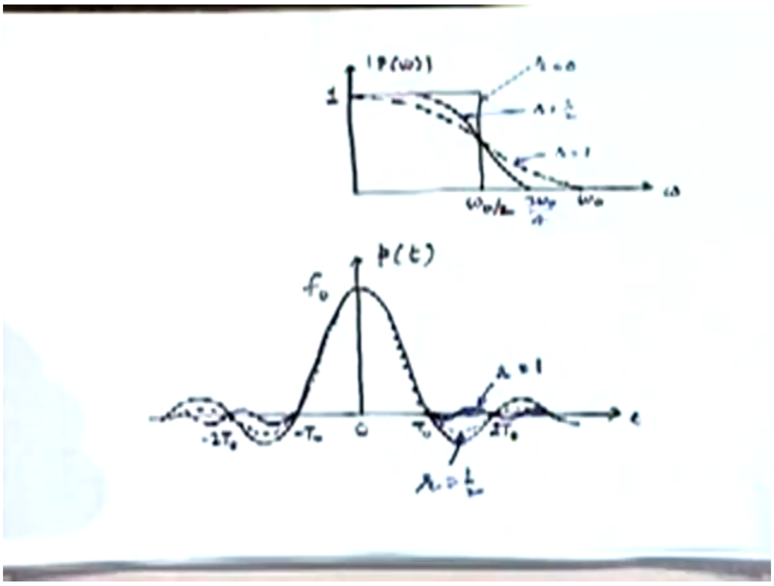

But unlike the sinc pulse these family of pulse shapes occupy more spectrum than, they occupy more bandwidth than the corresponding sinc pulse right, the sinc pulse has this brick wall kind of spectrum whereas these pulses have a more gradual roll-off decaying smoothly to 0 rather than suddenly to 0 and the net result of that is that you get the desired feature of zero crossings that regularly space intervals of T0 seconds at the data rate.

But instead of having very large side lobe levels we have very small side lobe levels and also the asymptotic rate of the decay is also quite high, it is 1 by T cube as against 1 by T square, 1 by T of the sinc pulse, so therefore we call this spectacle pulse shapes for eliminating inter-symbol interference, this is the so called raise cosine family it is spectacle from two points of view, first it is perturbation tolerant to timing errors right.

Any perturbations that may take place in timing will be tolerated much better causing much less inter-symbol interference in the case of these family of pulse shapes than the sinc pulse itself, similarly it is also practically realizable more easily because the kind of spectrum that they have is easier to approximate with real life circuits then this kind of spectrum right, you can appreciate the difficulty in realizing a spectrum of this time which has a certain fall, very sharp transition.

Whereas a spectrum which has fairly gradual roll-off is much more, much easier to realize by real life component like RLC components suppose you are to decide to do it by using only a passive filter you could do so by approximating this gradual role of characteristics with an appropriate rational function because RLC circuits can only realize rational functions of frequency, ratio of polynomials in omega right.

So you can approximate this by a suitable polynomial and then realize that rational function by means of an RLC circuit the approach is to do that or you could do it by some other means but the fact that it is gradual roll-off enables a practical approximation, renders the practical approximation to be much easier than the one which has this kind of characteristics okay of course we are not going into that aspects all at the moment because of time limitations.

Now so far so good, we, question that might arise from here is the following, what we have seen is that the minimum bandwidth required to transmit at f0 is f0 by 2 right the nyquist frequency or the nyquist bandwidth and if you want good perturbation tolerance what we have argued so far is we need excess bandwidth over and above the minimum, the question that people ask was is it possible to get rid of the menace of inter-symbol interference also have the nice desirable feature of perturbation tolerance to timing errors and still use not more than the minimum bandwidth that is a question that is of interest today okay.

And the answer to that is yes or no, it should be yes because I am asking a question right, but it is yes with a qualification and the qualification is you do not completely eliminate inter-symbol interference you in fact introduce a certain amount of inter-symbol interference deliberately at a transmitted sub, the only difference is since it is being introduced deliberately and by design by you, you know precisely the manner in which this inter-symbol interference is taking place and can eliminate it in an appropriate manner at the receiver can take care of it in appropriate manner at the receiver.

Rather than this inter-symbol interference taking place on the channel in an unknown manner you are allowing it to take place in a design manner so that you can later take on take care of it and the moment you allow this kind of a thing it is possible to do what we were trying but we just wanted to do namely get all the three features in one, three features being perturbation tolerance using minimum bandwidth and good realizability, easy realizability right.

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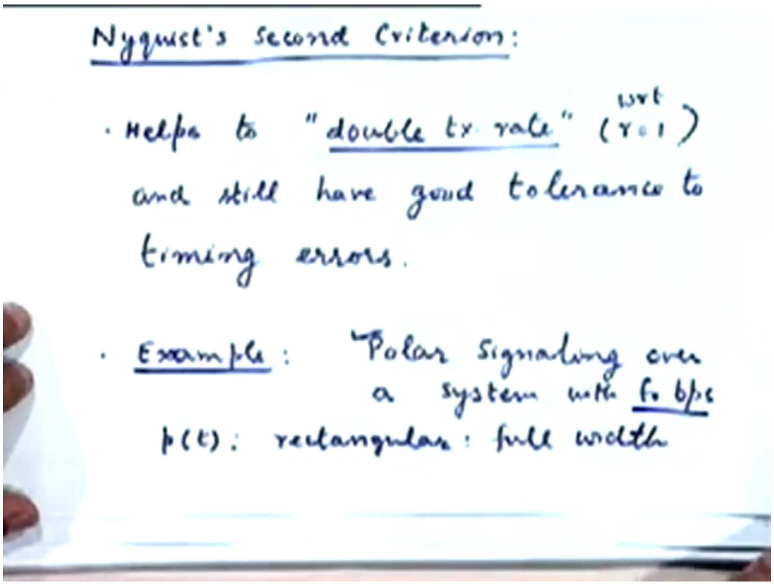

So let us see how we can (())(06:54) and this in fact brings us to nyquist's second criterion for which deals with this issue, the nyquist first criterion was based on eliminating inter-symbol interference altogether whereas nyquist second criterion instead of saying we should eliminate it all together permits a controlled amount of inter-symbol interference will take place at the, in the pulse design itself okay that is essential difference.

