Evolution of Air Interface towards 5G
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Lecture - 14
Waveform in 3G

Welcome to the lectures On Evolution of Air Interface towards 5 G. So, in the few lectures we have seen how the evolution of requirements have happened. And, we have also been seeing the basic signal structure which has helped us in understanding the way of representation and, how it lays the foundation for the second generation as well as for the fourth generation and the future generations.

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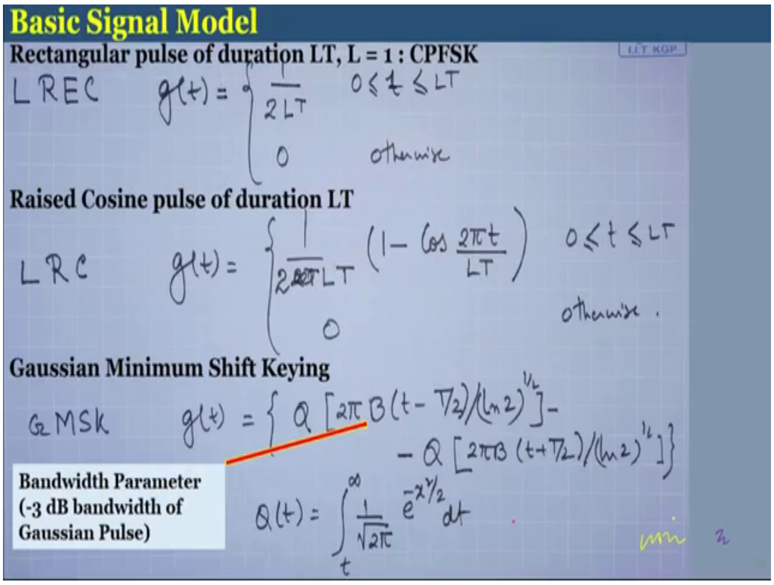

So, what we have seen till the previous lecture is that in the different pulse shapes. We have actually talked about a g t, which is the pulse shapes and there could be a various forms and the well-known form is the LREC the REC tells us that it is a rectangular pulse shape and L tells us the length. So, it could be L equals to 1, it could be L equals to 2 and so on and so forth.

And, we have also said that how the value of L would affect the representation of the signal. So, we also said that when L is equal to 1 it would be the full response signaling; otherwise if L is more than 1 then it will be called partial response signaling. So, we had talked about 3 different pulse shapes, one is the rectangular pulse shape, then we had talked about the raised cosine pulse shape, and we also talked about the Gaussian minimum shift keying pulse shape were the pulse shape is Gaussian in nature, which has a bandwidth parameter and the t parameter. So, b t product which was optimized.

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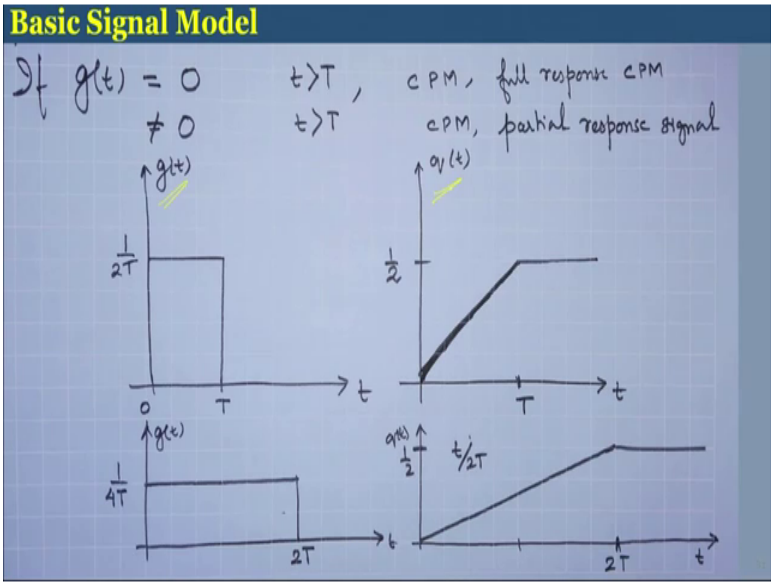

And, in this slide we had seen the how the pulse shape g t; that means, this is the g t and q t is the integral of g t, because we discuss that in a typical FSK one shifts from one frequency to another, and because of which they could be huge amount of increase in the side band. So, to avoid that one would do the pam followed by fm.

So, when you do pam you have to choose the a certain kind of pulse shape. So, this is the pulse shape we are talking about and when you do fm with the pam signal, then this integral of the signal comes in and which results in q t. So, what we clearly sees for rectangle if you do the integration with 0, then as time increases the integration increases. And, then after time t time small t equals to capital T there is no longer no other value which gets added and hence this value remains constant, with 2 T duration of pulse; that means, l is equal to 2 what we will see is that the integration will increase slowly. And, after this point the value is going to remain constant which is depicted over here.

