Indian Institute of Technology Kanpur

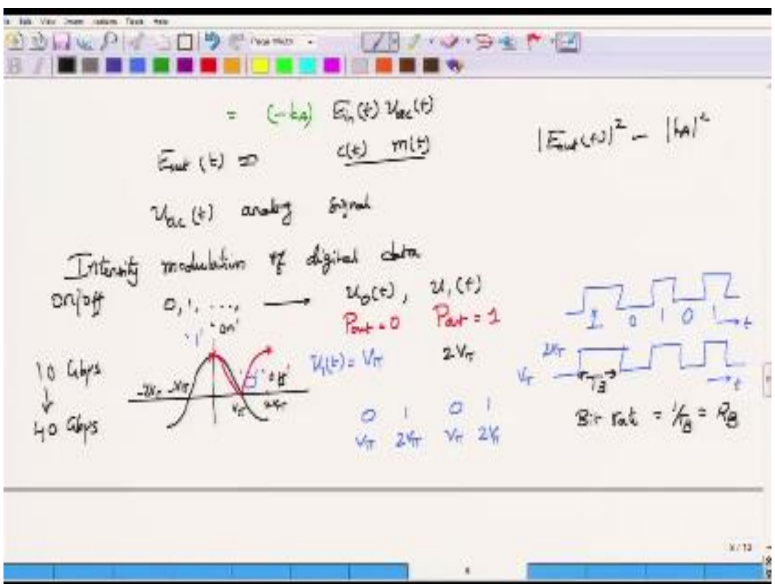
National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Optical Communications

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

by
Prof. Pradeep Kumar K
Dept. of Electrical Engineering
IIT Kanpur

(Refer Slide Time: 00:13)



As we said digital modulations are much popular than analog modulation one of the most popular digital modulation one of the most popular digital modulation technology that has been used since the first generation optical communication system is what is called as intensity modulation okay intensity modulation of the digital data okay as we know digital is an abstract term it comes as a sequence of 0 and once but this zeros and ones they themselves cannot by apply to a modulator I cannot take a modulator and say 0 I would not get anything I take cannot take a modulator and say one.

I will not get anything I have to convert this zeros and ones into appropriate voltage values okay so let us say for 0 I will use some u(t) and for one I will, say u1(t) this hoe exactly we do go from 01 to u0(t) and u1(t) is a subject of line coding that we will take a platter but now let us simply recall our transfer characteristic of the Mach center modulator and see if I can perform this digital modulation okay what I would like to do in this digital modulation is that when I get an input 0 I should pick a value of u0(t) such that the output power will be equal to 0 or should be very, very small.

When I get a bit one this bit one has to be mapped to output power equal to one that is to the maximum operating point of the Mach center modulator so you have to switch between minimum transmission point or the 0. Of the modulator to the maximum transmission point which could be at this stage right so you have switch between these two values as and when I get a sequence of 0 sent once okay so I have to choose the values of u0 (t) such that for bit 0 I get the output power equal to 0 I have to choose u1(t) such that the for the bit one which is map to u1(t) the output power should be equal to one.

From transfer characteristic is very, very simple and obvious what this value should be at least there of course there are an infinite number of choices because the modulator transfer characteristic is periodic but over this one period from – VЛ + VЛ or from – 2VЛ + 2VЛ the choices are fairly simple how do I obtain 0 transmission point I have to choose u0(ts) VЛ correct if I choose VЛ then if I map u0(t) or if I take u(t) is equal to VЛ whenever this u0(t) is applied which is equivalent of applying VЛ then I will be at the 0 operating point and this would represent the bit 0 right.

So bit 0 comes in that 0 means we have to convert that 0 x VЛ okay so I get a 0 operating point so my 0 bit is located here okay this is a 0 bit not the output power this is a 0 bit similarly whenever so if I want to operate at the maximum transmission point I have to choose eitheru1(t) as 0 or I have to choose that one to be as 2VЛ because at 2VЛ the power transfer characteristic would be going to it is maximum right so the power characteristic would be going to is maximum so either I choose 0 or I choose 2VЛ okay so this 2VЛ this is – VЛ and this follow if – 2VЛ if I choose 2VЛ then I will be operating in the maximum transmission point and my output would be equal to one.

So this would be my one bit okay, so if I have a sequence of 0 1, 0 1 then this sequence has to converted into the appropriate u0(t) u1(t) what would that conversion be send VЛ when you get one you sent to VЛ you send 2VЛ okay in time of course it would go like this so this is my 0 sorry this is my 1 0 1 0 1 input sequence corresponding to this, this is in time and the corresponding analog signal of course this has to be an analog signal eventually.

