Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Optical Communications

Week – I
Module – II
Optical Transmitter-I(continued)

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The next job for me to take light from the laser which for now I will assume to be ideal and then modulate that laser light so how do I modulate a laser light I have to has some way of converting this PS softy which is flat.

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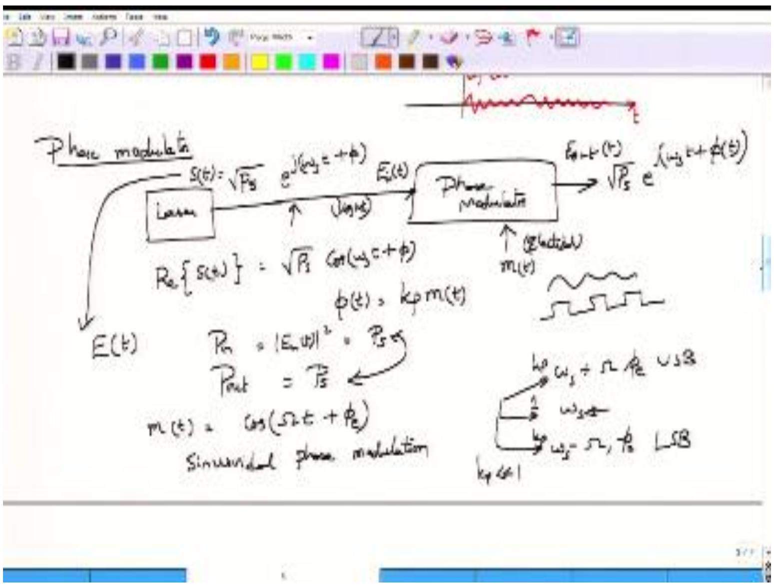

In the ideal laser that would be the green line with power is not fluctuating if the power is not fluctuating if the power is not fluctuating if the frequency is not changing if the phase remains constant then I cannot communicate anything so everything is constant I am not communicating any data to the receiver if I want to communicate I have to change this characteristics so I have to change the power our equivalently intensity or I have to change the phase and frequency so we will see how this can be done by postulating certain optical transmitters.

Okay or optical modulators it turns out that later has be look at the physical implementation it turns out that it is easier to modulate the phase of the optical signal rather than modulating the amplitude in fact amplitude modulation can be obtain high speed amplitude modulation can be obtained by actually converting that into or by using the phase modulators in a way to change the amplitude.

So we will see that one in order to look at that we will start with the basic element called a phase modulator okay so we look at phase modulator and as it names such as it is job is to modulate the phase of the incoming light signal so the incoming light comes from a laser which is producing a nice optical signal having an amplitude of √ PS for equivalently power PS and instead of writing this as cost ωFT + 5 I will shorten the notation and write this as ejωst + 5 and at this point my five or the phase does not really matter to me so I will remove that one from the considerations I will simply assume that the output of.

This laser is a very nice optical signal having an amplitude of √PS and having the frequency ωs okay so this is a notation that we normally use if we do not normally use cause ωst this is the shorter notation that we normally use okay because I can of course always recover back what that cause ωst signal is all have to do is take this √PS $e^{j\omega st}$ and then take the real part of it right so if I take the real part of so if I call the signal that is coming out as s(t) so if I take the real part of s(t) I get √PS cause ωst this is in fact the signal that actually laser producers but for notation simplification and mathematically manipulation.

We normally go this I mean go to this exponential notation okay alright so this is the laser output I am now going to put this one through a phase modulator okay so what should I get well what I should get with the phase modulator is the phase of the optical signal oh sorry I miss the phase actually I thought the phase is unimportant but the phase is important because I am actually looking at the phase modulator I thought that I am looking at amplitude modulator no I am looking at the phase modulator so it is important.

So we go back and put this phase as a five now instead of having this five to be a constant if we somehow make the phase of the optical signal dependent upon what we are sending as a electrical signal is okay so if I take the electrical signal and then somehow alter the phase of the optical signal coming from the laser then I obtained optical phase modulation so that is all that is there to the optical phase modulator the input is this sinusoidal signal coming out from a laser and the output of this would not change the amplitude because it is just change in the phase it would also not change.