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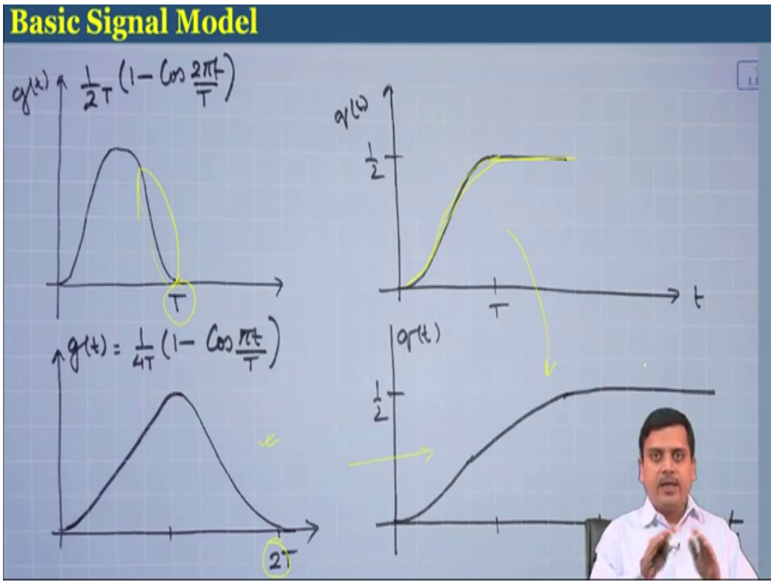

What we see over here is the raised cosine pulse shape and this is the one corresponding to l equals to 1. And, this is the 1 corresponding to l is equal to 2 and accordingly as you integrate slowly it rises I mean it rises and the rise is not that fast, because the value decreases and at time T equals to small t is equal to capital T, there is no other value and hence it remains constant at that value.

So, that the difference that we see from here is that, there is a linear increase and there is a sharp change whereas, here we see that there is a smoother transition of the q t. Similarly, this one extends for 2 T the more or less the same shape, but it is just elongated longer. So, when things are over longer duration of time you would expect that the pulse to be to be the sprectrum to be narrower.

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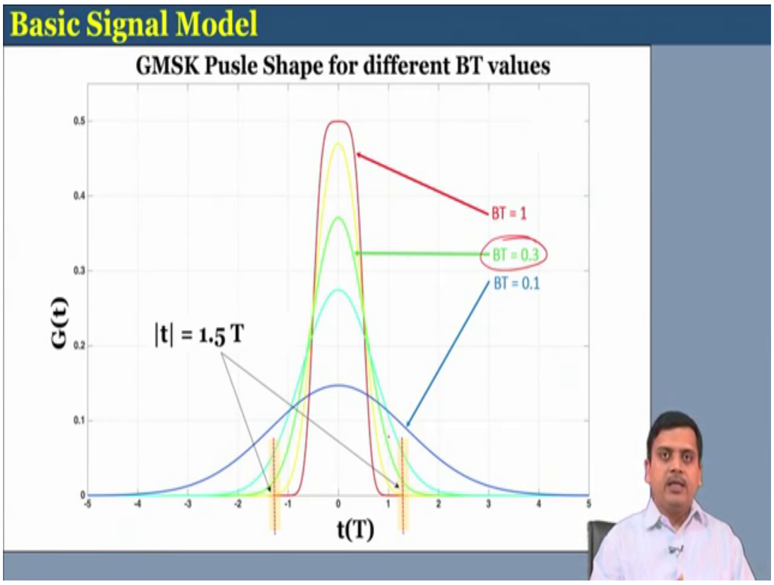

Now, this is the one, what we see for the GMSK. We had also discuss this and what we had pointed out is that for the for the BT value of 0.3, this is very critical value. And, it provide us good tradeoff between the band width and the pulse duration and helps us have a good shape which is used in the GSM modulation.

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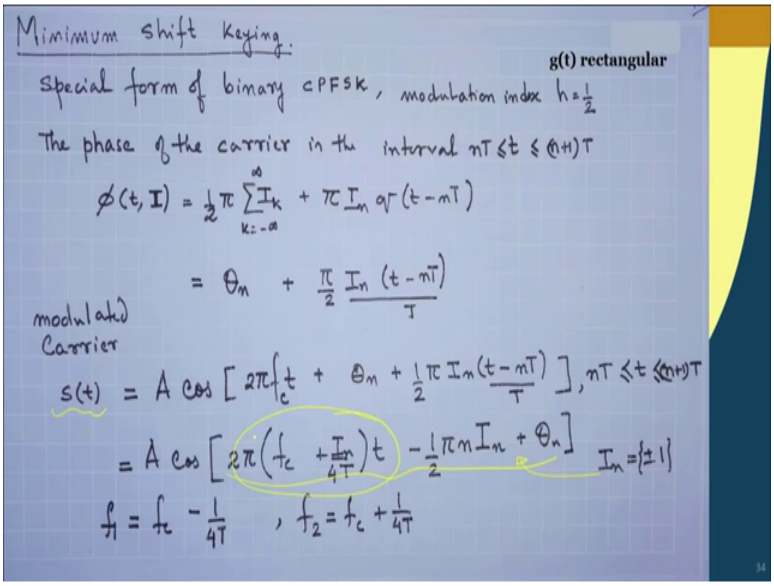

So, at this point we also reviewed the MSK, where we looked at the same signal structure which we had started off with and in the same signal structure, we were able to establish that the signal that goes out can be represented in a form as is written in this particular equation.