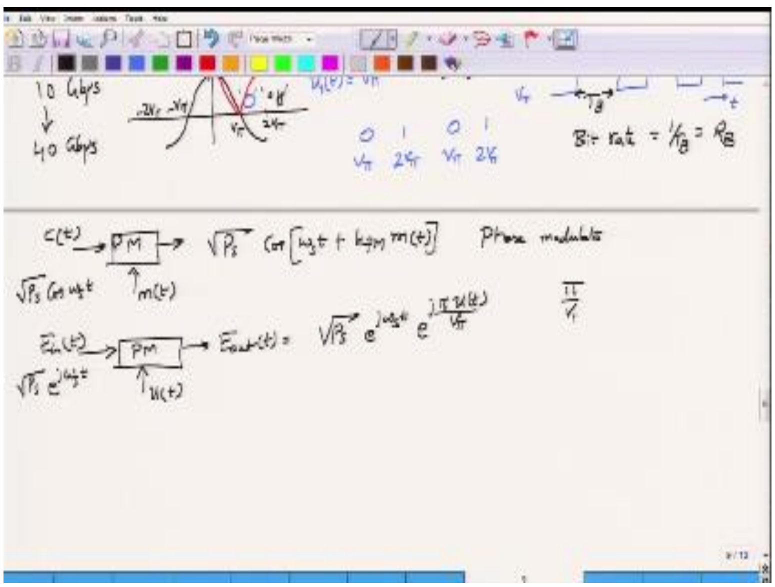
This is the digital signal 0 1 01 is the digital sequence or digital signal but this has to be convert into a way formula to apply to a Mach center modulator this would from the analog signal but the modulation is happening digital okay so the signal corresponding to this or the way from corresponding to this bit sequence would be for a 0 you put VЛ and for one you put 2VЛ right so this would be the corresponding sequence okay this would be function of time the duration of 1 or 0 is called as the bit duration so the duration of 0 are 1 is called as the bit duration in this case each bit or each pulse of duration TB carries one bit of information so the bit rate the rate at which we are transmitting.

This bits is equal to 1/TB this is sometimes return as RB, RB denotes the bit rate in each time window of TB I am sending one pulse and each such pulse right so each pulse would carry one bit so there for the bit rate f this intensity modulation or on of keying why is this called on off keying well when you are sincere moving between the on point of the Mach center modulator and your transition from on to the off point of the of the Mach center modulator this is called as on off keying so it is kind of operating like a key so whenever you get a 0.

You go to the Mach minimum transmission point so this is how you can perform intensity modulation of digital data or the on off keying this is a popular modulation technology that has been used up to 10GB PS optical communication systems it has also been used for 4oGb Ps although beyond this you saying on off keying is not advisable because the efficiency of the modulation which is measured as the number of bits that you can send for a given bandwidth bits per/h is very small in fact it is a smallest possible for this intensity modulation sequence so for the this on off k.

Okay let us now go from this complicated analog I mean amplitude modulation to a slightly simpler modulation that of the phase modulation okay because for the phase modulation the physical.

(Refer Slide Time: 07:06)



Or the functional layer should tell you that if I have my carrier c(t) which would essentially the sinusoidal carrier and if I drive this modulator phase modulator with signal m(t) which is the message signal what should I get well I cannot just write c(t) into m(t) or do anything I have to assume what c(t) is so let assume that c(t) of some square root PS cause ωst so if I assume that the carrier a2 PS cause ωst and m(t) is the message signal that I am applying then the output of this would be √PS cause ωst + some constant kpm this pm stands for phase modulator phase modulation times m(t).

This is the sinusoidal carrier whose phase is being modulated or changed according to this m(t) this is the phase modulator functional relationship can we now look at what is the functional relationship for the phase modulator in the optical domain that we talked about well in the phase modulator what we had was a input signal u(t) which of course would be equivalent of having m(t) here and then to this phase modulator the input was en(t) coming from laser this laser output was √PS and in the real case it could b cause ωst that is the real expression would be cause ωst but the complex.

Expression would tell you the this would $e^{j\omega st}$ for this phase modulator the output electric field would be equal to input electric field which is square root PS $e^{j\omega st}$ and because your sending in this u(t) your additional term that comes in because u(t) would be $e^{jЛu}$(t) divided VЛ but if you understand that π/vπ with whatever the input voltage that you are going to get with u(t), the peak value of the u(t) can be taken to be some Kpm.