The frequency ωs okay but it would change the phase to 5 to 5(t) in the sense that this 5(t) will be dependent with some constants kp if you want on the signal that you are putting to the phase modulator so this phase modulator takes in two inputs one is the light input in the form of the laser light and the other if the electrical signal in the form of a voltage and that voltage signal let us call this as m(t) m(t) could represent and analog signal it could represent this one or it could represent the digital realization or pulse realization of a digital signal.

Okay so it could represent a sequence of pulses in both cases these m(t) is the one which will actually change the phase of the optical signal so this is the time remain description of phase modulator that is sufficient for us now we ask what is this light going into it I have said that light can be modulated as a sinusoidal carrier okay but this s(t) is actually the electrical field which I am assuming is polarized in only one direction and the signal is propagating along so it access okay for now you can think of this electric field of the laser as a oscillator output is just an electrical analog to the oscillator.

If an optical analog of the electrical oscillator you can think of that way but in the modulation literature this is typically called as the input electric field and this is called as the output electric field then you might be wondering what this electric field is remember light is an electromagnetic wave and you can represent this electromagnetic wave by specifying it is electric field and or magnetic field so we have chosen to represent them with the electric field for now you now harm is if you simply thing of this as some s softy and this one has some par of t or s hat of t does not matter.

Whatever the name whatever the symbol that you give to this one this would just be the phase modulated version of whatever the input that is going here okay now if you look at what is the output power output power will be equal to the input power why output power is PS the input power which is obtained by taking the electric field magnitude square you know in some sort of normalized sense will be equal to PS similarly P put would be obtained by taking the magnitude of e out of t2 which will again give you PS so this is a loss less optical phase modulator.

For the case where m(t) happens to be a cos sin signal but in the electrical domain so let say this is cause ωt + some 5 electrical signal if this is the case and Kp is the phase modulation constant what you are phase modulator produces are three ways in a approximation that kp being very small okay it produces three waves one is the carrier which would be fluctuating at ωs or which should be producing which would be varying at signal frequency ωs and side bands are ωs + ω this is called as the upper side band.

And ωs – ω okay the amplitude of these things will be dependent on what kp that your giving but for kp which is very small you can think of the amplitude has being essentially unchanged at the carrier and the amplitude of the side bands are down to kpn and kp okay so the amplitudes of the carrier is essentially one because it has not changed much and kp would be the amplitude of the upper side band as well as the lower side band the upper side band will also have a phase 5e while the lower side band will have a phase of – 5e relation to the signal phase which is at ωs this is the simplest case of sinusoidal phase modulation okay something that we do not really look at it.

For now okay for few more modules okay we have looked at the output power input power the electric field output and the electric field input characterization of the phase modulator so for our purpose the time domain characterization of the modulator is it takes in some electrical input signal puts out in the electric field output which will have only it is phase changed compared to the input if you want to plot output power verses input power it would be just equal to one or output power by input power ratio that would be equal to one for all time t there is no change in the power of the phase modulator.

It will preserve a loss less phase modulator will preserve whatever the input power is there and just puts it out now let us look at how can we obtained amplitude modulation by utilizing cleverly the phase modulator structures okay.

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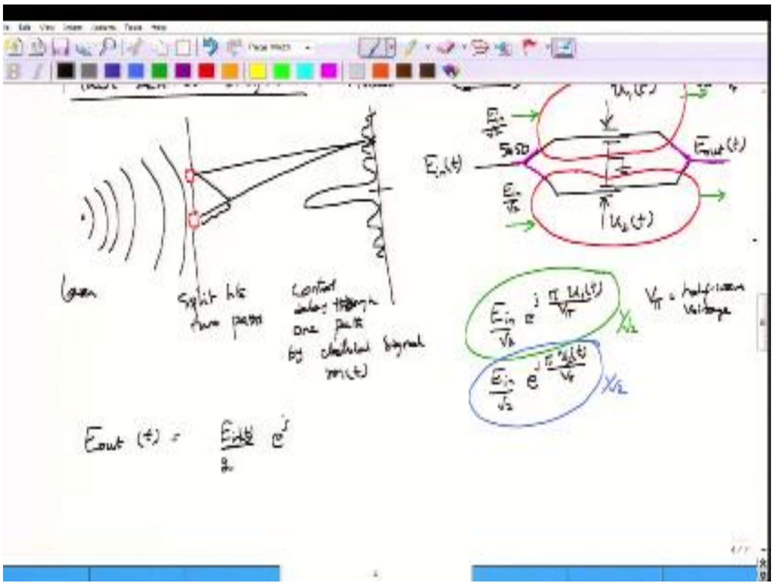

This structures is called as a Mach zehnder interferometer and it is based really on the idea of interferometer what is a our interferometer Mach zehnder sorry Mach zehnder interferometer what is the idea of an interferometer perhaps the simplest interferometer that you are familiar with is the so called young interferometer right so in which you had a light wave coming in from some distance source and then you had two slits.