And, in this particular equation what we also saw is this particular term which is of our interest, which can be studied as if there is a particular frequency f 1, which is fc minus 1 by 4 T depending upon the value of I n. And, it could be f 2 another frequency which is fc plus 1 by 4 T depending upon the value of I n. If, I n takes minus 1 you get this value otherwise it takes this value.

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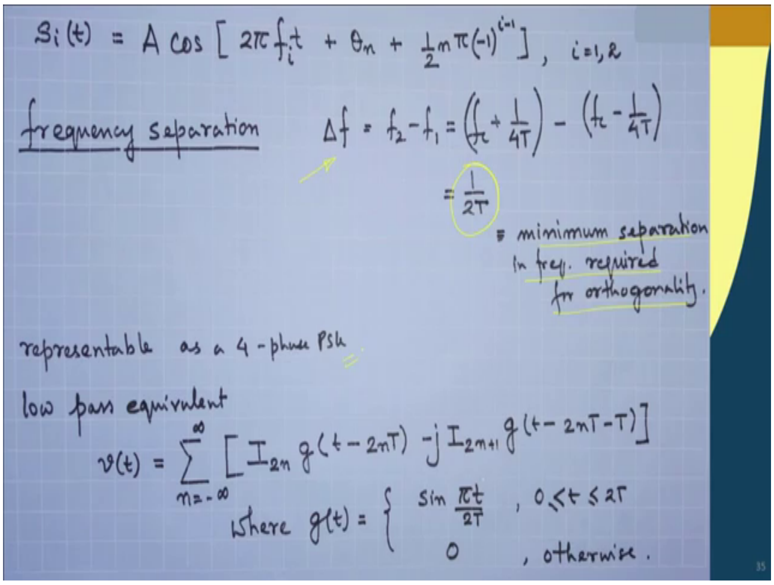

And, then we computed the difference between the 2 frequencies which turned out to be 1 by 2 T, which we also said is the minimum separation required for the orthogonolity criteria which we discussed in the previous lectures. And, hence we could also call it the minimum shift key and you could also represent it as the 4 face PSK as well. So, there are different ways of representation whereby in that case your g t would appear as sine of pi t by T.

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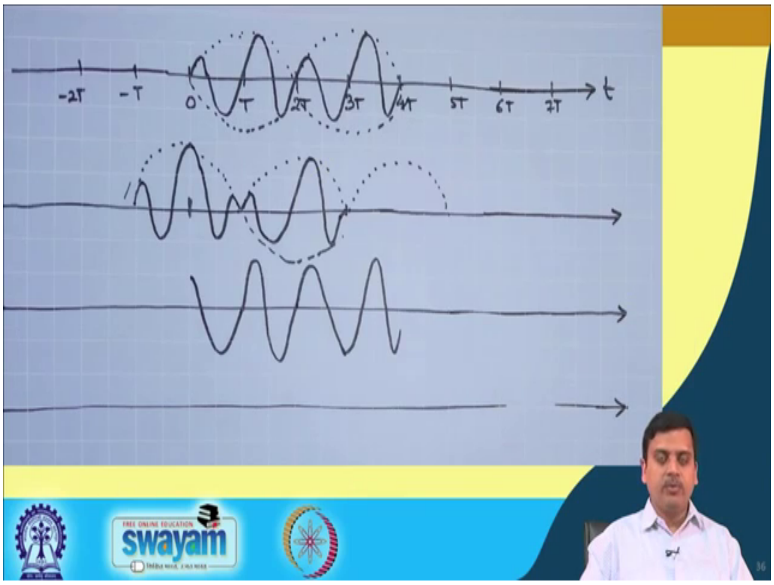

So, this is the basic structure on which the GSM modulation stands. And, in this picture we are trying to show how the wave form would look like.

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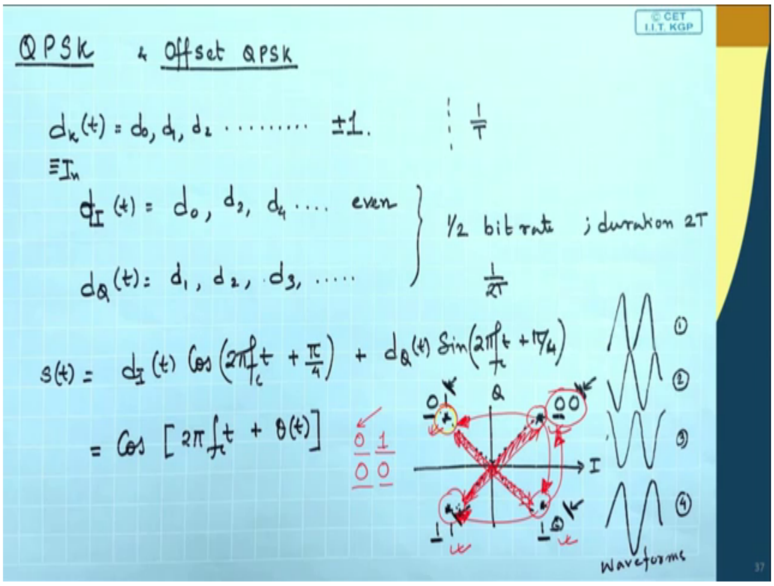

And in this context it is sometimes interesting to look at QPSK can offset QPSK. So, QPSK as we all know that there are this 4 constellation points, which are very vital. So, these 4 constellation points and in every signaling interval that there are 2 bits which are sent right. Depending up on the bit value if it is 0 1 this constellation is sent, if it is 0 0 then this would be sent, if it is 1 0 this if it is 1 1 this. At every signaling interval edge if both the bits would change simultaneously as you can see that there will be 180 degree phase reversal. And, hence there would be a 0 crossing.