Then you see that these two relationships are exactly equivalent, one of course return in terms of cosωst, but all that you are saying here is nothing but the complex representation would be $e^{j\ \omega st}$, e^{jkpm} m(t),right if you identify u(t) with m(t) Kpm with π/v π, then your phase modulators has exactly the same functional relationship as a phase modulator that you would expect from your ,or you would have studied from your earlier courses.

So you expect phase modulated to have it to perform its job by changing the phase of the carrier and that is precisely it is optical phase modulated is do it, so optical phase modulate has a exactly same phase relationship and you can now do analogue modulation if your u(t),happens to be analogue signal, for the case of sinusoidal phase modulation ,you can take u(t) to be sum peak value U_{ac} cause of ωmt, and then you can see that the spectrum will have this vessel functions ,you know it will have side bands which are infinite number and so on.

So you would have you can recall all these things ideas about phase modulating, in the analogue domain, is a analogue phase modulation, so that’s I would not be discussing that one but rather let us look what we can do in terms of digital phase modulation? Okay what do we mean by digital phase modulation? Let us consider the simplest case of what is called as binary phase shift keying? Abbreviated normally as binary or abbreviated BPSK, PSK stands for phase shift keying, B stands for binary phase shift keying.

What is the point of the binary phase shift keying? Well if I get a 0 I would like this 0 bit ,this is actually 0 bit right, this 0 bit be represented as phase $\varphi 1$,if I get a bit 1 at the input I would like this to be represented as phase $\varphi 2$, how can I do that? In terms of the optical phase modulator well, what is the phase that you want? Let us suppose that $\varphi 1=0$ and $\varphi 2=\pi$, these are two widely separated phases.

So it could be natural to assume that you can map 0 bit to 0 phase and 1 bit t π, or you can turn it around doesn't really matter which ever that you take that is up to you, the convention you can follow with either 0 being π, and 1 being 0, okay, so let us try with this consultation, later we can switch it if we think that this is not a very nice representation.

Okay, when I have $\varphi 1=0$ what should my u1(t) should be chosen such that I get no phase shift I can choose 0 or I can choose 2vπ, if I get a phase shift of what should of π what should I have to choose? I should choose u2 (t) which is the signal corresponding to phase π2 which then corresponds to bit 1, I should choose this one to be vπ correct, so if I alternate between 2vπ and vπ I am changing the phase of the laser light that is laser light which is given as the input to the optical phase modulator I am changing the phase of the light wave, to go between 0 to π.

Let us look at this well the output electric field here would be $\sqrt{ps}$ $E^{j\ \boldsymbol{\omega}st}$ and then E^{j0}or j2vπ so 0*π/vπ, this is nothing but 1 and this is equal to $\sqrt{ps}$ $E^{j\ \omega\ st}$ so this is exactly what we have transmitted at the input, so this E out =E in with no phase difference ,okay, when you have u2=vπ so this was the case where u1(t)=0,if you have u2=vπ then in this case the output electric field will be given by $\sqrt{ps}$ E^{j} π, vπ/vπ, but this vπ and vπ will cancelled, and $e^{j\ \pi}$ =-1,so I get – $\sqrt{ps}$ $E^{j\ \omega st}$, okay, so i have obtained binary phase shift keying.

If you wants to draw some wave forms to indicate how it would look let us assume that I am transmitting this particular sequence, this is 1, this is 0 this is 1 and 0, okay correspondingly to this one u1 (t) will be 0 and for 1 you need to have v π, okay, so the corresponding values here would be 0, voltage v π voltage 0 voltage and then v π 2 times this one would be again last sequence.

How would the wave forms look? Well corresponding to 0 i should have $\sqrt{ps}$ $E^{j\omega st}$,then I should have $-\sqrt{ps}$ $E^{j\omega st}$ then i should have $\sqrt{ps}$ $E^{j\omega st}$,now i should have $-\sqrt{ps}$ $E^{j\omega 2st}$ so I should have this particular sequence, and then finally I should close it up by having $\sqrt{ps}$ $E^{j\omega st}$,if I want to graph this are complex exponential terms, obviously i cannot graph them like this.

What I have to do is take the real part of each of this, okay so I have to take the real part of the each of this and then plot it, so I have let say this is my time access and these are my boundaries which are I am considering, so this could be a high frequency sinusoidal signal which we will say take it to be a cosine signal right, so this would be a cosine signal, and you would come at this point.

