Integrated Circuits and Applications
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Problem Solving
Lecture – 11
Examples on Design of Adder and Subtractor Circuits

Ok. In the last lectures, we have discussed some of the applications of the operational amplifiers. So, in the coming 2-3 lectures, we will discuss some of the numerical examples or practicing problems. So, the first problem is like this. So, design operational amplifier circuit which produce the output v_0 given by. Basically, this operational amplifier can be used to realize the various mathematical equations ok. So, here we have to implement $v_o = -[0.1v_1 + v_2 + 10v_3]$, we have 3 inputs one output v_0. So, basically, this is a inverting amplifier you have to design with a gain of 0.1 for signal v_1, a gain of unity for signal v_2, gain of 10 for signal v_3. So, we know the inverting amplifier, but here we have to take 3 inputs.

The standard inverting amplifier with single input is this positive terminal you have to ground. basically, here, we are going to apply input, and there will be some feedback resistance. This is the standard inverting amplifier with single input. Now, we have to use 3 inputs. So, you can connect 3 inputs here with 3 different input resistances. Let this is v_1, this is v_2, this is v_3, this is let R_F, this is R_1, R_2, R_3.

So, the output voltage due to only v_1 will be what alone. So, you have to set $v_2 = v_3 = 0$. So, that the equivalent circuit will be simply a standard inverting amplifier. In fact, these 2 resistances which are going to be grounded here. So, this 2 will be because v_2 is equal to v_3, is equal to 0 this will be grounded. This is v_1, this is R_1, this is R_F.

Let us call this output as v_{01} due to signal source 1 only. Now, because this is ground this is also a ground potential. So, this is R_2, R_3. So, this is for R_2; both the sides are ground, R_3 also both the sides are ground. So, we can remove this; this circuit will be removed.

This is the equivalent circuit whose standard expression for the output is $-\frac{R_F}{R_1}v_1$. But in the given expression $v_o = -[0.1v_1 + v_2 + 10v_3$. So, comparing this v_1 coefficient should be minus 0.1. So, $-\frac{R_F}{R_1}$ should be 0.1. You have to choose the values of R_F and R_1 such that the ratio is 0.1. This minus minus will get cancelled ok. Implies $R_F = 0.1R_1$; this is one expression. Similarly, if you find out the equivalent circuit due to only v_2 we will get the expression as $v_{02} = -\frac{R_F}{R_2} v_2$. You can do it in a similar manner this is exactly similar to this procedure. Similarly, $v_{03} = -\frac{R_F}{R_3} v_3$. So, what is v_0? $v_o = -\frac{R_F}{R_1} v_1 - \frac{R_F}{R_2} v_2 - \frac{R_F}{R_3} v_3$.

If you compare this and this expression one is this one because this $-\frac{R_F}{R_1} = -1$ from this we are going to derive this. Similarly, if I take the second expression $-\frac{R_F}{R_2} = -1 \Rightarrow R_F = R_2$. This is the second expression, and if we compare this coefficient of R_3 this is $-10 = -\frac{R_F}{R_3} \Rightarrow R_F = 10R_3$. From equation 1, 2 and 3, you have to choose the values of R_1, R_2, R_3 and R_F, which satisfies the expressions 1, 2, 3. So, let $R_F = 10k\Omega$, you have to choose one value, then you can find out that $R_1 = \frac{R_F}{0.1}$ from this one, $R_1 = \frac{R_F}{0.1}$ or 10 times R_F 1 by 0.1 is 10. So, this is equal to $100k\Omega$ and what about R_2? R_2 is simply R_F is equal to R_F $10k\Omega$, and what about R_3? From this $\frac{R_F}{0.1}$, this is equal to $\frac{R_F}{10}$, this is equal to $1k\Omega$.

So, if I set this $R_1 = 100k$, then $R_2 = 10k\Omega$, and this to $1k\Omega$, and this $R_F = 10k\Omega$, you get the output expression v_0 as this expression. This is how you can implement any mathematical expression which consists of the multipliers and additions or subtractions using operational amplifier.

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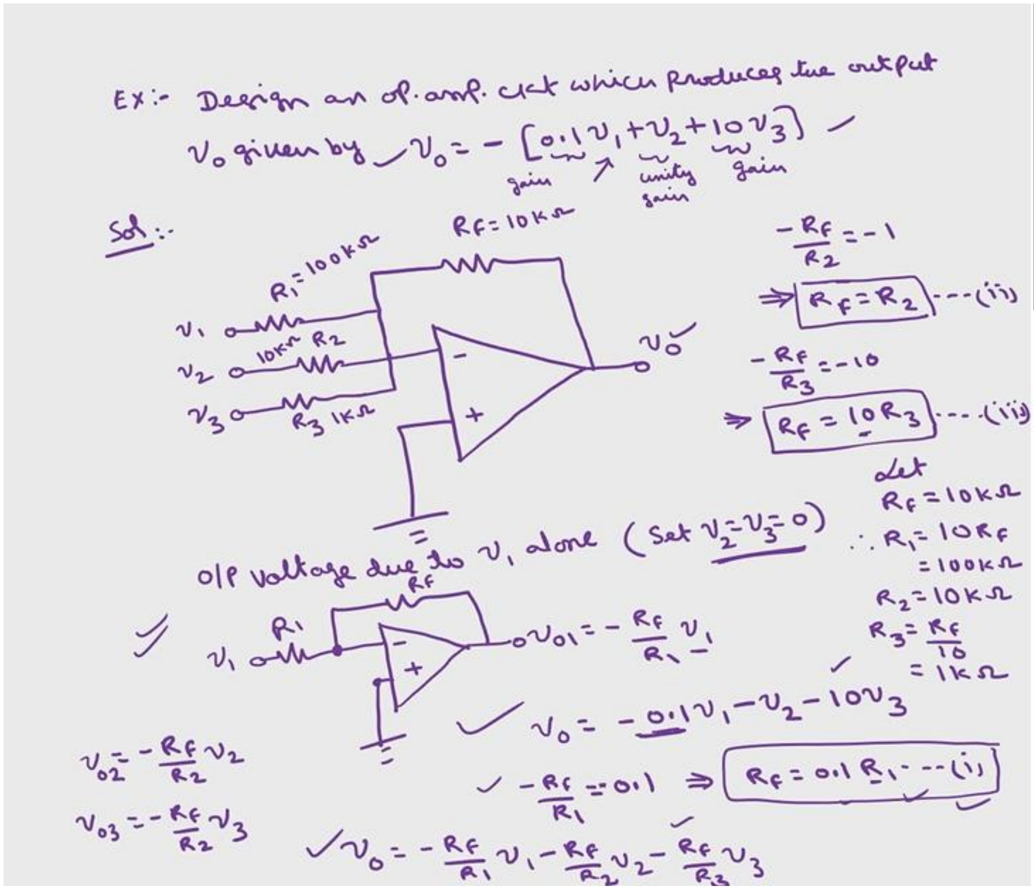

