**Optical Wireless Communications for Beyond 5G Networks and IoT**
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**Lecture - 15**
**Part - 1**
**ACO-OFDM**

Hello, everyone. So, today we are going to discuss about another modulation technique, which is asymmetrical clipped Optical OFDM, also called as ACO OFDM.

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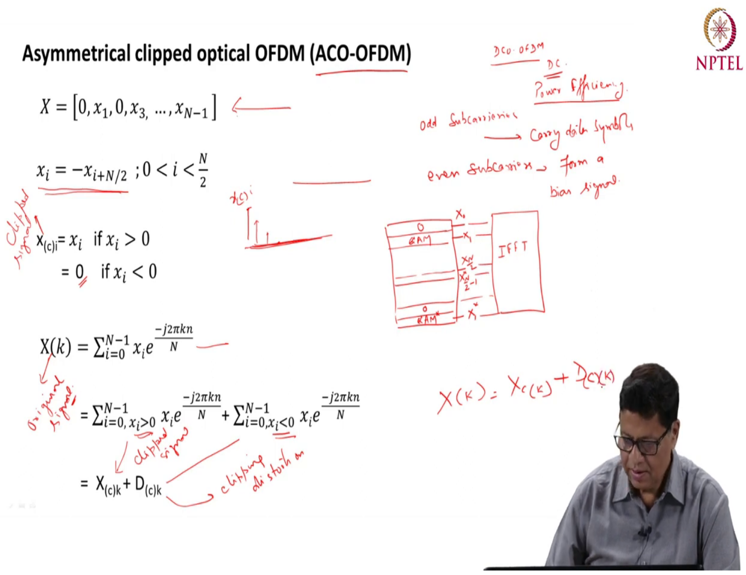


In the last class, we had discussed about DCO OFDM, where in order to make it unipolar and real, we had invoked Hermitian symmetry and also, we had given it DC shift. And because of this DC shift, the power efficiency of the DCO OFDM, power efficiency of the DCO OFDM is poor. So, let us discuss another technique, where we can solve this particular problem of power efficiency.

So, in asymmetrical clipped optical OFDM, you have the odd subcarriers, they carry data symbols, carry data symbols, whereas, even subcarriers, they form a bias signal, they form a bias signal. So, the symbol stream looks like this, you have 0, which is you know on the even subscriber and then you have 1, which is x 1 for the odd subcarrier and so on and so forth.

So, odd subcarriers are carrying data symbols and the even subcarriers are 0. And if I see the output of the modulator to the IFFT or the input to the IFFT will be something like this. And this is our IFFT block. So, this will be 0, this will be some QAM and this will be QAM conjugate, because we want to invoke Hermitian symmetry here as well. You want to make the complex signal real and this is 0 and so on and so forth.

So, this will be x 0 and this will be x 1 and in the middle, you have x n by 2 and this will be x 1 conjugate and below this will be x n by 2 minus 1 conjugate and they form the input to the IFFT. So, as we see here the odd subcarrier, they carry data symbols and even subcarriers are 0 and they are given to IFFT block and you get samples in time domain.

The property of such a signal, the output of the IFFT will be actually it anti-symmetric which means the samples, we can see in the next slide.

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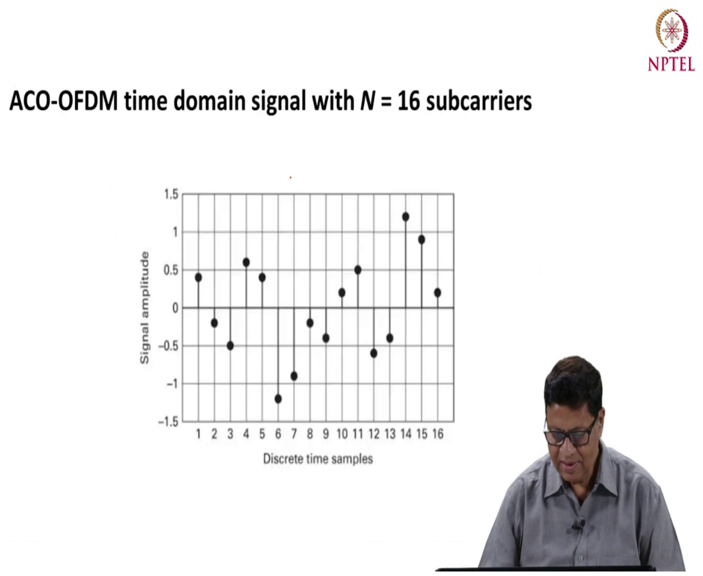


This is the output of the IFFT if the even the odd subcarriers are carrying data and even subcarriers are 0. So, you will notice this is a 16, N is equal to 16. So, you see here this is plus 1 and if you see exactly half way after the signal you have minus 1 and similarly this is minus some level, this is plus some level so and so forth.