Now, this causes distortion in the signal as it passes through the high power amplifier. And, hence to avoid such sudden fluctuations what was suggested is that, instead of letting the 2 bits change simultaneously, what if we offset one of the bits compared to the other.

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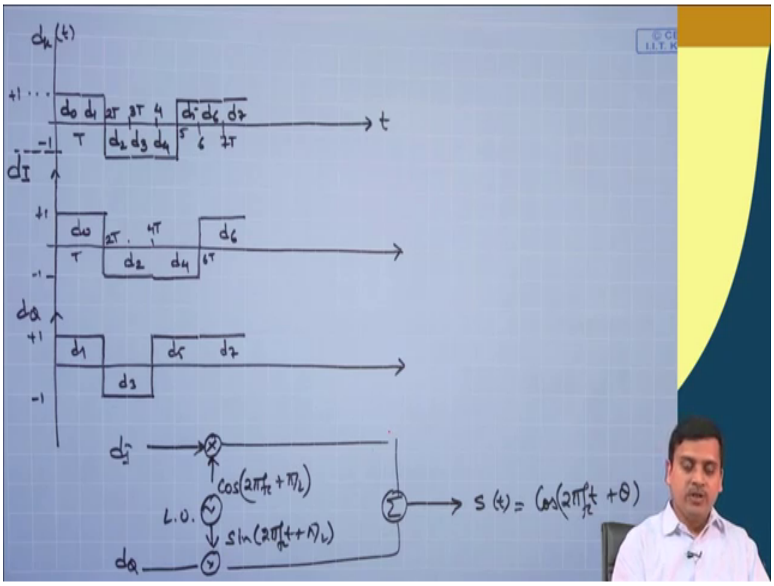

So; that means, instead of doing both the transitions at the same time.

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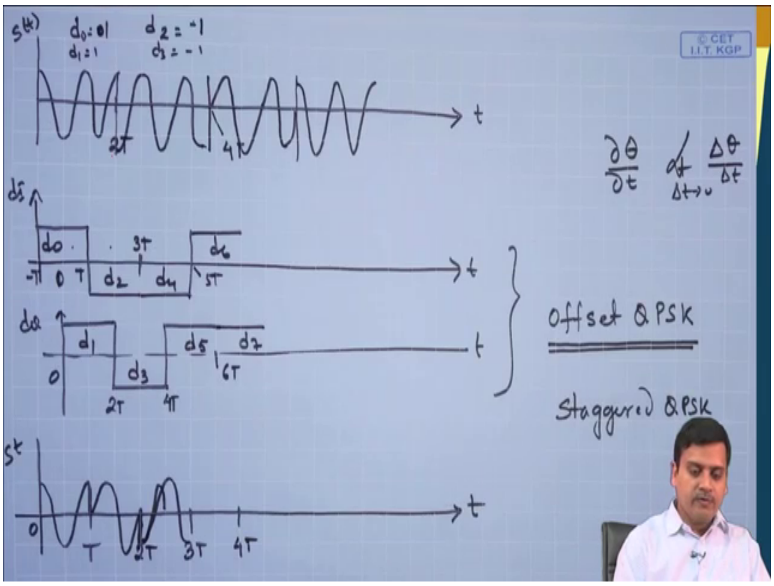

One could think of sending an offset; that means, a d 0 is for duration 2 T is for the entire duration 2 T and d 1 is also for the duration 2 T. So, in the unlike the previous case where both were for duration 2 T, but both were transiting at the same point in time, were is here what you can see is that, when one is changing the phase the other is remaining constant and when another one is changing phase the other one is remaining constant.

So, as a result what happens is that one is not changing from one of the constellation location to another, where there is 180 degree phase shift. So, one can avoid that and one would restrict to only 1 bit change; that means, from this constellation either it would go to this point or it would go to this point. And, from any other constellation again this one it would either go there or it would go there, and avoid a direct transition to this. This particular path is avoided.

And, hence the signal shape is restricted. The phase change is reduced to the phase change is reduced then out of band is expected to be lower, but due to other factors also the overall spectrum requirement does not change, but the signal characteristics as it goes out into the r f section is now improved.

So, with this we have this called as the offset QPSK. Now, you could also see MSK in the same form whereas the pulse shape instead of being rectangular, you would recognize it as the sine of pi T by 2 T. So, you could also write the representation in this manner and the other form is that your pulse shape would be Gaussian in nature and then you have the GMSK a modulation.