Now what it helps to do therefore is the net effect will be, we will be able to double the transmission rate right as compared to let us say the raised cosine family with r equal to 1 raised cosine pulse with r equal to 1, there the bandwidth required was f0, f sub 0, yeah it will be f sub 0 by 2, so if you are transmitting at f sub 0 using this kind of a technique you could double your transmission rate and still have good tolerance to timing errors right.

So either you could double the transmission rate half the bandwidth and still have good tolerance right, (())(08:48) doubling is respect to raised cosine with r equal to 1, with respect to r equal to 1 case, of course if you are using the sinc pulse then we are not getting anything but then the sinc pulse does not have this tolerance so we want both the features together we want bandwidth efficiency as well as good tolerance, these are the two features which we want together to be present.

Whereas as far as the raise cosine pulse is concerned with r equal to 1 we have achieved good tolerance with timing at the cost of bandwidth efficiency right, that is something that you must appreciate, now this is looks very interesting and surprising but actually it is a fact which was known if you want to early telegraphers then the only kind of communication that used to take place was by dots and dashes manual Morse code kind of transmissions.

Even they knew about this that if you have a communication system which supports transmission of let us say dots because dots are the one which appear faster at a certain rate f0 or f0 by 2 whatever one could double the rate from f0 by 2 to f0 on the same system by just simple trick of reinterpreting the received data, this was a trick known to them as long as worked 80 years ago or more even before Nyquist formulated this in a proper analytical fashion.

Now I will illustrate this fact by an example, so I am not at the moment coming straight to the nyquist criterion but just trying to motivate it by means of an example let us say we are back to our polar signalling right with the rectangular pulses, with full width rectangular pulses being used right so let us return to our polar signalling, let us say over a system of rate communication system which can support transmission of f not bits per second or f not digits per second or f not symbols per second alright.

And let us say the pulse shape that we are going to use p t is the rectangular pulse full width rectangular pulse okay, so suppose we have this arrangement our good old polar signalling, this is the bandwidth available to us, this is the data rate that we can use and the pulse shape is full width rectangular pulse.

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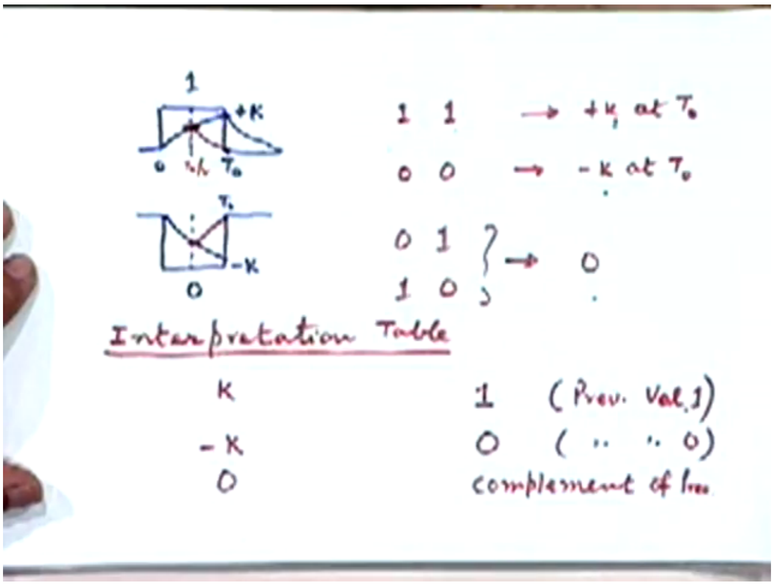

So what we are perhaps transmitting is either this pulse or this pulse alright, now since it is band limited to f0 and f0 is reciprocal of t0 right, the received pulse will not look like this is not it, you are passing this pulse to a low pass filter with bandwidth approximately the reciprocal of this duration right can you make a guess what can kind of received pulse you will get, going to get?

You will get a smoothen out pulse, it will rise slowly to some peak value and then decay slowly to some whatever is the value here right this is way you are going to, so it is let us say going to rise to some value plus k volts, when you transmit a 1 using p t of this kind at the, what you are going to sample at T0 is this peak value k on the basis of which you might try to decide whether a 1 or a 0 was transmitted.

Similarly if you are transmitting 0 by a negative pulse minus p t this will slowly build upto a value minus k as you mean symmetry of oppression and everything going ideally okay so under idle conditions at the sampling instant T0 you will see an amplitude either plus k or minus k okay on the basis of which you could decide whether a 0 or 1 is being transmitted, now suppose I double the transmission rate which essentially means there are now going to, if we use a different colour for that.

I am now going to use pulses of half the width right, instead of using a full width pulse corresponding to t0 I will use a full width pulse corresponding to T0 by 2 right, but the response to this pulse is going to be same so instead of building up to the full amplitude I will build up to this value right, similarly here instead of building upto minus k I will build upto to this value against I will not be at the end of T0 by 2, I will not be able to see the complete response of the complete build-up of the pulse which is expected out of that (())(14:42) if you were to transmit at a slower rate right, is that clear?