So, it is exactly opposite of the signal amplitude at different time stamps. So, in one symbol you will see the anti-symmetric property of the ACO-OFDM. So, which is described by this x i is equal to minus x i plus N by 2 where i is between N by 2 and 0 and if you see the clipped signal, this is x c i is actually the clipped signal, clipped. is x i if x i greater than 0 and it is 0 if it is less than 0.

So, your signal basically if you see the OFDM signal you will have only positive samples. The other samples, the negative samples will be clipped. So, this is actually x ci right. And x k is equal to the data symbol is equal to summation i is equal to 0 and minus 1, this is the same as we have done in the DCO OFDM case x i into e raised to power ae raised to power minus j pi to 2 pi k n divided by N.

Now, this can be broken into two parts when x i greater than 0 and x i less than 0. x i greater than 0 is the clipped signal which is represented by X c k and this is the clipping. So, this is the clipping signal x i less than 0. So, this is the clipping distortion. So, this can be written as clipping. Distortion because you have clipped there is a hard clip at 0 level.

So, there is no concept of the DC here. You are not giving any D c to the signal as was the case in DCO OFDM. And this x key X c k is the clipped signal. And this is the original signal.

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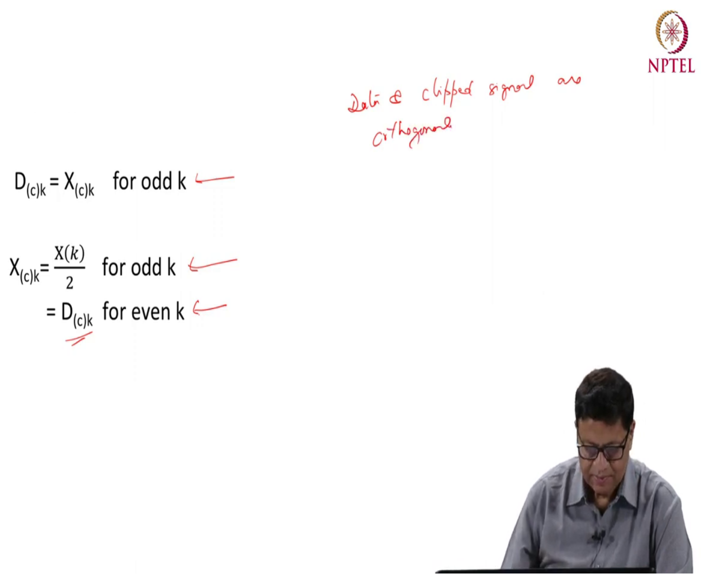

So, it can be shown that this D c k that is the clipped signal is equal to the distortion signal is equal to clipped signal for odd subcarriers. And if you put this value here in this expression, then this expression and the expression which is X k is equal to X c k plus D c k.

What you get is X k by 2; that means, the clipped signal has half of the amplitude of the original signal for odd area and it is a clipping distortion for even k. And here if you see the data and clipped noise or clipped signal are orthogonal.

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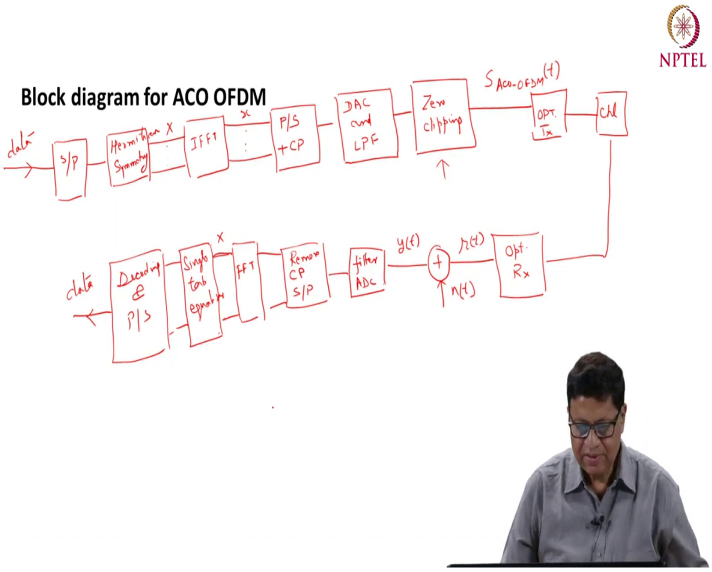


So, if I make the block diagram of ACO OFDM, it will be this is the input data and then first block first you do serial to parallel conversion. And then you have to invoke Hermitian symmetry to make the signal real Hermitian symmetry. And then these are the capital X and then it is given to the IFFT block.