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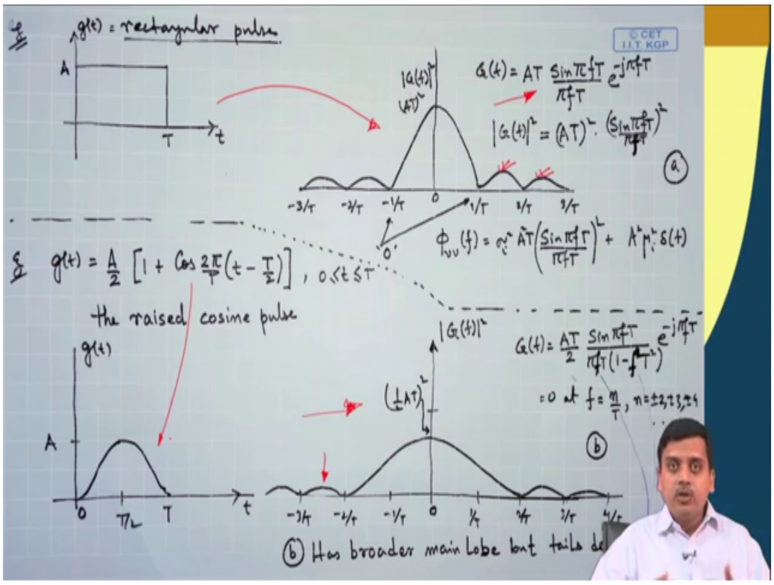

So, these modulations ultimately influence the spectrum. And, what we see is that a typically for the rectangular pulse shape we all know that it results in a sync spectrum; that means, we have the sync expression over here correct. And, the sync expression gives rise to large side lobes, the side lobes does not decrease very fast whereas, if we have the raised cosine pulse shape which is much smoother, it is naturally expected that the side lobes would be lower compared to that of the rectangular pulse shape.

And, hence one usually goes for the raised cosine which you generally study in a typical course of digital communications and we just revisit here for the sake of going back to the basics. And, also gives us a impetus towards understanding how this pulse shapes and the spectrum is related. And, we have already seen the pulse shape for the Gaussian pulse shape in the previous slide.

So, more or less what we are trying to show is that the choice of pulse shape is very very critical depending upon the spectrum occupancy and out of band reduction. So, this would typically influence the out of band emission would typically influence your choice of pulse shape. And one would like to restrict the pulse shape in a manner in a manner which is pretty tight.

However, when we go to multi carrier systems like the fourth generation and beyond it becomes imperative that the orthogonality criteria is also maintained. So, will have a look at that as we go into details in the next few slides.

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So, this particular rough sketch a compares the spectrum of the raised cosine and that of the rectangular, where it kind of depicts that raised cosine in a relative performance has a lower out of band. Although the main band is slightly wider, but finally, the out of band emission is lower compared to that of the raised cosine pulse shape.

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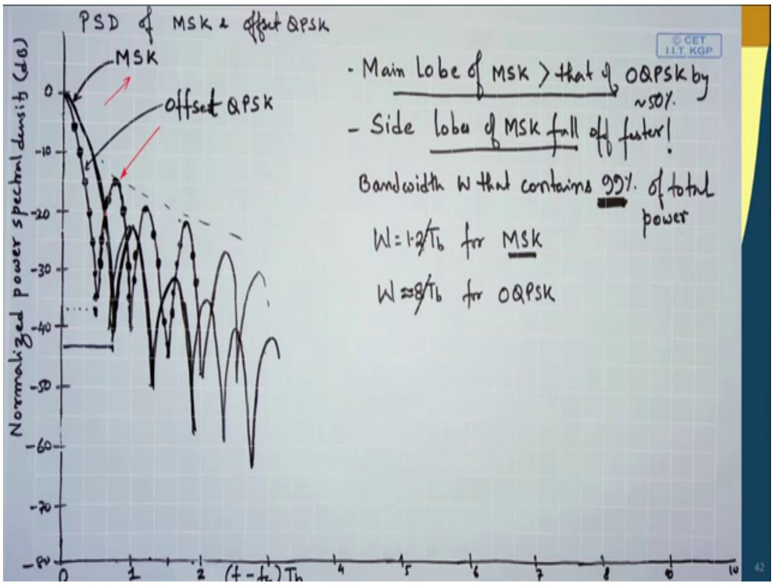

So, here what we have is the comparison with the MSK right and this is the one for the offset QPSK, whereas this is the one for MSK. Now the difference is that in MSK your pulse shape would appear like sine pi t by 2 T, where as in offset QS QPSK, it would still remain as the rectangular pulse shape.

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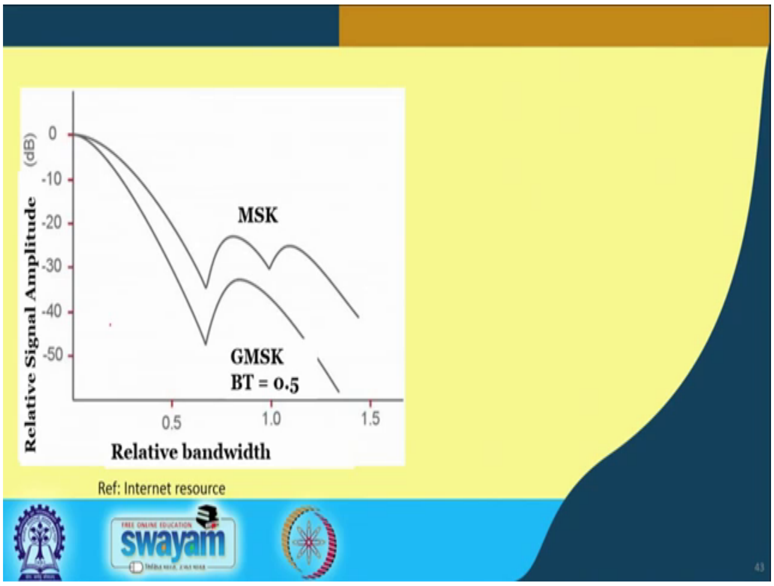

And, as a result we get MSK it is lower and in this particular one, what we see is comparison of MSK with a GMSK with a BT product of 0.5 0.3 has a different GM spectrum. So, here what we see is that compared to MSK GMSK has even lower out of band and over all smaller bandwidth occupancy.