Therefore doubling the bandwidth obviously is going to create trouble in this channel because my response is much smaller as compared to what I could expected at the end of the full pulse interval right, however now suppose I would in this double rate situation were to transmit a sequence of two 1's, what will I get? I will get a full width pulse again if I transmit two successive 1's effectively I am transmitting a full width pulse and if I sample it here I will get a plus k value.

Similarly if I get a sequence of two 0's, I will be transmitting two pulses of this kind and I will again build up to minus k value so this will build up to plus k at T0, this will build up to minus k at T0 right and if it was a sequence of this kind either a 0 followed by a 1 or a 1 followed by a 0, what will happen, at this point the response will become 0 right, so now all I do is, I operate at double the speed but I make an interpretation not by just observing plus k and minus k but I observe whether it is plus k, minus k or 0.

If it is plus k, I know that the present bit is 1 and the preceding bit was also 1, if it is minus k the present bit is 0 and the preceding bit is also 0 and with this 0 the present bit is the opposite of the previous bit right so if I make an interpretation table of this kind then I am in business, I hope you appreciate that, so I think, let me make this table here, interpretation table now will be like this. (())(17:14)

Let me just finish this then you come back to your question, so you see the amplitude is K, interpretation is that the transmitted digit in the present interval is 1 and the previous value also was, is also 1 which is minus K, it is 0 and the previous values are also 0, if it is 0 it is the compliment of the previous bit so somehow if I knew my starting bit then I am in business right, suppose the starting bit was always fixed to be 1 and is it clear, basically what I will do is I will sample at very T0 seconds and make a decision okay, corresponding to the previous bit.

Student: Sir (())(18:18) you are sampling at twice the speed

Professor: You will be sampling at twice the speed, I will be sampling at T0 by 2, T0, 3T0 by 2, of course for the first bit, very first bit I will sample at T0 after that every T0 by 2 seconds right.

Student: So we will be sampling at every T0 seconds

Professor: No, because I need to make a continuous decisions at regarding the present bit as well as the previous bit. (())(18:44) I think that is trivial you can just check out yourself, this hardly requires any explanation, you need to look at each pair of successive pulses and pulses are being transmitted at the rate of reciprocal of T0 by 2 now okay.

So every pair of successive pulses with overlapping of one pulse right so that you can, in fact it will also give you an another detection capability to some extent right, because if you find inconsistent decision over two successive decisions then you know that there is some problem.

Student: Sir is it a half bit pulse or full width pulse the one in the discussion right now?

Professor: It is a full width pulse since your interval, similarly interval is no longer T0, it is T0 by 2 but respect to the old signalling interval, this half width, there is a confusion.

Student: Sir if there are three 1's continuously and.

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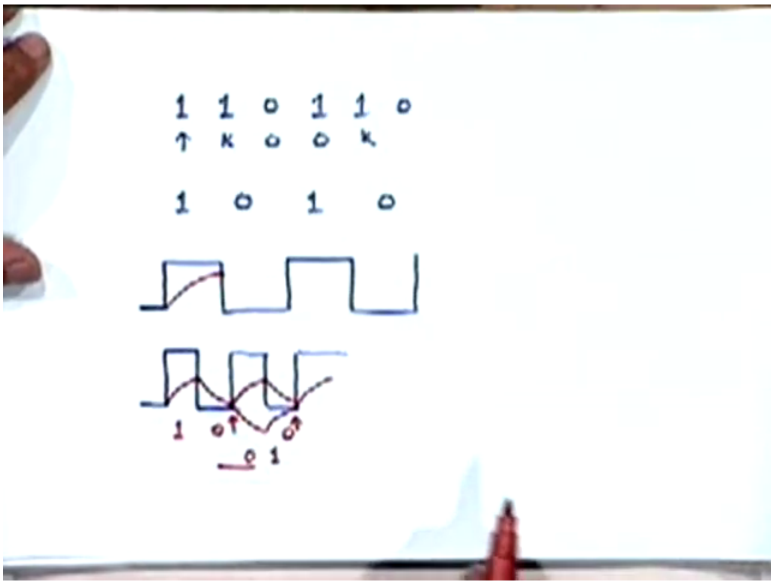

Professor: There can be any number of 1's continuously right, it does not matter only thing is, suppose I have a, alright let us take a fresh page, let me try to resolve your doubt suppose, you have a sequence like that right, that is why initial bit is always known to be 1, so I will look at this point if the received, we expect the received amplitude to be here plus k right, (()) (20:15) waveform will behave like that, let us assume that it is building up and building down in the same way that we have just described.

Student: (())(20:25) the half wave and full wave part.

Professor: See all that will happen is because we are transmitting at double the rate instead of building up like this, it is going to go like this and there is going to if the next one, the next pulse transmission is like that it will start building up like this so the waveform is this, this, this kind right, either it is building up or it stops here and starts building down these are the only two options at any stage right.

It builds to here or bits further or instead of going in this (())(21:03) it comes like that, if it is coming like that either it can go like that or it can go like that, so those things will not change right, so whatever I have discussed for one pair will continue to hold for every successive pair so here it will build up to K, will build upto 0 to 0 to K.

Student: Sir the point is that suppose it builds up to K and then there is a 0, it would not go down to 0, it would not go down to 0 there. (())(21:37) we saying that first we should (()) (21:44) and later on after every T0, the first sample should be at T0.

Professor: Yes okay I think you are right, yes okay that is right the sampling rate is at T0 because we are sampling every T0 seconds and at T0 seconds we expect the waveform to be building upto either plus K or minus K okay.

Student: Sir what you just take a sequence of 1 0 1 0 and (())(22:15)

Professor: Alright let us see 1 0 1 0 alright so.

Student: Sir we always assume that first bit is, starting bit is 1.