So these are the two slits that you had, and these slits would allow partial light to go through, and then you put a screen somewhere for back here, and you would see that well at any point on the screen the amplitude of this one would be the light that is coming from the first slit and the light that is coming from the second slit.

And there is a certain phase difference because the paths of these two lights are not equal, so any change in the path will change the phase of the light so depending on the phase change you probably would have seen an interference pattern that would look like this, so it would be the interference pattern that might have seen.

So there are certain places where the interference pattern is maximum because the two phase arrive in phase and there are certain places where there not equal because, they would arrive at different phases, so based on this idea that you can take light split it in to two part and delay one with respect to the other, right and then combine them is an interferometer, and there interferometer idea is behind what is called as a Mach - Zehnder interferometer modulator.

Or sometimes called as Mach- Zehnder modulator MZM so this MZM basically works on the principal that it takes light coming from the laser, so this would be the laser for us and it will split in to two paths, split into two paths and then create or control the delay through one path, by electrical signal so whatever the signal that you want to transmit, the electrical signal M(t) will go and control the delay through one path for the lighter is propagating through it.

The other path is normally not delayed and it is transmitted as it is, so when you combine them to on the screen or the equivalent on the screen, what you get is amplitude modulated electric field, which will then be used for amplitude modulation of the light waves. So you start with the laser splitting to two paths controlled delay through one path and then combine them.

This is of course not exactly how it is construct I mean this is exactly is constructed the actual physical details are quite different, we will talk about those difficult in details in the next layer we will be talk about the physics behind this modulators, okay. So let's proceed to look at the structure itself, the structure consists of an input wave guide, these are normally made on a wave guide, so the structure consists of an input wave guide, where the incoming signal will be the electric field of the laser.

So the electric field of the laser will provide the input and this is split into two parts by using what is called as a Y junction, which can be implemented on an optical waveguide itself, you send one through the other and instead of what we do is, instead of delaying one with respect to the other, we kind of put two controls, okay, so that we can control the relative phase between the two, remember all the time concerned is the relative delay.

The relative path difference between the two arms, okay, of the interferometer or it is path difference because it converts to face difference I am only concern with the relative phase difference between the two paths to do that one to normally use some structure you give one input called U1 (t) the other input U2 (t) and then combine them using one more coupler or a Y junction and what you get is the electric field output E (t).

This portion which is there here the light going in and light coming out is actually a phase modulator ,similarly what you are obtaining here is another phase modulator and we have already seen how to characterise the input output relationship of these two phase modulators, what we have not understood is what are this Y junctions so I know what if give the input to this phase modulator which has message signal M(t) in the form of U1(t), I also know that if I know the electric field input going into this second phase modulator ,whose input is U2(t), okay, i know what the electric field outputs that I am going to get here.

But what I don't know is how to deal with this Y junction, which is splitting and combining light, okay, we will again as I said we will talk about this split and how the physical implementation works, but for now we will simply postulate the relationship between that two, if there is no phase difference between the two arms, then whatever the power you send must come back without any loss.

Assuming that there are no losses through the wave guides, there are no losses through the internal structure of the modulator then whatever power you give could be 1millewat could be 2 mV, this power would appear at the output, okay, accordingly these two Y junctions have to split the power in a typical splitter, we use a 50-50 splitter indicating that half the power goes in one arm, and half the power goes in the other arm.

But powers are by them shelf is not important here or there of the secondary important, what is important is how the amplitudes get split, okay we will postulate that the amplitudes do get split in the form of one by root 2, and this power which I have will split into en by root 2, and while we combine we also combine them in the same fashion.

You can see that depending on the structure these splits are not exactly en by root 2 or en by root 2 there could some additional phase factors that could come in, but for now we will simply assume that this splits have happened in such a way that the electric field amplitude going into the upper phase modulator is en by root 2, the electric field amplitude going in to the bottom phase modulator is en by root 2.