So, this is the this is why GMSK modulation is used for the second generation, where we have sited that the peak to average power ratio is low as well as the out of band emission is low it is a pretty tight and very efficient spectrum, but the spectral efficiency is not very high, which is given rise to use of different modulation techniques and pulse shape for the future generation and next generation systems.

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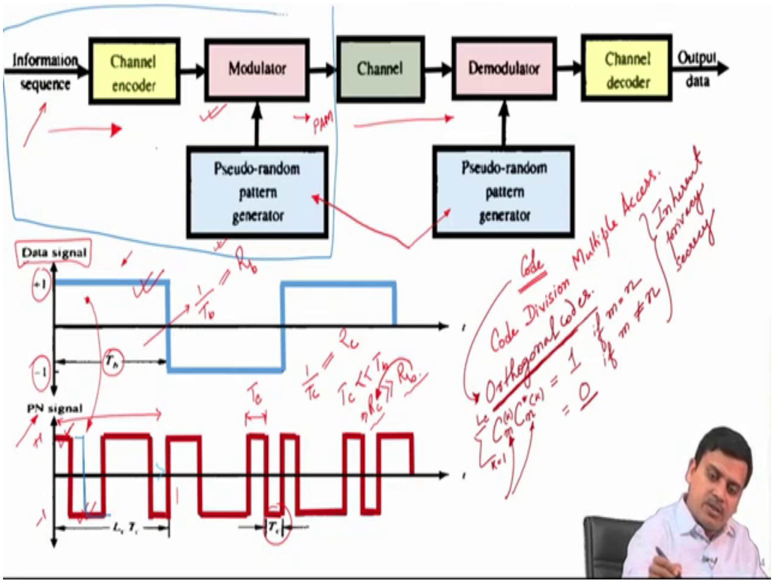

So, next what we look at is the third generation system, essentially the direct sequence spread spectrum, which is very much different compared to that used in the second generation system. So, we will take a brief look into how this things is structured and what is done and what is the advantage and how things are processed at the receiver? So, that we get to see the distinction between them. So, here what we see is that there is a data signal? Ok.

Data signal is our original message signal that is containing plus or minus 1, which was the I n in case of our analysis for the GMSK system. And, there is a pseudo random sequence or a pseudo noise signal present along with the original signal. So, this pseudo noise signal is a sequence of plus and minus ones in this particular case. So, it can be complex values also. So, what is done is the original signal is spread using this pseudo noise sequence. So, one can think of a direct ex-or at the bit level. So, one is doing the bit level processing, one can do the ex-or operation.

So, whatever is the signal that is present, one would multiply it in the time domain I mean if you are doing it in the base band signal processing domain, if you are doing it in the in the zeros and ones in the bit level 1 can do an ex-or, otherwise you will have this multiplication. So, there is this information sequence at the transmitter, which goes to the channel encoder.

So, the channel encoder would be the, for error connection code, which would include the forward like convolution codes or turbo codes followed by the modulator. Now, in the modulator one would have this conversion of bits into the signals here in this case it is depicted plus and minus 1, pseudo random generator would also generate the signal in the same domain as the data signal.

So, if we are processing at the bit level this will also generate at the bit level, where as if we are processing at the base band signal level, that is in the real domain it would also generate in the real domain or correspondingly the complex domain. So, if it is in the base band as in the bit domain we have said there will an ex-or operation whereas otherwise it will be a multiplication operation.

So, if we see carefully what happens is that the small duration; that means, this duration as has been identified over here is usually known as the chip duration TC. And, we had earlier stated when we were describing the specifications of third generation, there was a chip rate 3.84 mega chips per second MCPS. So, this chip duration is such that 1 by TC is the chip rate, whereas this is the signal rate.

So, now, what we see is that the number of chips that go in to the signal period would be termed as the spreading factor. Now, why it is called the spreading factor? Simply, because you can clearly see that T b, which is the bit duration, is related to the band width in an 1 by T b fashion. So, the band width is 1 by T b. Let us say an here the band width is 1 by T c or the bit rate is 1 by T b and here the chip rate is 1 by T c. So, T c being much much smaller. So, this is R c and this is R b. So, what we see is that T c is much much smaller than T b. And, hence we can write that R c is much much greater then R b right. So; that means, that rate of chip is much higher than the rates of the bits.

And, hence there is an effective increase in band width from the bit domain to the chip domain. So, when you are going from bit domain to chip domain there is a significant increase in the band width factor right. So, this can be used in multiple ways. So, here in the third generation system this chips are actually assigned or the codes the sequence of chips that are present are usually assigned to different user, whereby the they can identify their bit sequence by the reverse operation of what happens at the transmitter side. So, we will see it here shortly.