Professor: Let us, we have to make some assumption that is, so let us look at the waveform, this is what you are transmitting, this is what we are normally transmitting, transmitting double the rate okay, let us talk only of this (())(23:21) bits at the moment, so in this case it would have build-up like that right, now it will build up like that and then it will build up, build down like that right, build up like that and so on.

Now therefore if I am sampling here right, I knew that this was 1, I am sampling here so since this is 0, I know that this bit must be a positive of this, so this becomes, is it not according to same logic, the first bit I know is 1 right, now I am sampling here at T0 and finding that the value is 0 and that tells me that the polarity of this bit should be opposite of the previous bit, this is 0.

Student: (())(24:24) you have to sample it T0 by 2.

Professor: Okay there is a problem here.

Student: Sir the sampling does not make any difference, this logic is wrong.

Professor: What happens here that is the question, so I guess all it means is there are situations where this logic is failed right.

Student: Sir interpretation table we should have 1 (())(25:19)

Professor: Well I want it to deliberately keep it to only three levels system so as to motivate the duo binary system right, if you permit more levels yes what you are saying is possible but I think at the moment perhaps I should say that this is something which we worked most of the time but may fail occasionally right after all this is just an (())(25:48) way of doing things, it was just motivating you to what I really wanted to get you.

Student: (())(25:53) previous bit we have predicted a 0 and out there we have again got a 0.

Professor: Yeah one way of doing that would be there I was thinking about that, looks like it but we have to make sure that all possible combinations will be taking care of (())(26:14) yes he is quite right, see suppose if I sample it here and I find 0 here again but this could correspond to 0 1 or 1 0 right but you know if you keep track a bit round the past then this would not be possible. Why, because if we had a 0 followed by a 0, I would have built down to minus K which it did not to. (())(26:44) Okay I admit there is some problem here, it is not fully explainable, I do not, is it alright?

Student: We should get a 1 there because we are saying in the interpretation table that if it is 0 then it is compliment of the previous bit, previous bit is 0, it has to be 1, so 1 0 1, sir because previous bit is 0, so this bit should be 1.

Professor: I think we will leave this for a moment, I am not totally convinced about your argument.

Student: Sir but in interpretation table we have seen said that.

Professor: If one of you speak at a time perhaps we can discuss.

Student: As we know that two bits before that we got a 0 then there has to, that 0 has to be followed by a 1 sir and then it has again come back to 0.

Professor: For example here there is no way to know whether this is a 0 or a 1 here because I could have got this point either through this path or through this path there is no way for me to find out okay.

Student: Sir if we sample it T by 2, then?

Professor: If I sample it T by 2 either have to permit another level which I do not want to do for my motivation or I have to some (())(28:18) so there is some problem here which we will take cognizance of and I think leave it over here. The primary purpose of telling you this example was that thing like this was possible under certain conditions, may not be under all conditions okay, so I think we leave it at that with some limitations, it is not the main point of our discussion any way but unfortunately my motivation has not succeeded fully but it happens alright.

Maybe I am making some mistake but at the moment I cannot think of where the mistake is, we will leave it for a moment, we will not work with any more wild suggestions alright, anyway basically what I wanted to motivate was with a slightly fair in doing so properly that really speaking the basis of this trick that at f every two successive 1's will make it build up to plus K and every two successive 0 will make equal to minus K and 1 0 0 1 combination will make it equal to 0 that is similar to the logic of a nyquist second criterion.

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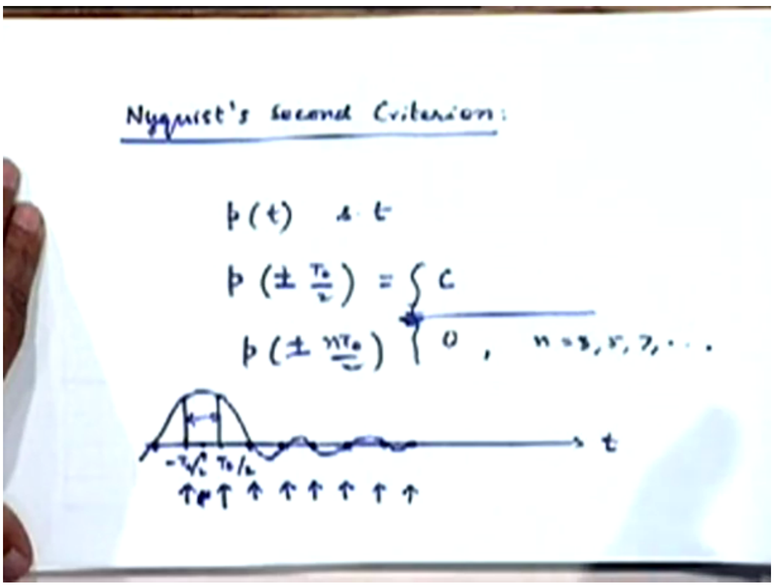

Let us hope we will not find a similar problem with the Nyquist Second Criterion, maybe after understanding this you can come back to this and see if you can resolve this issue, now this criterion is for the design of a pulse shape right, what it says is let us choose a pulse shape p t such that, see earlier what we said was p t is equal to let us say some constant at t equal to 0 and 0 at every other sampling instant plus minus n T0 right.

Here we are permitting some non-zero values other than just the central value in fact we are not even going to look at a central value right, we are looking at these values, the values of the pulse at plus T0 by 2 and minus T0 by 2, our receiving strategy will be based on looking at not the peak amplitudes at the signalling points but T0 by 2 away from the signalling points, at these two signalling values it says let us have some constants C as before.

