Electrical Measurement and Electronic Instruments
Prof. Avishek Chatterjee
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 73
Instruments with op-amp based amplifiers – II

Welcome. So, in this chapter we are studying several instruments, measuring Instruments using op-amp based amplifiers, ok.

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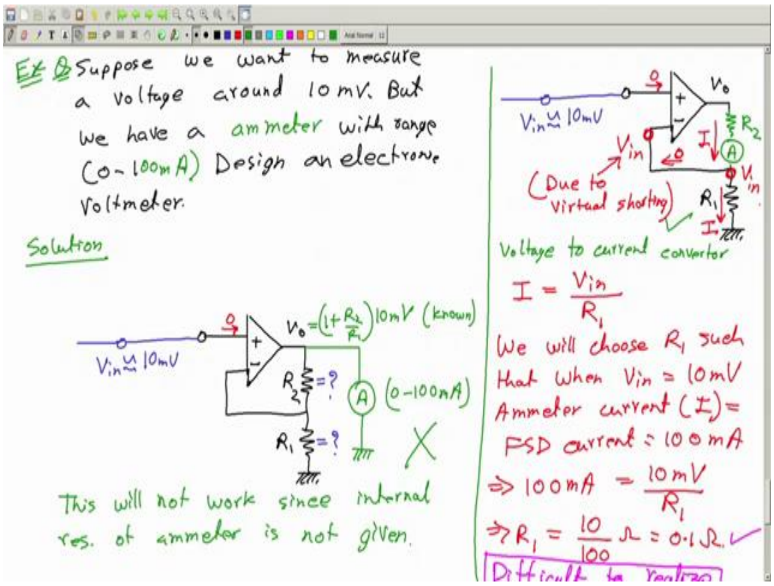

And so, we are taking examples and small numeric problems to understand this. What I see here last time we took an example, where we wanted to measure some voltage, I using an ammeter, ok and this is how we made the circuit. So, the voltage input comes here, this is primarily a non-inverting amplifier this structure resembles the non-inverting amplifier circuit and the ammeter we put here.

So, one thing which I did not tell you or I did not highlight the last time is that this circuit is acts like a voltage to current converter, ok. So, you can say that this is a voltage to current converter all you can say this is voltage dependent current source or something like that I mean this the idea is that the main thing is that you give a voltage and you get a current; the value of the current is proportional to the voltage.

So, if you give V in you get some current which is proportional to this. Why? Because you know if this V in then due to virtual sorting principle same voltage V in should appear here. And therefore, we have V in here this is 0. So, Vin/ R 1 is this current ok, which is same as this current. So, therefore this current is same as this voltage divided by R 1.

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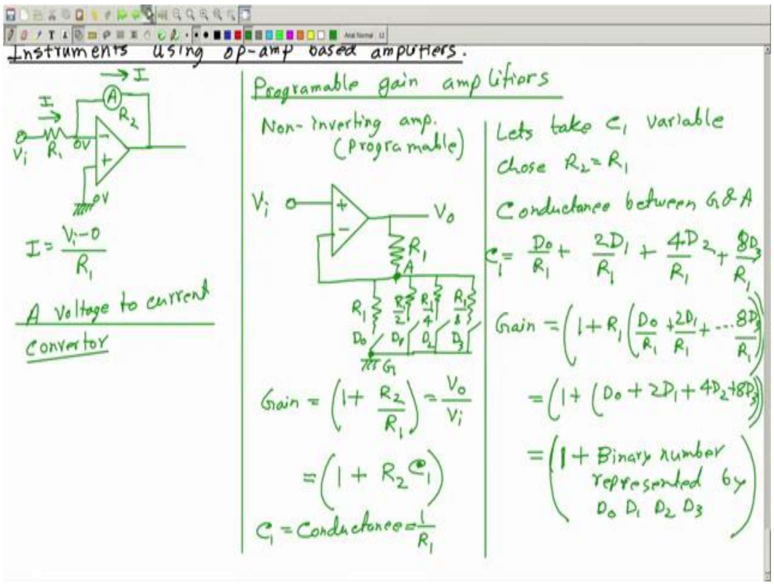

So, let us see another similar circuit which also will act as a voltage dependent, I mean voltage to current converter. In this case we have used primarily the structure of a non inverting amplifier. We could also use the structure of an inverting amplifier like this. So, let me first draw the inverting amplifier.