So what could be the output of the first phase modulator here? Well this would be en/√2, I have not shown that en is the function of time but it is a function of time because it is coming from the input signal, and then this part you know comes from this phase modulator thing right, so you had 5(t) ,and in place of 5(t),you had KP and m(t),rather than writing KP m(t), we will use a slightly different notations here, okay.

So i will write this as em/√2 e^{j} and the frequency and everything is known, so only thing which have to write here will be the phase part, and that phase part i will write it as πui(t)/tπ, let me rewrite it down her, so for the first phase modulator the electric field output would be em/√2 ,that is at this point which i am writing ,and then you have $e^{j\pi}$ u1(t)/nπ, this vπ is called as the half wave voltage of the phase modulator.

We will talk about what half wave voltage means, when we look at the physical structure of the phase modulator, okay what could be the output of the second phase modulator? Well we already know how to do that one so it could be en/√2, e^{j}π but not the u1(t),it is u2(t)/vπ, okay.

Now how do we combine them to form the outputs, again you take this electric field divide by 1/√2, this electric field divided by 1/√2 and combine them, so when you look at the electric field output E out of T it would be the combination of this particular output, okay, which has been reduce by amplitude 1/√2, and this output which again has been reduced by amplitude by 1/√2, and simply combine them, okay.

So let us combine them in this way so what i get is Em/2 Em(t) let me write-down Em/2 is a constant, which can be written out and i have $E^{j\pi}$ u1(t)/vπ+$E^{J\pi}$U2 (Tπ) Vπ, so there is some difference in hoe the electric field at output of the MZM is compare to the output of the phase modulator correct? So that is this the different between the two and U1(t) would be the signal M(t),that you could be providing U2(t), could be the signal then M(t) that you are providing ,later we will see that depending on weather these two are driven with the same size or driven with different size.

You can get different modulator outputs. But this is the relationship between input and output without simplifying further, however we normally want to simply to understand what is going on. We can do that by removing one of these two terms, that is taking one of these terms as common, let me arbitrary choose to take this particular term out to obtain electric field at output of m side m modulator or m side m as En(t)/2 the face factor which I am taking out is $e^{j\pi u2(t)}$ divided by vπ, if I take that out what would I left in, well there would be one in place of $e^{j\pi u2(t)}$, but here I will have $e^{j\pi u1(t)-u2(t)}$ divided by vπ.

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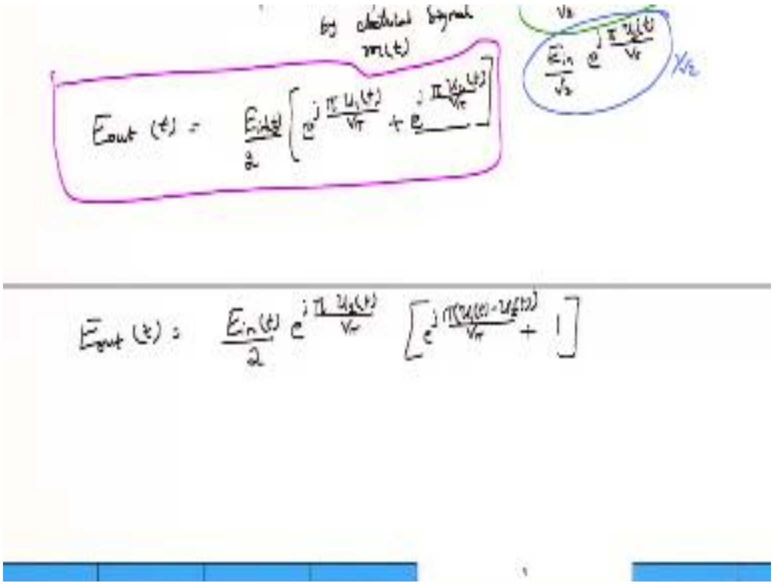

So this what I have now, now this hasn't completely solve my problem but what I can do is, I can write u1(t)-u2(t) as u2(t) which could represent the difference between u1 and u2(t), so that could represent the difference between the two signals, u1(t) and u2(t). These are electrical signals by the way, so please remember u1(t) are electrical signals, u1(t) and u2(t) are electrical signals. So further simplification can be performed by removing one half of this and then recognizing that the quantity inside is actually a quotient function, so cause of the x is $e^{jx}+e^{-jx}$ divided by 2, sin x is equal to $e^{ix}-e^{-jx}$ divided by 2j, so if you remember these two formulas from all its identities, that would be helpful here.