But there are two of them now instead of one right, at plus T0 by 2 as well as at minus T0 by 2 but it is 0 so this it is just C at these two points it is 0 for, I should put this here p plus minus n T0 by 2 for n, let me separate this out, n equal to 3, 5, 7, etc so if draw this time axis t at minus T0 by 2 have some non-zero value at plus T0 by 2 have some non-zero value but from there onwards at intervals of T0 seconds separate it from T0 by 2, T sub 0 by 2, at all these points the values are 0.

So we are looking through, looking at some pulse which passes through these points right which has 0 here, this amplitude here, this amplitude here, 0 here, 0 here for example I could have some pulse shape like that okay that is what the Nyquist Second Criterion is all about, designing a pulse shape such that we may have inter-symbol interference from two successive pulses, but not from far removed pulses okay, basically that is the idea.

So such a pulse, is it okay, we will discuss it in more detail now I am just introduce the basic definition to you of the second criterion, (())(33:15) even? What is even?

Student: Like T1 n, multiples of T not n, multiples of T not.

Professor: Are you talking about even and odd? (())(33:28) oh that is because I want zero crossings only at these points, see the first non-zero value I am looking at is T0 by 2 from there onwards every T0 seconds I want a 0 crossing because what I am going to sample is at not these points, my sampling points are not going to be these, my sampling points are going to be these.

Student: Right, so you will have ISI coming from the previous sample.

Professor: Right, it is precisely what I was going to explain next okay, these are going to sampling, my sampling points are going to be not at multiples of T0 but at multiples of T0 by 2 and obviously since my sampling interval has to be T0, I have taken odd values here, there is no need for even values okay I am not going to look at here or here alright, can I remove this slide now?

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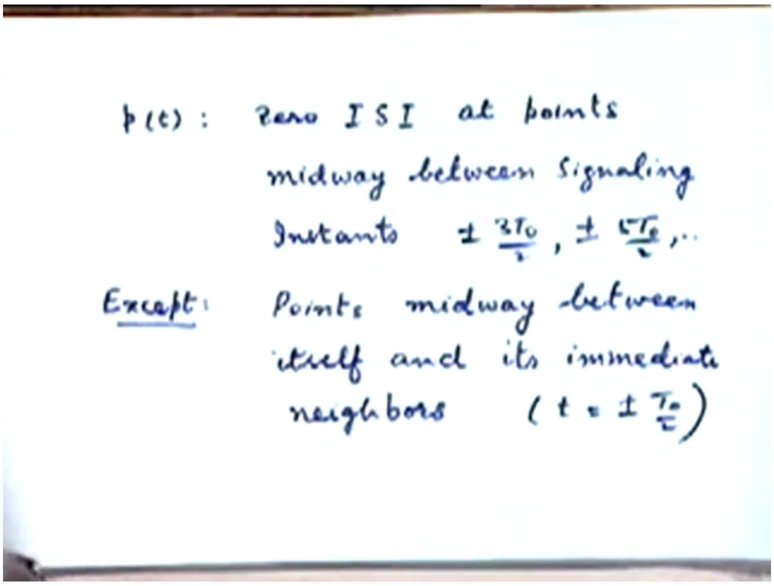

So what will happen is such a pulse shape will cause or will be associated with zero ISI if I sample at points which lie midway between signalling instance okay that is plus minus 3T0 by 2 plus minus 5T0 by 2 and so on, so if I sample at these points I am assure of zero ISI right from other pulses except with one exception, what is exception, except the points which lie midway between the current, along the neighbouring, sorry, midway between itself and its neighbouring transmissions except the points lying midway between itself, that is the current signalling interval and its immediate neighbours okay that is T equal to plus minus T0 by 2.

Now if you understood this broad idea behind this pulse let us get to the question of how do you synthesize or how do you specify a pulse of this kind with minimum possible bandwidth you should not loose side of our bandwidth requirement right, we want to continue to use the minimum possible bandwidth so the next question that arises is we will look at the functioning of this a bit later as to how we will decode our data using this pulse let us forget that for a minute.

Let us just look at the question of what kind of pulse shape should this actually be so as to give this kind of characteristic this kind of behaviour at sampling instance and also have a minimum possible bandwidth namely the Nyquist bandwidth can you think of a construction procedure it is logically very simple in fact question is not clear, synthesize a pulse shape having these kind of values at the sampling instants as prescribed here and having the minimum possible bandwidth associated with it corresponding to the signalling interval T0.

That is right, a combination of sinc pulses, each sinc pulse will be having that minimum Nyquist bandwidth right, so if I take two sinc pulses which are mutually displaced from 0 by minus T0 by 2 and plus T0 by 2 and we nearly combine them I will have all the desirable properties right, should be obvious, because shifting them to either minus T0 by 2 or to plus T0 by 2 will shift their peak values as well as their 0 crossings but both them, both these sets will have zero crossings at multiples of, odd multiples of T0 by 2 right.

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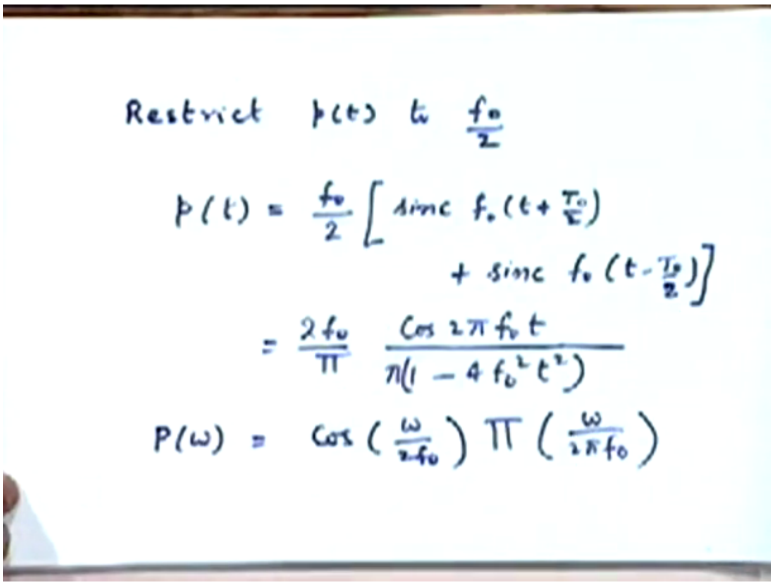