So, at the transmitter side your input bit stream is multiplied by the PN sequence and then one can send it to the modulator. So, after the multiplication one can do a pulse amplitude modulation, where by whatever signal you get you can modify the amplitude and you can send the signal out. Through the channel it goes to the receiver.

Now, at the receiver you again use the same PN sequence that has been multiplied with the data source right. So, now, a user should know it is PN sequence or the code that is associated. So, it is also called the code ok. And, because this is called the code we also call it the code division multiple access. The reason is that here if we have the same code; that means, the same pattern and we accumulate it. So, what we see is, when we multiply a 1 with the 1 it is a 1, when we multiply minus 1 with a minus 1 it again becomes 1. So, effectively we have all the values in the entire duration to be plus ones.

And, hence we can recover this particular signal when we add it up right. Whereas, if the code is of a different type; that means, instead of having plus 1, if let us say we draw another sequence, which let us say is minus 1 over here, and it is plus 1 we just have the reverse sequence let us draw the reverse sequence ok. So, if you have the reverse sequence in that case the original signal is plus 1 whereas, at the receiver we are multiplying with minus 1.

And, hence at the end of the entire thing what we are going to get is 2 sequences which cancel out each other to produce a 0 sum. So, generally the codes which are assigned to users, the codes which are assigned to users can be generated in various different forms, and one of the way of generating the codes is to provide orthogonal codes.

So, orthogonal codes would have the property that if I have the code sequence C m and at the receiver I multiply with the code sequence C n, and I just put a conjugate to write the generalized expression of k let us says k th chip right. And, sum over k and sum over k equals to 1 to L L c, which indicates the chip length, I will be getting a value I can use I can normalize the entire thing 1, if m is equal to n and this could be defined to be 0, if m is not equal to n right. If such happens then if let us say the transmitter generates with the code sequence m and the receiver decodes with the code sequence n. So, when will this happen?

This will happen because if the transmitter has created the signal for m ith user, but m ith user tries to decode it then the n result at the receiver of the m ith would be 0. However, if it is the same m ith receiver in that case it is going to get a 1 right. So, that is the property of orthogonal codes. So, in that case only the desired user can decode the signal and undesired users will not be able to decode the signal. So, this way there is an inherent privacy or secrecy, which is included into the mechanism. So, if you wants to have a secret or private communication 1 gets the benefit of that by virtue of using code division multiple access.

Whereas, if we consider this with respect to other schemes there just different time and frequency slots are used; so, if 1 user knows or decodes all time and frequency slots, one is able to decode all the other signals, but here they mal intention user needs to know the specific code that is been assigned to a user. So, if it is the orthogonal sequence of codes then 1 may be able to try using all possible combinations of codes and able to decode the signal finally. But, then they were other codes which are known as the pseudo random codes, which need not necessarily be orthogonal in that case the code sequences can be made very very large and one in to find the particular code that has been used by another user will not necessarily be a easy task.

Now, here when you decode such a thing amongst a several problems, one of the issue is to synchronize the code. So, now, just look at the whole thing, if the user who is the desired user instead of using the code which is the which is kind of depicted in this picture, one tries to use let us say let us clean up some of the earlier things here. Let us say one tries to use the same code, but it is shifted ok. Let us take another color. So, let us say it is shifted and instead of that it is shifted over here ok.

So, if it is shifted version them it would appear that we are kind of doing a delayed correlation. So, here again different properties of the codes are necessary the code should have very good autocorrelation properties as well as very good cross correlation properties. Cross correlation properties would mean that when you are cross correlating with other codes. It should be producing a number which is as small as possible.

Whereas, you are correlating with itself it would give you the peak. So, if it has good autocorrelation properties then that can also be used in code synchronization. So, code synchronization is a very vital property of such schemes. So, if you are not able to synchronize the code properly and the delayed version of the course somehow is very close to another code then the end result would be pretty much futile. So, these are some of the vital things that one has to remember, when operating with such a scheme.

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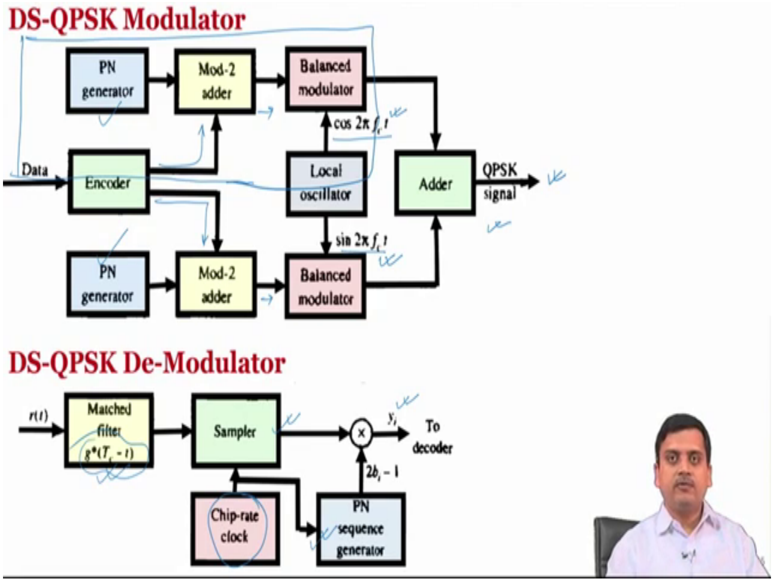

So, there are different modulation techniques also. So, this particular one shows the direct sequence QPSK modulator. So, where we have the encoder and 2 parallel streams, where one goes with the cos, one goes with the sine. So, one has the data which is split from serial to parallel and it goes in 2 different directions. There are 2 different PN generators and after processing one would go through the balance modulator. And, one with the cosine and one with the sine in quadrature with respect with each other and you generate a QPSK signal. So, what you see over here is only one of the channels.