So let us see if I caught in the number of terms correctly, so I have 1 I have 2 then I should actually have one more here, because the number of cycles here should be an integral multiple, okay, so the number of cycles here must be an integral multiple, so I have to be little careful while sketching, so let me assume for simplicity that I have only one sketch here like this, okay please note that this could not be the carrier wave form.

The carrier wave form actually be like multiple such this one because the frequency has to be very large I am showing a very small frequency see just for clarification, just to clarify the diagram here, but you should remember that this would actually be the carrier which is oscillating heavily, what is the phase here? The phase is 0 here the phase should become π which means that I cannot start a cosine ω ft, I have to start a – cosine ω ft , so I should actually have this particular wave form right.

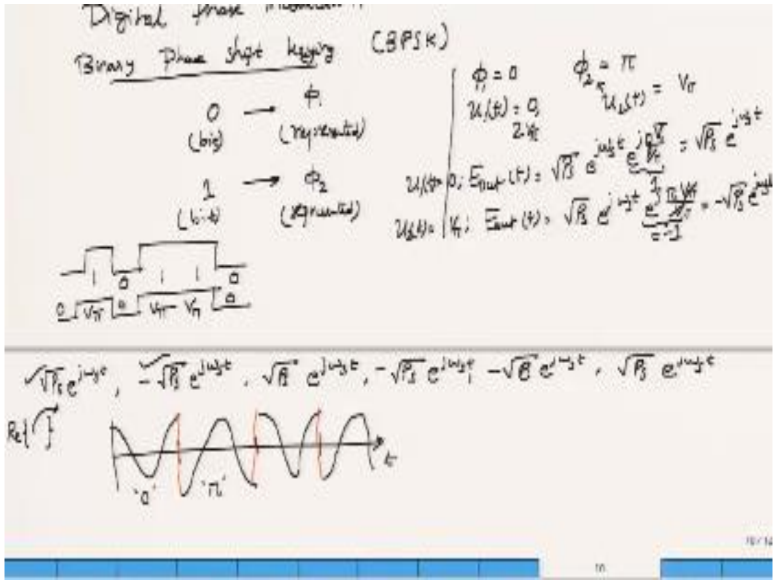
Now what happens at this particular junction where the bit the phase is going from 0 to π, what should happen is there is a discontinuity in this phase, okay, there is a discontinuity in this phase, also I have change the amplitudes, but this have to be the same amplitude you can forget that amplitude part, i mean you can forgive that amplitude part, so what is happening is as the phases changes from 0 to π, there is a discontinuity at the boundary.

What should be the next wave form well i should have done $\sqrt{ps}$ $E^{j\ \omega j}$ I done this one, now I should again get $\sqrt{ps}$ $E^{j\ \omega st}$ which could be a signal, that could look like this, right it could be a signal which is the cosine wave form then I should have a minus root, two phase discontinuity over here, so whenever there is a phase change there would be a phase discontinuity okay.

This thing you have to keep in mind this wave form that you have is again analogue, you can see that things are changing except the discontinuity boundaries ,so how can I call this a digital modulation well it turns out that what your interested is not in this amplitude variations but rather in the phase and you perform the appropriate phase detection on this wave form we will see that we will be extracting the phases 0 π π 0 which are then map actually to πt 0101and0, so all though the modulation is digital the final wave form that will be transmitted over the fiber is actually the analogue wave form.

Okay, so this completes our understanding of BPSK and phase modulation of course we will revisit all these in much more detail when we take up higher order modulation formats, before leaving this subject of BPSK, let me introduce you to one figure in which we normally think of when we say BPSK or this type of be represent BPSK, this figure represents what is called as the in phase and quadrature components it is a plane in which the x-axis in phase components and the y-axis is quadrature components.

(Refer Slide Time: 18:01)



I will explain to you what is in phase and quadrature is shortly or in the next module, but in phase simply means that part of cosine ωs t, whatever the components that get multiplied to cosine ωs t is the in phase component, whatever components gets multiplied to sin ωs t is called as the quadrature components.

Sometimes called as cosine components and sin components, the point about cos ωs t and sin ωs t is that they are orthogonal to each other, we will discuss what orthogonality of the two waveforms mean, and we are used to see orthogonality of two vectors. Later we will see that signals themselves can be considered as vectors, cosine ωs t and sin ωs t can be considered as vectors in some sense, which we will talk about and in that case these two are orthogonal or perpendicular to each of them, now if you look at the expression that we have obtained or the binary phase modulation, what we will see that, the waveforms are consistently given by square root Ps cos ωs t or minus square root Ps cos ωs t,.