And you will get time samples which is represented by a small x. And then these are parallel to serial and we also add cyclic prefix. And once you have this signal, you have digital to analog converter and LPF, low pass through a low pass filter. And then there is a hard clipping here, zero clipping.

So, whatever signal you get is actually x ACO or we can write it S ACO OFDM. And this signal is given to the optical transmitter. And it is a positive signal because you are clipping at 0. And remember that we are only loading half of the subcarriers. Rather one fourth of the subcarriers because half of the subcarriers are conjugate and the remaining we are having data symbols only on the odd subcarriers and even subcarriers they are 0.

So, optical transmitter and then you have the channel optical wireless channel. And then you have the optical receiver which will convert into electrical signal. And what we get is say received signal r t. And this is the noise, call it n t. And then this is what you get is y t. So, this y t is you know filter and analog to digital converter. You are doing the reverse operation here. And you remove the cyclic prefix here, remove CP.

And serial to parallel converter. And then this is given to reverse of IFFT that is FFT block. So, this is FFT block. So, these are the samples here after output of the FFT. You get the x here and then this is single tab equalizer for each one of them. Single tab equalizer. And then you do the decoding and convert all the parallel signals into a serial. And what you get is the your data back.

So, this is the complete diagram of ACO OFDM. So, this is you know similar to DCO OFDM. But in DCO OFDM we had given a DC shift to the signal. Here we are hard clipping at 0. And the data is carried only on the odd subcarriers and even subcarriers they do not carry any data.

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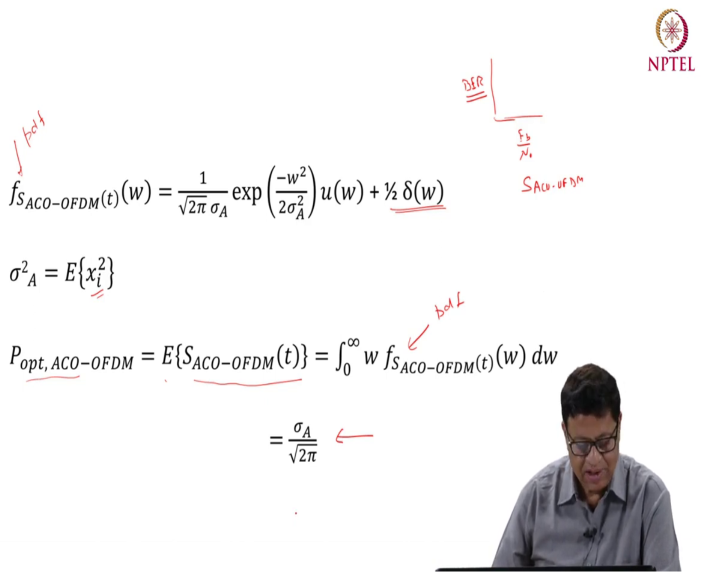


So, this is the block diagram of OFDM. Now, let us see the try to calculate. Ultimately, we want to find out the performance of such modulation techniques by giving either E b by N odd or SNR versus BER. So, if you see the signal ACO OFDM signal which is S ACO OFDM signal, the amplitude of the signals are samples which are coming they follow a Gaussian distribution.

So, the pdf for such a signal S ACO OFDM is given by a Gaussian function. And this term is because of the clipping. This is the Dirac delta function. And the standard deviation of the sigma square A is given by expected value of all the samples x i whole square. So, if I want to calculate the optical power which is actually proportional to the amplitude when you give it to the LED then taking the expected value of S ACO OFDM will give me the optical power of the ACO OFDM.

So, this will be expected value will be W into the pdf. And if you plug in these values what you get is sigma A divided by root pi. So, this is the optical part optical power of the ACO OFDM signal.