What you see in this particular picture is one of the channels. What you see in this particular picture is that one of the channel is part of it. So, that is the part which was depicted in the previous slide, but in this slide we have both the things together. Now, the demodulator part one would have a matched filter. So, in the matched filter one is using a complex version of the matched filter, because you have the complex signal over here, and then there will be a sampler.

The clock rate that will that will be given over here would be at the rate at which the PN sequence is generated. And, again typically you would multiply with it and produce the y bit that is output and goes to the decoder. So, it is a little bit more complicated version of what is mentioned in the previous slide, but this is what would be typically used in the communication system.

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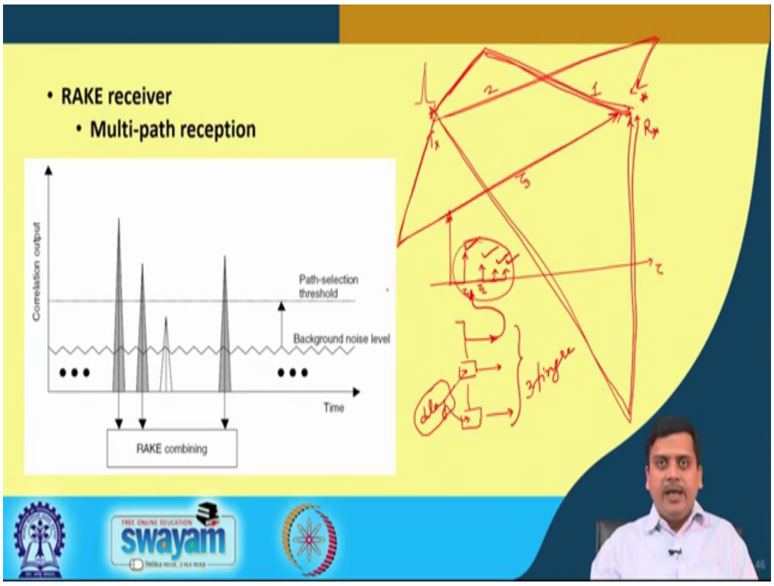

Moving at further so, what we have over here is description of or rake receiver for multipath. So, what it does is that before we discuss this is that, when signal propagates from one point to another. So, let us say this is the transmitter and let us say this is the receiver.

So, in a typical wireless link there would be multiple reflections before the signal can proceed to the desired direction, there could be to the desired intended user there could be reflections and it proceeds. And, if one things of sending an impulse just for the sake of doing it, at the receiver what we will find this is the delay axis we will discuss this again later on. The first path let us say let us identify this as path number 1 would take a certain propagation time and it would show up at a certain distance.

What we will find is that the next path would appear at a certain delay, which we can call it as tau 2 and it will appear over here from the second path and so on and so forth. If this path takes time tau 3 for propagation as you know this is a little bit longer path, it will appear over here and this is even a longer path as we can see over here what we see is that the signal is going to appear over there. So, now, what we see is that the signal which has been sent is received as if there are echoes at multiple delays; that means, a same copy is received over several delays and like an echo.

So, in this case a typical architecture known as rake receiver which has the signal going for further processing, and the signal is delayed through several delay units and again sent for processing and it is delayed further and sent for further processing. So, this particular structure would be a 3 finger rake receiver will be a 3 finger rake receiver and each figure would be hooked on to a particular delay of the path.

So, in this kind of receiver the delay estimation for each of the path is also important. So, at each of the fingers the entire processing as shown in the previous slide can be done and combining can be done later on. So, there are different kind of combining techniques which are also used. So, effectively what it does is it captures the signal that arrives through multiple paths through a combining procedure.

So, when it combines the signal which arrives through multiple path, it essentially retrieves the energies, which has been scattered in different directions right. So, the energy gets scattered in different directions by virtue of wireless propagation, because when it radiates it radiates in all direction. And, some of the paths get reflected and finally, it arrives at the receiver. So, the receiver all it tries is to individually track the different most power full signals and process them and combining them.

So, otherwise if one would have processed the entire thing together they would have cost a heavy amount of inter signal interference. So, when there is lot of interference this signal quality degrades. Whereas, here what we are trying to do is to extract the different paths individually and combine them in a phase coherent manner. So, that we are able to maximize the energy that has been received at the receiver end.

So, in the next few lectures we look at one or two more interesting points and which are related to the to the third generation air interface, especially about the other additional things which go beyond the signalling, and then we will move into the fourth generation which again will form the basis for the fifth generation or the nr or the fifth generation new radio.

Thank you.