So I can think of this as this term inside this square bracket as some $e^{jx}+1$, and if I take $e^{jx}+2$ as the common factor, I can write here as $e^{jx/2}+ e^{-jx/2}$, you can verify this by multiplying this $e^{-jx/2}$ inside, so when you multiply this will go and this will become 1 and x is nothing but π/vπ into ud(t). So by making this associations here, I can write thy electric field output E_{out}(t) of the m side m modulator, so this will be equal to some E_n(t)/2 $e^{j\pi u2(t)}$ divided by vπ, so this divided by vπ, I have taken $e^{j\pi ud(t)}$ divided by 2, sorry again 2vπ and in brackets what I have is $e^{j\pi ud(t)}/2+ e^{-j\pi ud(t)}/2$, which is nothing but actually a cause of πud(t)/2vπ, so this would be πud(t)/2vπ, so this would be simplified electric field of the output after taking some terms which are constant.

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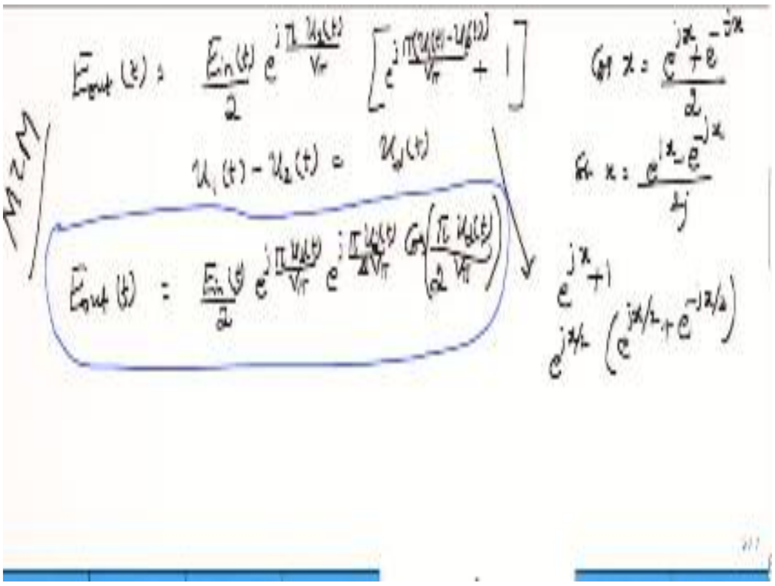

Now if you look at what is the relationship between input and output, sorry this could be, there is no 2 here so 2 this could be common, because when I take this term here I need here because coz of x is there is a 2 in the denominator, so I already have 2 here at $E_n/2$, I will push the 2 into the brackets, so to form the term into cos π ud (t)/2vπ. If you look at this expression, there are this two times which is essentially imply that there is some global face change that is happening, where is some global face change which is completely not important for me.

So this global face, I can ignore as long as I am looking only one m z m, I am not connecting the output of m z m to another m z m, I can conveniently ignore this global face factor. For an isolated m z m that I have which I am giving the input and looking at the output, this global face factor OI can ignore. What I am now left is, $E_{out}(t)$ is square root Ps $e^{j\omega st}$ and then I have cos πud(t)/2vπ, so this could be again the ,a signal whose central frequency ωs, but whose amplitude is now a function of time.

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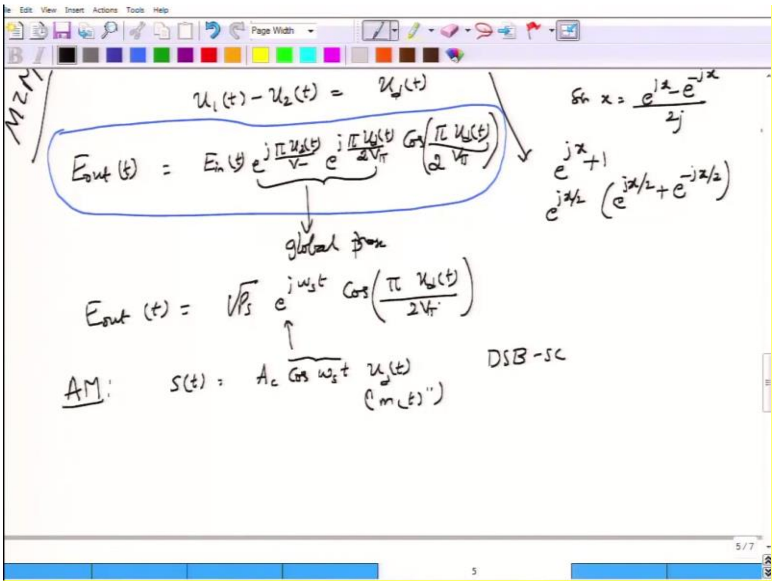