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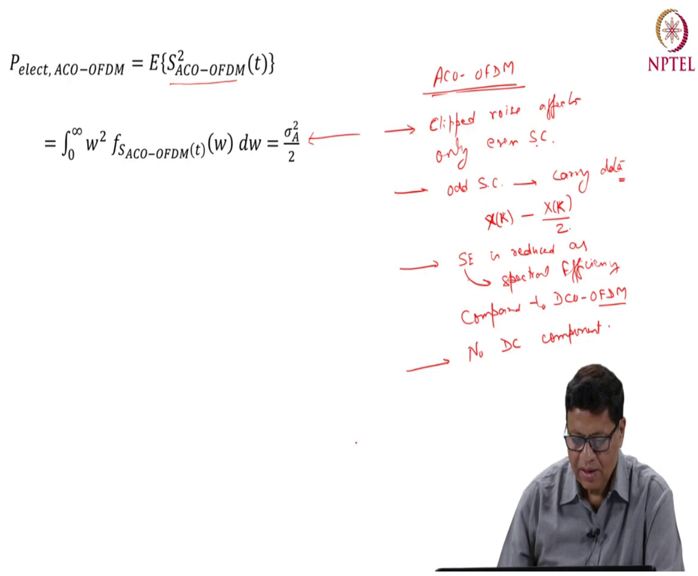


And if I calculate the electrical power so, that will be given by this is the amplitude proportional to current. So, expected value of square of the amplitude S square ACO OFDM T. And if I plug in the values of PDF and calculate this expected value it will give me sigma A square by 2. So, this is the electrical power. So, in ACO OFDM let us list down what is normally done here ACO OFDM.

The clipped noise affects only even subcarriers. Where there is no data, data is only on the odd subcarriers and odd subcarriers they carry the data. Only issue is that amplitude is half 50 percent. The amplitude of the symbol gets reduced by half. So, x k which was the original data symbol has become x k by 2. And there is no DC here.

So, the power efficiency of ACO OFDM is much better is better as compared to DCO OFDM. But the spectral efficiency is reduced as compared to DCO OFDM spectral efficiency this is spectral efficiency is reduced as compared to DCO OFDM. And as I mentioned there is no DC component. So, it is power efficient modulation technique no DC component. But your spectral efficiency is reduced.

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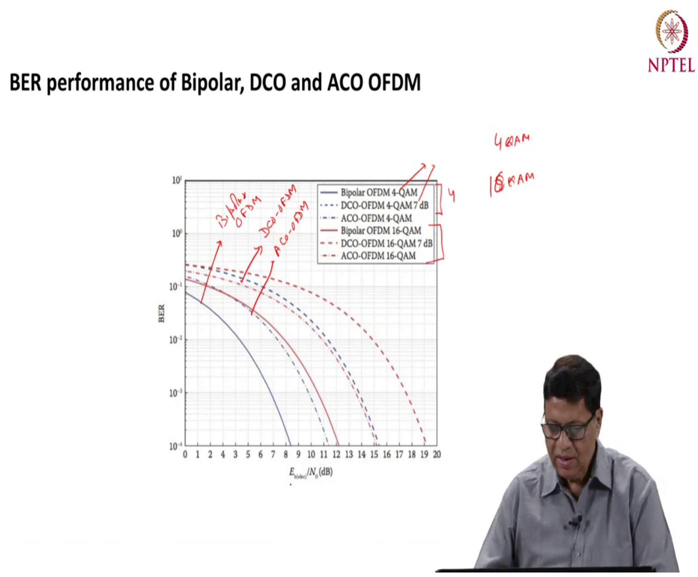


So, this is the advantage of using ACO OFDM. And if I see the performance of these techniques. So, here in this plot the comparison has been shown between two type of modulation. One is 4 QAM and 8 QAM. So, this set is for 16 sorry 16 QAM and this set is for 4 QAM. And this is standard bipolar OFDM with 4 QAM. And this is DCO where a DC shift has been given by an amount which is equivalent to 7 dB. And the third one is ACO OFDM with 4 QAM and similarly for 16 QAM.

So, the blue colour that is this one this is actually bipolar OFDM which performs the best. And if you see the other one which is this one this blue this is DCO OFDM. And the third one is ACO this ACO OFDM. And same trend you will notice at 16 QAM also. So, bipolar OFDM by far is the best, but it is not suitable candidate for optical wireless communication.

So, we have I mean there are many choices, but we have discussed DCO OFDM and ACO OFDM. If you see the performance of ACO OFDM in terms of B R versus E B N naught is better as compared to DCO OFDM. But DCO OFDM has got better spectral efficiency as compared to ACO OFDM.