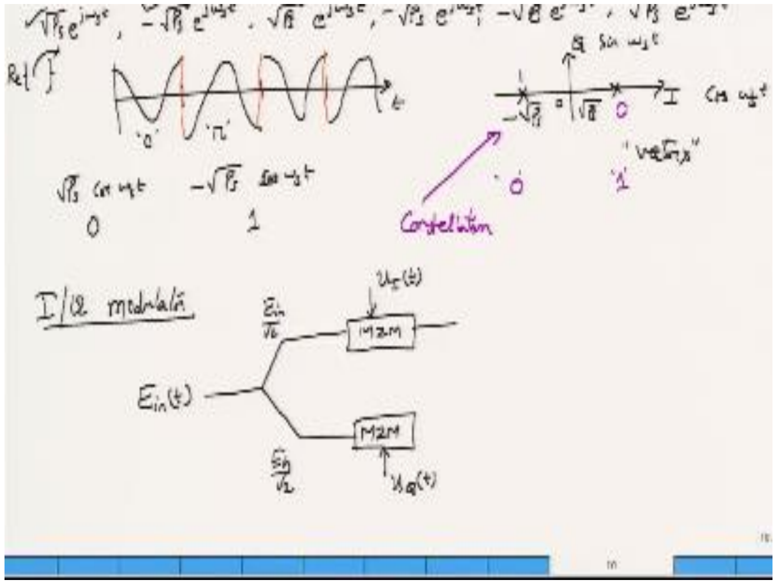
So on one side which is representing bit 0 and bit 1, you have square root Ps cos ωs t, so this portion is already talking about cos ωs t, you can mark of a point whose distance would be square root Ps, so this would be square root Ps and you can think of distance signal vector, which lies entirely on the I or the interface line. How about representing minus square root Ps, by a point which is at minus square root Ps itself, this is the 0, at minus square root Ps.

This would correspond to bit 0 and this corresponds to bit 1, if you are not happy about this constellation representation, you can write this at 1, write t5his as 0, all your writing are the bits and the corresponding phase value are 0 or π and the corresponding amplitudes are square root Ps or – square root Ps. This figure is incidentally called as a constellation, at this point we have constellation with only two points, later you can see that you can modulate not only on cosine ωs t component but also on the sin ωs t component and you can mix both of them, you can multiply both of them, what is called as the quadrature multiplexing or the in phase quadrature both getting modulated and you will get quadrature amplitude modulation.

Because both amplitude as well as phase are being modulated and this modulation can be represented graphically by this constellation diagram. Now how do we, actually realize this, iq modulation, can we do iq modulation in the optical domain? Well it can be done by using what is called as the iq modulator, we will talk about what is iq in the next module later but for now, since we are talking about the modulator part of optical transmitter, let us finish by looking at iq modulation.

What is the structure of an iq modulation, it will look little, you know intimidating that first you have the source coming in Ein(t) and then it splits into two portions, so far no surprises, what I should get here is Ein/ √2 what I should get here is Ein/ √2, now I put 1 max ender modulator here, drive this one with the voltage which would be the difference voltage max ender modulator, I call this as ui(t) and also I drive this second m z m which I put with uq(t), so this I stands for the in phase voltage and q stands for the quadrature drive voltage.

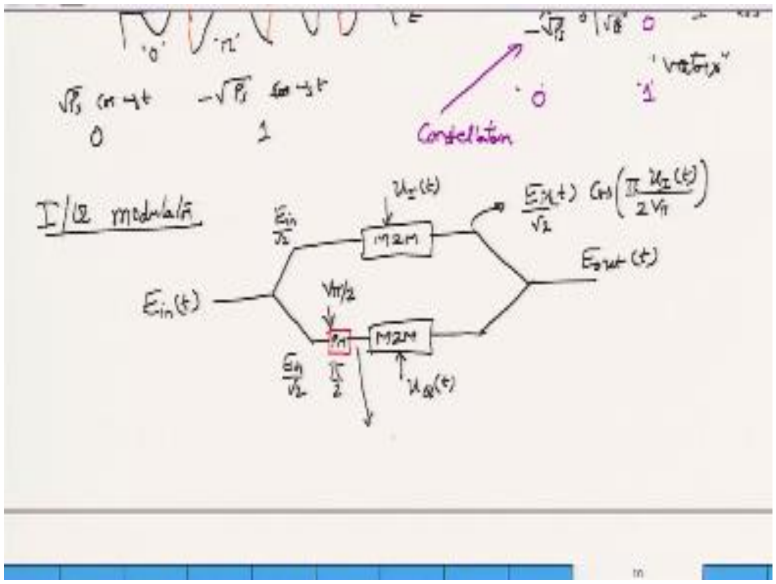
(Refer Slide Time: 22:56)