So when we nearly combine the zero crossing points will stay the same but the nature of the centre lobe will change right and that is the kind of pulse shape you are likely to dedicate so if the motivation behind it is clear the maths is then very simple what we have just argued is that if we restrict this p t to a bandwidth of f0 by 2, f sub 0 by 2 then the only pulse shape that you can think of is in fact is just some amplitude factor not very important a sinc pulse displaced by T sub 0 by 2 and a sinc pulse f sub 0 t minus T sub 0 by 2 right, fine, are you all with me on this?

Which again if you simplify very straightforward simplification will turn out to be equal to this functions that is a mathematical function of the pulse shape corresponding to this construction procedure if you are not followed please let me know so that I can repeat it, anybody who wants to repeat this or is it okay, good, for power spectrum of this is also very easy to evaluate because we know what is a Fourier transform of each of this, it is this rectangular function with the bandwidth f0 by 2.

So basically it is a two rectangular functions associated with a phase function into the power minus something right when you combine those two terms it will become cosine function, you will get e to the power minus j omega t0 by 2 from here, e to the power j omega t0 by 2 from here both of them otherwise a rectangular functions which will factor out so it is quite clear without going through the formalities that the power spectrum with the cosine function multiplying that rectangular function, right.

Cosine function coming from these two shifts, time shifts in frequency domain they will become exponential functions and e to the power plus j omega T0 by 2 plus e to the power minus j omega T0 by 2 will essentially (())(41:36) to this, the rest all normalization factors which you can take care of okay.

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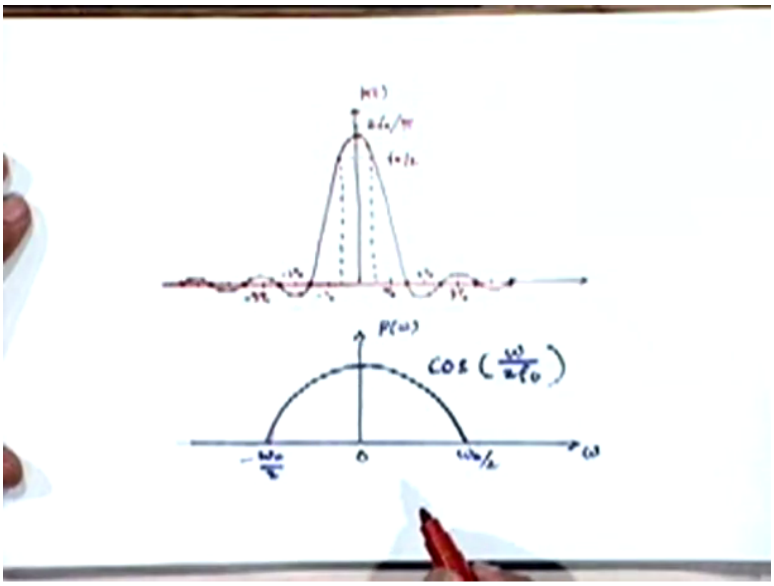

What is it look like, looks like this, that is your power spectrum you see it is confine to what this says here is there should be, it is a rectangular the overall confinement is between omega 0 by 2 to plus omega 0 by, that significance of this product function is function, rectangular function which is multiplying this cosine function right and within this that constant value is being multiplied by this cosine function right.

So you once again you have a cosine kind of function here and this pulse shape is given by this expression looks like this okay, you have at minus T0 by 2 you have some constant value at plus T0 by 2 you have some constant value but all other multiples, odd multiples of T0 by

2 that is here, here, here, here you have 0 amplitudes as desired, any questions regarding the construction and the spectrum of this pulse, since there is no question I believe it should be alright okay.

Now let us try to understand if we use at a pulse shape how do we really go about interpreting the received data and decoding the correct sequence, so one thing is clear use of this pulse shape will allow us to work with full bandwidth efficiency right, because we are not going beyond the nyquist bandwidth also intuitively you may expect this to be a well behaved pulse otherwise in terms of its side-lobe levels and things like that right, because we do not have a sharp transition in the spectrum, you have a gradual roll-off right, there is no sharp transition.

So it will be very easy to approximate also the corresponding pulse will decay rather quickly in fact a mathematical function here shoes the rate of decay asymptotically is 1 by T square right it is not as good as the raised cosine pulse with r equal to 1 for which it is 1 by T cube but still predictable it is 1 by T square alright asymptotically, so it has those perturbation tolerance features, it uses a minimum nyquist bandwidth right.