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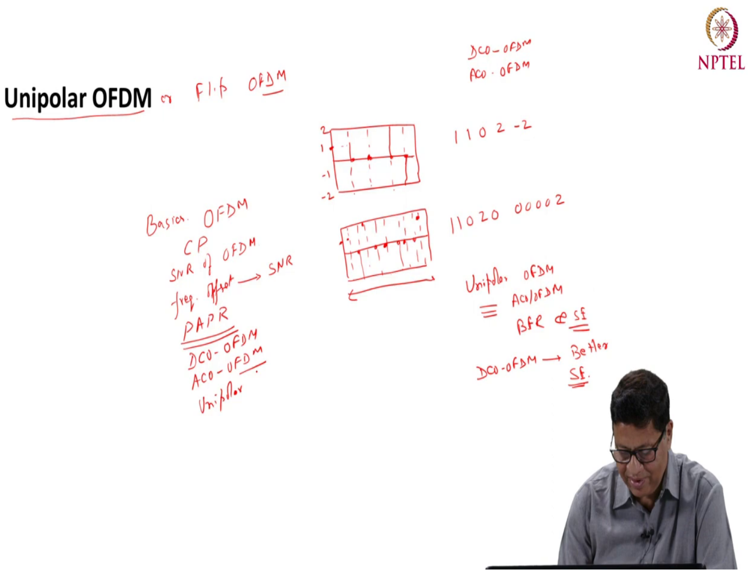

So, there is another type of OFDM technique apart from DCO and ACO which is also which is called as unipolar OFDM. So, we have studied about DCO OFDM and the ACO O|FDM. There is another which is called as unipolar or it is also called as flip or flip OFDM. So, in this case if I see the samples here for example, let us see again block and these are the points where samples are there.

So, if samples are say for example, this is 1 and this is say 2, this is 0, this is say 2 and this is 1. Let me also draw the timing instant here. So, you have both negative as well as positive and also you have 0 samples somewhere in between. So, in unipolar OFDM what normally is done, you would divide this into further two parts. So, this is this divided into say two parts. So, in the first part you transmit.

So, this is actually let us write here this is 1, this is 1 and then this is also 1, 0, 2 and say minus 2, this is say minus 2, this is minus 1. So, in the first half you transmit this 1, 1, 0, 2 and wherever you have minus 2 it is transported as 0. And in the second half. So, this will be; this will be 1 here, 1 then again 1 here and then you have 0 here and then 2 here and 0 here and in the second half you will transmit the second half will have I mean you are already transmitted this positive signal.

So, this will be 0, 0, 0, 0 again the last one will be 2, the reverse. So, you will transmit this. So, the second half will have 0, the 4 0s and 2. So, basically all the samples are positive and the information on the negative samples is covered in this time frame. So, this is called as unipolar OFDM. So, there is no need of giving any DC shift here. So, this is another this is also one of the technique which is used in optical wireless communication unipolar OFDM.

So, unipolar OFDM the performance is and the spectral efficiency is same as ACO-OFDM. So, if you see unipolar OFDM the performance BR performance is similar to ACO-OFDM in terms of BER in terms of spectral efficiency. Whereas, DCO-OFDM it is not power inefficient because of the DC and also it has you know better spectral efficiency.

So, depending upon the complexity, depending upon whether you require a power efficient system or you require a spectral efficient system, one has to make a choice among these techniques. Unipolar DCO-OFDM, ACO-OFDM and unipolar OFDM or flip OFDM. So, this is in brief about the OFDM. So, in the whole discussion on OFDM, we have studied some basics of OFDM. We also understood the addition of cyclic prefix and how we are able to make a frequency selective channel into a flat channel.

So, we studied addition of cyclic prefix and also, we calculated SNR of typical OFDM system. Then we studied if there is a frequency offset either in the local oscillator or in the sub-carrier frequencies, then what is the effect on SI SNR or it will become SINR actually because there will be interference because of this frequency offset.

And we also studied about PAPR peak to average power ratio for OFDM, why it is why it is a problem for optical wireless communication system and we need to contain this PAPR. And then we shifted to discussion of OFDM which is for optical wireless communication of our visible light communication.

And under these two categories we discussed, under this category we discussed DCO-OFDM and we discussed ACO-OFDM And we did not discuss in detail about the unipolar, but it is the analysis is similar to what we have done for DCO-OFDM or ACO-OFDM. So, this completes the discussion on OFDM and in the next lecture we will discuss about the another modulation scheme which is called as colour shift scheme or CSK.

Thank you.