We have my, negative feedback, this is input V i call it R 1, R 2 this is grounded 0 volt, due to virtual shorting this will also be at 0 volt and this is inverting amplifier. Now, what we can do say if we replace this with an ammeter, then the current that we will have in this part ok, this current I is given is determines only or only by this voltage, how? Because you know this current and this current must be same.

Same current goes like this nothing can go into the op-amp therefore, these two currents are same, how much is this current from this branch I can say that I is V i -0/ R 1. So, therefore, this current will be determined only by this input voltage, ok. So, this is again a voltage to current converter.

And you see no matter whatever is the impedance of this ammeter resistance of this ammeter R 2 that does not matter at all. So, I can take any value of R 2 different values of R 2 within of course, some range otherwise the op-amp made may get into saturation region. So, within a range of values of R 2 or the ammeter or whatever impedance is connected here that will not affect this current. The current is only determined by this voltage and this resistance.

So, this is another similar circuit which we can use. And now, next thing that we will study is say, some programmable gain amplifiers. What is the programmable gain amplifier? It is basically an amplifier, whose gain can be altered change. So, we will have switches with which we can change the gain at desired value, ok.

So, let us first take say a non-inverting amplifier, which looks like this; a fraction of the output goes to the input this is the input voltage V i this is the voltage output V o. And here the gain is how much? We know this is $1 + \frac{R2}{R1}$ =V o / V i.

Now, we want to make it programmable changeable alterable so, what we can do? We can take either of these two resistances as variable simple. So, you change any resistance this one or this one, you can change the gain because the gain is given by this. So, this is not a very big deal but let us see so, what we can do. So, if we for example, take let me first write this as R2 x C 1 ok, where C 1 = 1/R 1; that means, C 1 is the conductance of this, ok. C 1 is the conductance which it is same as 1/R 1. Now, is therefore, you see we can take let us take C 1 variable, ok.

So, what we will do here instead of having a fixed resistance we can connect it say to this set of resistances and so, you can connect any of them right. If you connect this one you have value of R 1, you can connect this one another value of R 1 therefore, the gain will change. In fact, you can connect this in different combinations; so, you can connect only one or two at a time three at a time all 4 they will all give different value of this equivalent resistance, right. And therefore, the gain will be different this will be changeable programmable, ok. So, this will become programmable.

Now, I want to just choose the values of these resistances in a bit interesting way not nothing difficult. So, what I will do? I will say choose these conductances in ratios like 1 is to, 2 is to, 3 is; 1 is to, 2 is to, 4 is to, 8 in this ratio; one is the double of the other and so on, and what I will do? So, this is the ratio of conductance ok, conductance should be like this. So that means, the resistance should be like this, ok.

And let me take it this way, R 1, this is R1/ 2, this is R 1 / 4 and this is R 1 /8, ok. And call these switches as ok; you can call them D 0, D 1, D 2, D 3 etcetera. And let me also choose R 2 = R 1 ok. So, choose R 2 = R 1 and now let us see what happens if we connect these different switches.

So, the conductance of this part ok, the equivalent conductance between this and this point is can be written as C conductance between call this point G, G for ground and call this point as A between G and A. This we can write is equal to for this is 1/ R 1 ok, for plus conductances in parallel they get added right so, plus this plus 1 over this which will be 2 / R 1.

Conductance b/w G & A $C1 = \frac{D0}{R1} + \frac{2D1}{R1} + \frac{4D2}{R1} + \frac{8D3}{R1}$

Gain = $(1 + R1\,(\frac{D0}{R1} + \frac{2D1}{R1} + \frac{4D2}{R1} + \frac{8D3}{R1}))$

$= (1 + D0 + 2D1 + 4D2 + 8D3)$

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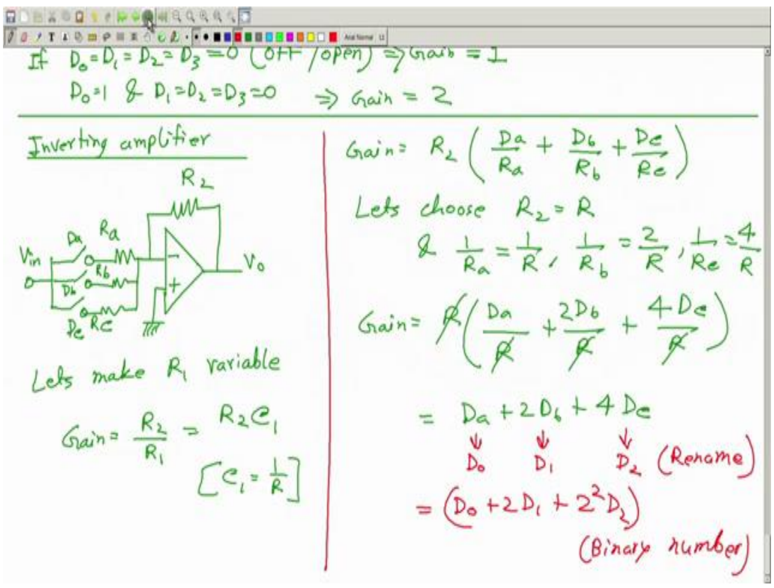