So in the frequency domain, the output could not just be a signs of, I mean not would be a impulse function ωs, but it will now be modulated, be u1(t) changes with time, u2(t) changes with time, the difference between the two signal also changes with time. Have you obtained amplitude modulation, well not quiet yet, because in an amplitude modulation as we normally understand, the output or the signal s(t) after modulation would be written something like Ac cos ωs t which would be the electrical carrier; this would be the carrier signal, multiplied by the some u(t), where u(t) is the message signal.

This is what called as double side band, separate carrier if you remember, so not yet quiet obtained here, so just to make it consistent I will write this as ud(t), ud(t) being the message signal, so this is the message signal I have; equivalent of the message signal. But I have not yet obtained, this coz ωs t is not the problem, because I can convert this simply into $e^{j\omega st}$, but then I still left out with this cos πud(t)/2vπ, to really obtain the modulator, what we need to do is, we need to understand what is the relationship between Eout and ud(t) in a slightly more detailed manner.

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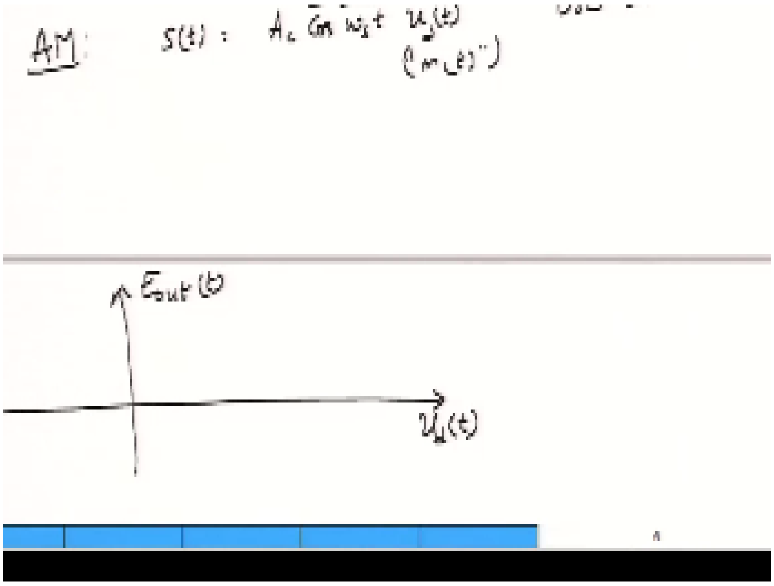

We do that by drawing a graph of electric field output as a function of ud(t), what would the function relationship look like, rather than looking at Eout(t), let me look out as this ratio Eout(t)/En(t), this is known as the field transfer function and this transfer function of the transfer ratio, this is not exactly a transfer function in the signal system point of view, but this is the just a name for that because there is output to input ratios.

Now as ud(t) changes, initially when ud(t) is zero cos of the argument 0 is 1, so it would be equal to 1, and when will this go to 0, when ud(t) equal to vπ, so when this is equal to vπ, the cos function, inside the cos function the argument vπ cancels and you get cos π/2 which means it's going to 0. So this is at vπ, what would happen when ud(t) =2vπ, the transfer ratio becomes -1. So would happen at 2vπ, so this would become -1, so you will actually have, something going to be 0, something becoming -1.

Similarly on this side at –vπ and at -2vπ, you will get a -1. Of course this will again keep repeating, so we don't really want to look at it. If you look at what is the ratio of the power, it can be obtained as Pout(t)/Pin(t), but power ratio will look like this, because amplitude, could be minus but the power would be plus. Now in the next module we will see how to make an amplitude modulator, we will also see how to make an optical pulse shaper using this m z m that we have just described. Thank you

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