Now before I give this to the max ender modulator, what I do is, I will put this through a phase modulator. I will put this through a phase modulator. Let me write down my phase modulator here. This phase modulator produces a $\pi/2$ phase shift, how can I produce the $\pi/2$ phase shift, all I have to do is take this phase modulator, which let us call this as Pm, and then supply a constant voltage of $v\pi/2$, so as long as you hold it constant to value of $v\pi/2$, we can supply this and phase modulator can produce the $\pi/2$ phase shift.

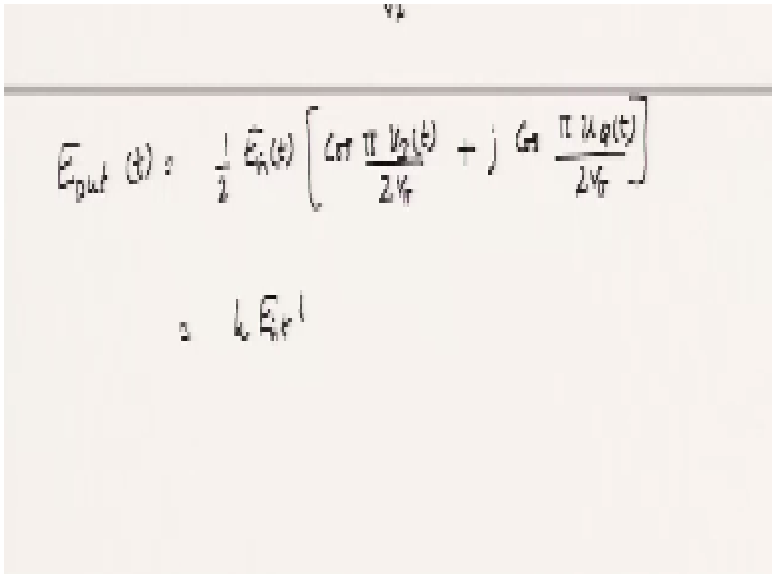
Once you get the max ender model outputs, here we can then combine to form the electric field output Eout(t). If you of course look at the max ender modulator construction is you know that this itself is a interferometer. If you want to describe the relationship of Eout (t), I need to know what is the electric field here, this electric field is nothing but Ein/$\sqrt{2}$ Ein (t) $\sqrt{2}$ times cos π ui (t)/2vπ, let us assume that both modulators have the same value of vπ, in fact we will assume that even the face modulator has the same value of vπ.

(Refer Slide Time: 24:16)



What would be the electric field here, the electric field here would be j time Ein $/\sqrt{2}$, why should be there j this indicates 90 degree phase shift, so this j Ein (t)$/\sqrt{2}$, the electric field here will be $j/\sqrt{2}$ Ein(t) cos π uq(t)/2vπ. So that sum of these two after multiplying by $\sqrt{2}$ will be the electric field output Eout(t), so Eout(t) is equal to half Ein(t),which is the constant I am talking this out I get cos π ui(t)/2vπ + j cos π uq(t)/2vπ. If I can somehow remove this cosine by going back to same kind of biasing that we did for the amplitude modulation, we can remove this cos and forget about the minus signs I am going to get and take this π/2vπ as some constant ,put everything to a constant thing.

(Refer Slide Time: 25:29)



What I get is constant times Ein (t), which would be my carrier, Ein (t) times ui (t) +j uq (t), so this would be the iq modulator electric field. We will discuss more about iq modulator after we introduce iq terminology in the next module. Thank you

<u>Acknowledgement</u>

Ministry of Human Resource & Development

Prof. Satyaki Roy

Co-ordinator, NPTEL IIT Kanpur

NPTEL Team

Sanjay Pal

Ashish Singh

Badal Pradhan

Tapobrata Das

Ram Chandra

Dilip Tripathi

Manoj Shrivastava

Padam Shukla

Sanjay Mishra

Shubham Rawat

Shikha Gupta

K. K. Mishra

Aradhana Singh

Sweta

Ashutosh Gairola

Dilip Katiyar

Sharwan

Hari Ram

Bhadra Rao

Puneet Kumar Bajpai

Lalty Dutta

Ajay Kanaujia

Shivendra Kumar Tiwari

an IIT Kanpur Production