So, if D 0 equal to D 1 equal to D 2 equal to D 3 all of them are 0, which means off or open then the gain is these all will be 0, then the gain will be just 1, which also means actually all these resistances R not present they are already moved. So, we only have a direct feedback; so, this will just act like a buffer ok; so, this will become a buffer.

Similarly, you can take say only D 0 equal to 1 and everything else D 1 = D 2= D 3= 0, then the gain will be, how much? 2, ok; so, you close only one switch and you have a gain of 2.

And similarly if you want if you say connect these two D 0 and D 1 then the gain will be how much? So, this will be one this will be 1 so, 1 plus 1 is 3 plus this total will be 4. If you close this switch and this switch then the gain will be four. So, this way you can change the gain, ok. Now, so this was one programmable gain amplifier which we used which we have made using a non inverting amplifier. Similarly, one can also take first inverting amplifier and then one can make it programmable.

So, let us draw it. So, I strongly request you stop the video, do it yourself and then check your answer your solution with mine. So, once you know what we are going to do, always in this say in these videos I request you once you know what we are going to do, do not watch that do not watch that try it yourself first. And if you can do it yourself you do not have to watch the videos at all ok. So, R 2 R 1 this is non this is inverting amplifier and we want to make it programmable. So, we can take either this variable or this variable both will give me some programmable amplifiers so, I have many choices.

So, let me choose to make this variable and keep this constant that is my choice there is nothing sacred about it. So, I; so let us make R 1 variable and once again we will make R 1 variable so, that the gain can be changed in a binary fashion like this, ok. So, what we will do, we will take many such R 1's ok, let me just take three, three of them and then let me connect switches. So, if you give the input here this is V in and you have the switches, and we have to choose these resistances in a way that the gain the pattern of the gain follows some binary pattern ok. So, let us try that.

Gain = $\frac{R2}{R1}$ = R2 C1

Gain = R2 $\left(\frac{Da}{Ra}+\frac{Db}{Rb}+\frac{Dc}{Rc}\right)$

R2=R

$$\frac{1}{Ra} = \frac{1}{R} \quad ; \quad \frac{1}{Rb} = \frac{2}{R} \; ; \; \frac{1}{Rc} = \frac{4}{R}$$

Gain = Da+2Db+4Dc

Let us just now rename this let us call this D 0, call this D 1 D 2, because we see that, this is going to act like D l s b of a binary number, because the coefficient 2 it is just 1, but the coefficient of this is 2 coefficient of this is 4. So, that is why I rename them; rename new names and therefore, this is simply D 0 plus 2 D 1 plus 4 or 4 you can write 2 square D 2 so, you see this is just a binary number.

And once you know how you want to do it you can always do these calculations or back calculations so, that you get what you want. Do not memorize anything do not memorize or try to remember these things ok. So, we have seen some programmable gain amplifiers let us take a new topic.

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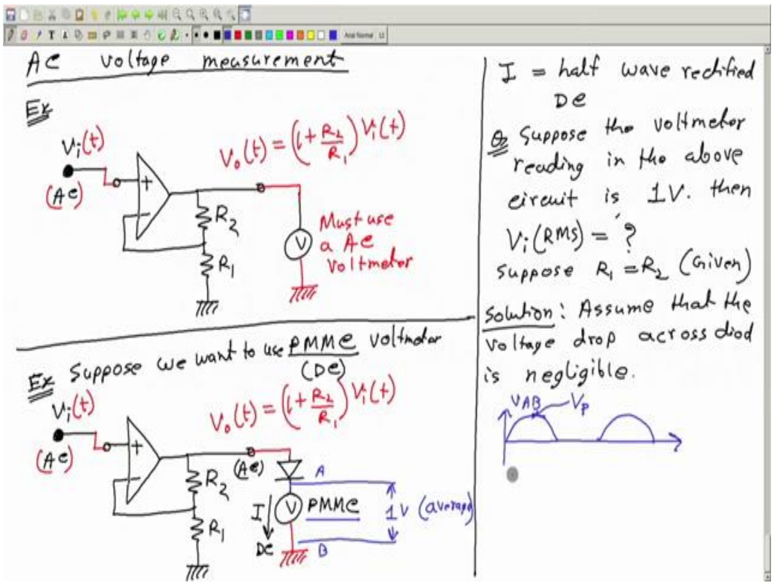