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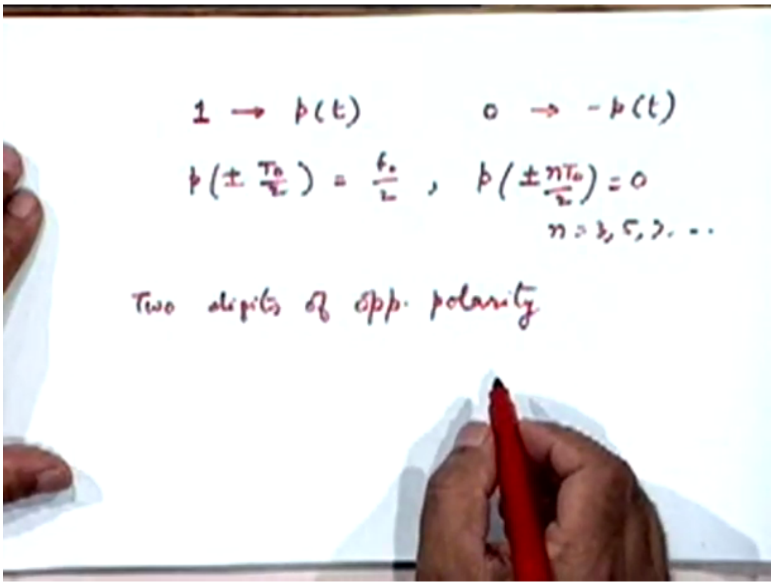

These requirements are match the only thing left to do is to understand how exactly we will decode the data when we use such a pulse okay, let us get that to that, to do that we have to think of the, we will have to talk about the coding scheme which will be same as a polar scheme as before that is we will say 1 will be represented by p t of this shape, 0 by minus p t right, at the receiver what we really be doing is sampling at multiples of T0 by 2, odd multiples of T0 by 2 right, so what we know then is this is going to be equal to some f sub zero by 2 and is going to be 0 for n equal to 3, 5, 7, etc I think best thing is to can you now.

Well in this case it turns out to be f0 by 2 is not it? For the specific function that we have finally constructed p t equal to this, its amplitude is 2f0 by pi which is the peak value which we are not looking at, we are looking at these values right okay now similar to the argument that I gave for the telegraph situation which we were not fully comfortable with but something similar to that holds here also.

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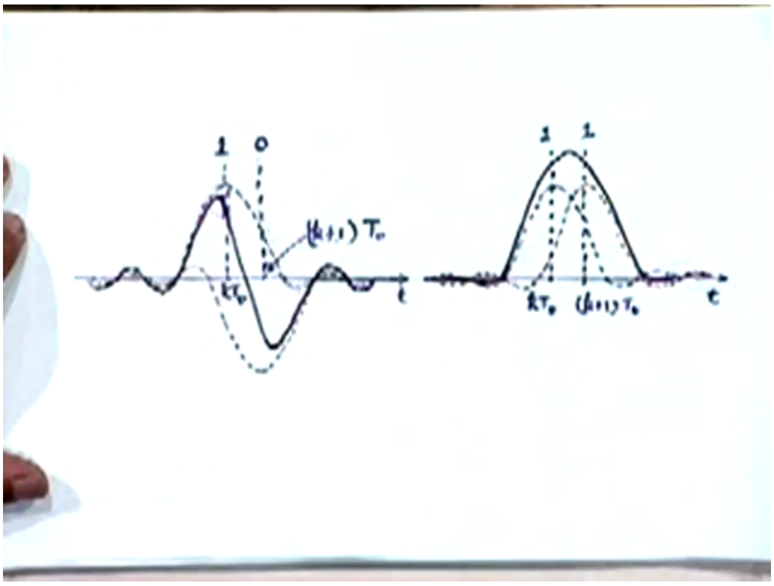

When we transmit two digits of a positive polarity what will happen at the midpoint I think I best illustrate by a diagram, I do not know whether you will be able to draw this in the time that we have here but I think it is more important to understand than to draw this picture right let us say I have a 1 followed by a 0 right for this 1, I have this blue waveform that is transmitted right it has, this is the peak of the waveform K T0 is the signalling interval right.

That is called corresponding to the symbol interval, symbol time K T0 this is where the peak value builds up, but at the receiver of course I am not looking at this value I am going to look at T0 by 2 seconds later right, the next one is a 0 which is a negative pulse of this kind, the only difference between these two is one is positive the other is negative and there is a mutual displacement of T0 seconds alright.

If you look at the resulting waveform of these two transmissions that this black curve is what you will, right you will find you are going through a zero crossing at K T0 by 2, K T0 plus T0 by 2 right, so a 1 followed by a 0 will result in a zero amplitude at the next sampling instance.

Student: Sir 1 followed by 0 will result in a 0 in between the two sampling.

Professor: At the next sampling instance, sampling instance is not here as I mentioned earlier it is going to be here, midway between the two, no midway between two signalling instance I am now differentiating between signalling instance and sampling instance right, corresponding to the signalling instant K T0, I am saying the sampling instant is K T0 plus T0 by 2.

Student: Sir what do you have to mean by signalling instance?

Professor: That is pulse actually arise there at time K T0 but I am not looking at the pulse, the peak value at this point but I am looking at T0 by 2 seconds later.

Student: (())(49:35) pulse actually arriving here at T0.

Professor: Well when I, it is in a loose sense that the peak of the pulse lies at K T0 in this context, okay, it is in a loose sense, the pulse has arrived of course long time ago right because of the tail there is a long tail with the pulse similarly you can argue, I thing is quite obvious 0 followed by a 1 would be again resulting in a of course it will be building up like that in the 0, a 1 followed by a 1 would lead to a situation of this kind, the blue curve followed by the red curve and the resultant curve would be this right.

Now if you look at the midway point here, no it will build upto some peak value, okay yes it will be left to f not because both of these are, this is also f not by 2, this is also f not by 2, the result will be f sub 0, okay I will go through the maths of that, I think that will come if you evaluate the function f T0 by 2 you will find that that function reduces to f0 by 2 okay, I skipped a bit of algebra okay.

So let us see what will happen what I have plotted here is what will happen when I transmit a sequence of 1's and 0's with an arbitrary set of pattern right you have 1 1 0 0 1 0 and if you were to put all those pulse shapes over here and find the resultant wave form this is what you will see okay so sampling at here will give rise to 1, sampling it here will tell me that so will tell me that there is a change in polarity.

Student: Sir here also you assumed that the first 1 is a 1, first bit is a 1.

Professor: Yes yes you have to assume that the first bit is a 1, quite true, because without that mean we do not have a reference to start with so that is required so there again we have since it is 0 followed by a 0 this is again change of polarity, again a change of polarity and so on right, of course I stopped here because there is no, I have not specify the next bit so the kind of situation we get is something like this.

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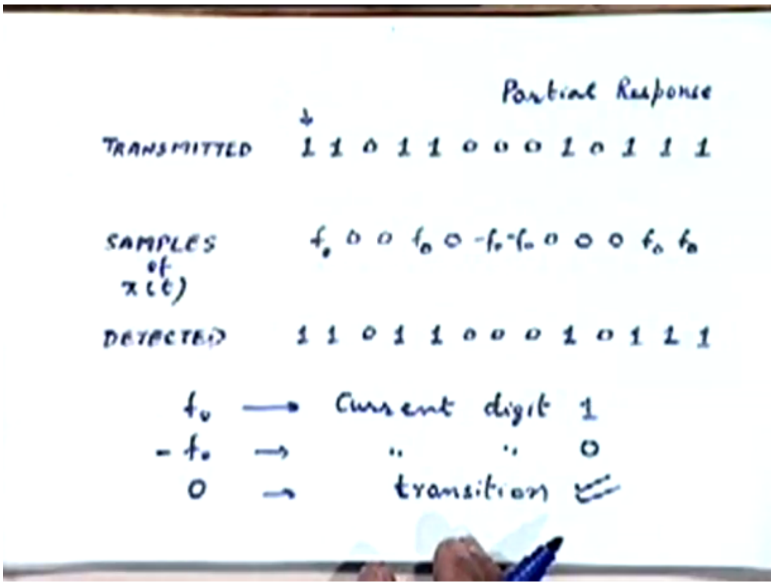

Let us say this is a transmitted sequence let us construct the waveform first as to if you look at the samples of the transmitted waveform x t what will that look like at (())(52:55) this 1 is let us say the initial 1 which you fix since the next value is also 1 we expect the waveform to build up to f sub 0 right since our next 1 is 0 it will return to 0 next is 1 again it will return to 0 and so on right and then it will be reinterpreted correctly.

So basically the logic is similar to what we have discussed earlier that if you receive f sub 0 interpret that the current digit is 1 minus f sub 0 current digit is 0 and if you get a 0 amplitude there is a change in polarity it transition is to be interpreted. So which is similar to what we try to motivate in the beginning or I hope that in this case there is no problem it does not look like.

Student: Current digit is, we again take a 1 0 1 0 in this case, current digit.

Professor: I will have to draw the waveform very carefully because there is a sinc pulse involved right I may not be able to do it very easily over here but we can try out that exercise, yes what is your question?

Student: Sir current digit refers to T by 0 2 after the sampling instant, after, because the first one, not the preceding one, succeeding one because preceding one we know right from the start, when we receive the first of zero we know there is a one in the first one so the one after it will be one, then we start the succeeding one.

Professor: That is right quite true, any other question? So this waves what is called in fact before I tell you what it is called, do you see something interesting in this transmitted pattern of samples?

Student: If they are separated by odd number of zeroes and same.

Professor: Something that you have seen before in duo binary signalling right, what you find is that even number of zeroes separate amplitudes of same polarity and odd number of 0s are separate, let us say between these two between amplitudes of opposing polarity right, which is precisely what you learnt in your duo binary signalling but then that was obtained from a line coding point of view, this is obtained from a pulse shaping point of view right, this is the result of the wave you have carried out of pulse shaping right and we are looking at the received pulses alright.

So therefore the Nyquist Second criterion pulses essentially duo binary pulses, duo binary signalling schemes of some kind, another thing to, another name that is sometimes used for these kind of signalling is called partial response signalling right, partial response signalling, I will mention it here, yes that is right this is what you are looking at that final, what are the advantages of what?

Student: Duo binary.

Professor: The advantage is this that we got everything that we wanted, we want, we have used only the Nyquist bandwidth you have got 100 percent bandwidth efficiency, 100 percent is the wrong way to use it here but in some sense it is 100 percent because this is a minimum required and you are using only that much right you have perturbation tolerance.

Student: We have the tolerance of on-off signalling.

Professor: Like what? Which problem? Not that of on-off signalling, this is polar signalling.

Student: Sorry polar signalling.

Professor: Those disadvantages we will get right. Whatever disadvantages polar signalling has those might continue right because we are considering polar signals, it is not bipolar it is really duo binary, yes it is bipolar in the sense that it has got three levels right but yes it is bipolar signalling so it is okay it is not even polar thanks, thanks for pointing that out, it is not strictly polar.

Although our scheme of allotment of 1 and 0 is polar that is we are allotting a p t to 1 and minus p t to 0 then that result is that the sampled values are exhibit a bipolar kind of duo binary kind of behaviour okay, so we have everything that we want in this kind of scheme in fact except everything except one thing can you tell what is the factor which is still missing. (())(58:10)

Okay that is a minor problem you will come back (())(58:15) important point that we have discussed before is the DC is not 0 right so that is something we will try to remember, how much time we have, oh we have crossed the time. I will just take a couples of minutes to tell you the point that has just been mentioned that in this kind of decoding scheme there is a problem, particularly due to this third entry here in this table right, you talking of a transition.

Transition means it is assumed that you know your previous digit correctly right, suppose there is a mistake in that due to noise or whatever then the error will propagate right, now this kind of, this kind of thing can be easily taken care of by pre coding the information at the transmitter itself by carrying out some kind of coding of your binary data at a transmitter itself or perhaps we can take care of in the next class.