Let us move to some AC voltage measurement. So, example so suppose there is AC voltage this is AC at this point call it V i which we want to measure. This is a small voltage so therefore; we want to amplify it before we will measure. So, what we will do? Let us take an amplifier something with an op-amp that is our favorite.

Let us take a non-inverting one for example. So, we take a non-inverting amplifier my negative feedback plus so, this is the amplifier this is R 2 R 1 grounded output input so, this is the amplifier. And now we have to use a voltmeter at the output. So, let this be a voltmeter so, let us now connect this on.

So, we connect the input to the input of the amplifier then the output of the amplifier goes to the voltmeter and it is done, alright. So, and if this is AC quantity; this is a AC voltage so, the voltage at this point will also be AC definitely. So, this is function of time this

$V_o = V_i(t)\ (1+\frac{R2}{R1})$ now this is a time varying quantity AC. So, therefore, we must use a Ac voltmeter; must use a AC voltmeter in this circuit. And then this will directly give you the input voltage ok, after multiplying with this factor definitely.

Now, let us make, let us take a different example where, suppose we have PMMC voltmeter ok, then how to use it, PMMC voltmeter you know this is a DC meter. So, this can measure only DC, if you apply AC across it; I mean if this was for example, a PMMC meter and if you apply AC across it, it will give you 0 reading or if the frequency is low the pointer will oscillate that we know.

So, we cannot connect a PMMC meter in this circuit this way it will not work. But ok, you may ask, why you do you want to use PMMC meter? One practical reason could be that PMMC meters have several advantages. Number 1 you know, this scale is linear one small advantage. Another advantage is that PMMC meters are generally more sensitive.

We have talked about it particularly at low values of the input current you know; because it has a permanent magnet compared to an electro dynamic instrument where the strength of the magnetic field also decreases when the input current is low. So, their sensitivity is lower compared to PMMC meter. So, PMMC meter is sometimes good, when you are trying to measure a quantity which is of low value.

So, it may have practical situation where we want to use PMMC meter. Suppose we want to use a PMMC based voltmeter what can we do? You know, we can use a rectifier-based circuit diode-based circuit to convert the AC into DC and then measure ok. So, how do we modify this circuit? So, let me just modify the previous circuit, ok. So, here I will just connect see a diode, now this need not be AC need voltmeter anymore. I can use a PMMC meter ok. So, this voltage at this point is AC; this is AC at this point right, but the current that will flow through the voltmeter this current is DC and call this I, ok.

Now, I you know this is DC and what kind of DC? Half wave rectified DC ok. And also now, let us take some bit of numeric example ok. So, question, suppose the volt meter reading in the above circuit is 1 volt a simple number 1 volt, then V i is equal to how much? So, then if this reading is 1 volt then what is the input voltage now this is AC. So, if I just ask you this V i is how much by default it means what is the RMS value of this voltage, ok. Because by default when we are talking about the value of an AC quantities normally the RMS value. But let me specify it also for you that, the RMS value of V i is how much?

And suppose R 1 = R 2 given this is given. So, this is also given in the question, now solution. So, this reading is 1 volt and ok, another small thing let us assume that the voltage drop across this diode is negligible. So, let us assume that the voltage drop across diode is negligible, ok.

I cannot make this assumption often practically. Or if in the question it is said that the voltage drop is 0.7 volt or something in that case I cannot make this assumption, I have to take care of the voltage drop appropriately. But for simplicity now I am assuming that this is negligible 0 for now, ok. If so, then I can say that that this voltage, this is 1 volt; this is given because voltmeter reading is 1 volt.

Now, 1 volt what? 1 volt average; 1 volt average, why average? Because this is a PMMC meter this you have to note because in the circuit it is say that this is a PMMC meter. So, even I do not specify it explicitly it is clear and evident that the voltage which is measured is 1 volt average, ok not peak, not RMS nothing else, it is 1 volt average. And what kind of average half wave rectified voltage and the average of that, ok.

So, the voltage here you call this point as A and B ok so, you we know that V A B how does it look like? It looks like this half wave rectified. In one cycle the voltage in one cycle current goes and in the other cycle current does not go. When current does not go, the voltage here across it should also be 0. If current is not going then definitely I can say the voltage across these two point at that moment is 0.

And in fact, the entire voltage drops across the diode, which is reverse biased at that point. So, this is the pattern of V AB between these two rights, ok. And this voltage this let me call it V peak this is the peak value of this voltage. Now, what can I say about the peak value of this voltage V AB in relation to the input voltage. So, what is the relation between V peak and V i.

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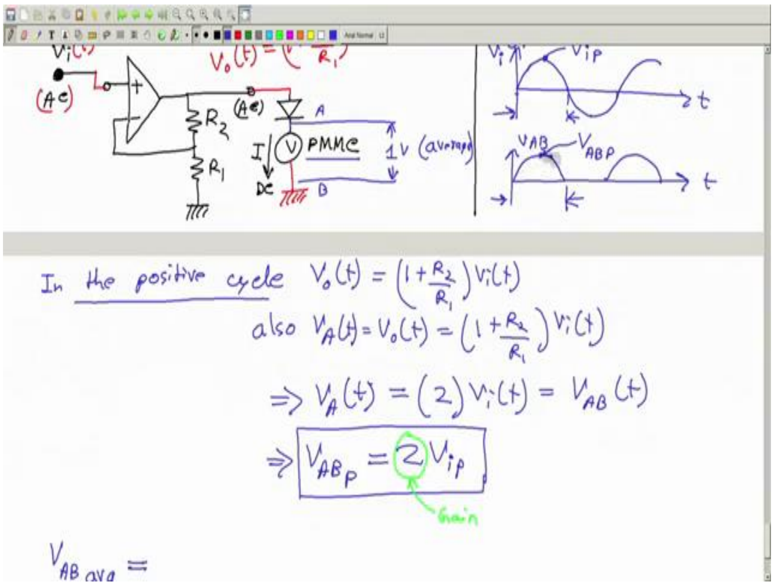

$$Vo(t) = (1+\frac{R2}{R1})\ Vi(t)$$

$$VA(t) = Vo(t) = (1+\frac{R2}{R1})\ Vi\ (t)$$

$$VA(t) = 2\ Vi(t) = VAB(t)$$

So, therefore, I can write that the peak value of this voltage ok, let me just call it V AB P peak value of V A B, I can write V AB P peak is same as 2 times the peak of V i P right. So, this is what I can write, this is one thing. And this 2; number 2 is nothing but the gain which is in this case 2. In general it can be anything else depending on the R 2 and R 1. Now, what can I say about the average value across A and B.

$$VABp = 2Vip$$

$$VABavg = \frac{VABp}{\pi} = \text{voltmeter reading} = 1V$$

$$VABp = \pi\ x\ 1V = 2\ Vip = 2\ (Virms\ x\ \sqrt{2})$$

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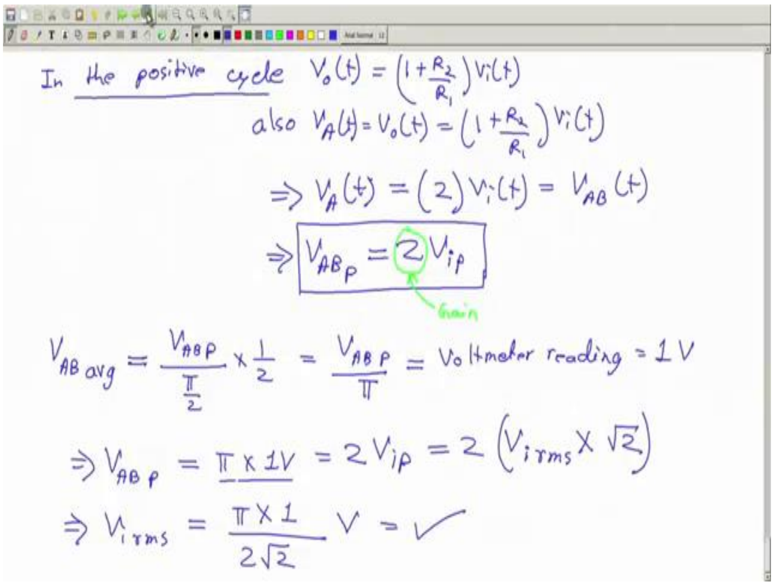

Virms= $\frac{\pi}{2\sqrt{2}}$

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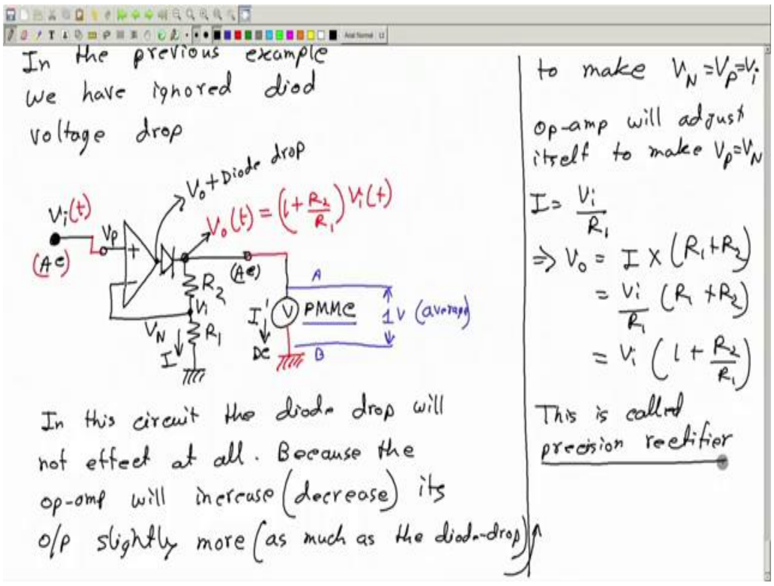

Now, let me just take ok, let me just mention an important observation which is so, in the previous example we have ignored diode voltage drop. So, the previous calculation was not perfect it was somewhat erroneous and we should take care of it. But I am going to give you a trick a small trick a small change in this circuit. So, that the diode voltage drop even if it is not 0 will not create any problem ok.

So, let us start with the circuit, let me modify this circuit such that these diodes drop even if it is not 0, even if it is large and significant it will not come into the calculation at all. What I will do is this, I will remove the diode from here let me connect it and I will put the diode here, ok. And now what will happen is this. Let us first understand how this circuit is physically different from the previous circuit, ok.

So, if you give any voltage here any say some positive voltage at this point at any instant, then this is the positive input therefore, the output of the diode will go up towards the positive value. And the output will increase how long, until and unless, the potential here B which is also here becomes equal to this, right. Because whatever is the potential here a fraction of it comes here this is a potential divider. So, the fraction of the output comes here which goes there and if you give some positive voltage this output will keep increasing. Keep increasing until and unless this value has reached equal to this input, right.

At that point the diode will be happy that is the principle of at sorry, at that point the op amp will be happy, that is the principle of the op-amp, ok. So, in this circuit, the diode drop will not affect at all, because the op-amp will increase or decrease its output slightly more, ok how much I mean as much as the diode drop?

Now I write here to make this voltage call it what can I call, this is V N write; V N, to make V N = V P which is here which is same as V I, ok. So, whatever extra voltage this diode consumes that will be adjusted by the op-amp. What will happen is that, the voltage at this point will definitely be this much. But the voltage at this point will be V o plus diode drop may be 0.7 volt, if this is 0.7 volt, ok. So, this voltage will be slightly more than this voltage, but this voltage will definitely be this multiplied by the gain given by R 2 and R 1. This has to happen because I mean you can do a back calculation.

So, we start from the fact that the diode will adjust sorry, I mean the op-amp will adjust its output to make V P equal to V [noise], ok. Starting from the fact that op-amp will adjust itself to make V P = V N so, starting from this fact let us calculate what will be this voltage. So, we know this voltage which is V N this will be V P because op-amp will make show so; that means, V P is same as V i so I have V i here.

$V_o = I (R1+R2)$

$=\frac{Vi}{R1}$ (R1+R2)

$= Vi\ (1+\frac{R2}{R1})$

So, you do a back calculation starting from the fact that op-amp will anyhow adjust its output so, that V P is equal to V N. And then you see this diode drop does not matter whatever extra voltage this diode consumes op-amp will provide that. So, this does not come into the calculation at all.

So, this is the beauty of this circuit, ok, and this has a name this is called precision rectifier; precision rectifier base circuit because you know the imprecision or in inaccuracy, which we had in this previous circuit is not there at all. So, this is called precision rectifier, ok. We will take a break at this point and we will take more and more interesting examples on this topic in our coming class.

Thank you.