I will take another example. Suppose you will be given an adder subtractor circuit, you have to find out the output voltage. Determine the output voltage of the following circuit. There are 4 inputs, say this is 2V, 3V, 4V, 5V, and they are, say, $10k\Omega$, $20k\Omega$, $30k\Omega$, $40k\Omega$, these are, say, $50k\Omega$ and $50k\Omega$. So, it is the value of the output voltage v_0. There are 2 inputs at the inverting terminal, 2 inputs at non-inverting terminal. The solution is output due to input set non-inverting terminal. If I call this one as v_1, v_2, v_3, v_4 that is output due to only v_3 and v_4.

Then $v_1 = v_2 = 0$. And what will be the equivalent circuit? These 2 will be grounded. This is $10k\Omega$, $20k\Omega$. These 2 will be this is 4V, 5V. Let us call this one as v_o^+ due to plus input set the non-inverting terminal. Sorry, $R_F = 50k\Omega$.

So, these 2 are in parallel. So, what will be parallel combination of 10 into 20, $10k\Omega$ in parallel with $20k\Omega$ is equal to $\frac{10\times20}{10+20} = \frac{20}{3}$. We can replace this with single resistor with resistance of $\frac{20}{3}k\Omega$. Now this is 4V, this is 5V plus v_3, v_4. This is $30k\Omega$, this is $40k\Omega$.

If I call this voltage as say, v_1, what is v_1? If I know v_1, then the remaining circuit is only if I forget about this part, then this is non-inverting amplifier with the gain of 1 plus feedback resistance by input resistance. But what is v_1? v_1 is actually due to 2 voltages, one is due to 4V, another is due to 5V. So, v_1 is given by due to 4V. So, these 5V will be grounded. So, that this 40k and 50k will come in parallel and 30k.

So, if you want to find out output v_1 due to 4V alone. So, what will be equivalent circuit? Only this circuit I am considering, not the entire circuit. So, this is 4V; this is $30k\Omega$. So, this here these two will be in parallel. This is 5V that will be grounded.

So, that resistance is $40k\Omega$, and this is $50k\Omega$, and this is the point where v_1 we are taking, but this v_1 due to 4V, I will call as $v_1{}'$. So, what is $v_1{}'$ in terms of these 4V? So, these two will be in parallel, this is equivalent to 4V, $30k\Omega$ and this is here we are taking $v_1{}'$, this is grounded, this is $50k\Omega$ in parallel with $40k\Omega$ and this is $30k\Omega$, this is 4V. So, 50, 40 parallel combination is $\frac{50\times 40}{50+40} = \frac{2000}{90}$, this is $\frac{2000}{90}k\Omega$, this is $30k\Omega$, this is $\frac{2000}{90}k\Omega$, this is $30k\Omega$, this is 4V. Therefore, what is this $v_1{}'$? $v_1{}'$ is given by v_1, that is 4V, input voltage is 4V, $v_1' = \frac{4\times\frac{200}{9}}{30+\frac{200}{9}} = \frac{800}{470} = \frac{80}{47}V$.

Similarly, if you want to find out the voltage due to only this 5V. So, this equivalent resistance is same, this will be now $40k\Omega$. So, if I call this v_1 double dash, this is due to 5V, this is given by this 5V, only change is here in place of 30, we will get 40 remaining thing is same. This is equal to and this 4 becomes 5, $v_1'' = \frac{5\times\frac{200}{9}}{40+\frac{200}{9}} = \frac{1000}{560} = \frac{100}{56}V$. Therefore, what is v_1? This v_1, $v_1 = v_1' + v_1'' = (\frac{80}{47} + \frac{100}{56})V$.

This is approximately this is 2 times almost this is 2, this is also 2. So, I am not giving the exact value approximately 4V; you can find out the exact value using calculators. So, you see the voltage here. Now, we can forget about this entire thing. This is v_1 now; this is standard non-inverting amplifier, whose gain is $v_o^+ = v_1 \times \frac{R_F}{R_1}$, that is $\frac{50}{20/3} = \frac{150}{20}$, that is $v_o^+ = v_1\left(1 + \frac{150}{20}\right) = 8.5v_1$.

Therefore, $v_o^+ = 8.5v_1$, is approximately, 34V. This is due to this source at v_3 and v_4 and I want to find out the output due to v_1 and v_2. So, $v_3 = v_4 = 0$, then what will be the equivalent circuit? So, these two points will be grounded and this is another $50k\Omega$. So, this the overall, there will be some resistance at the positive terminal, which we do not care normally. We will be using this for offset compensation.

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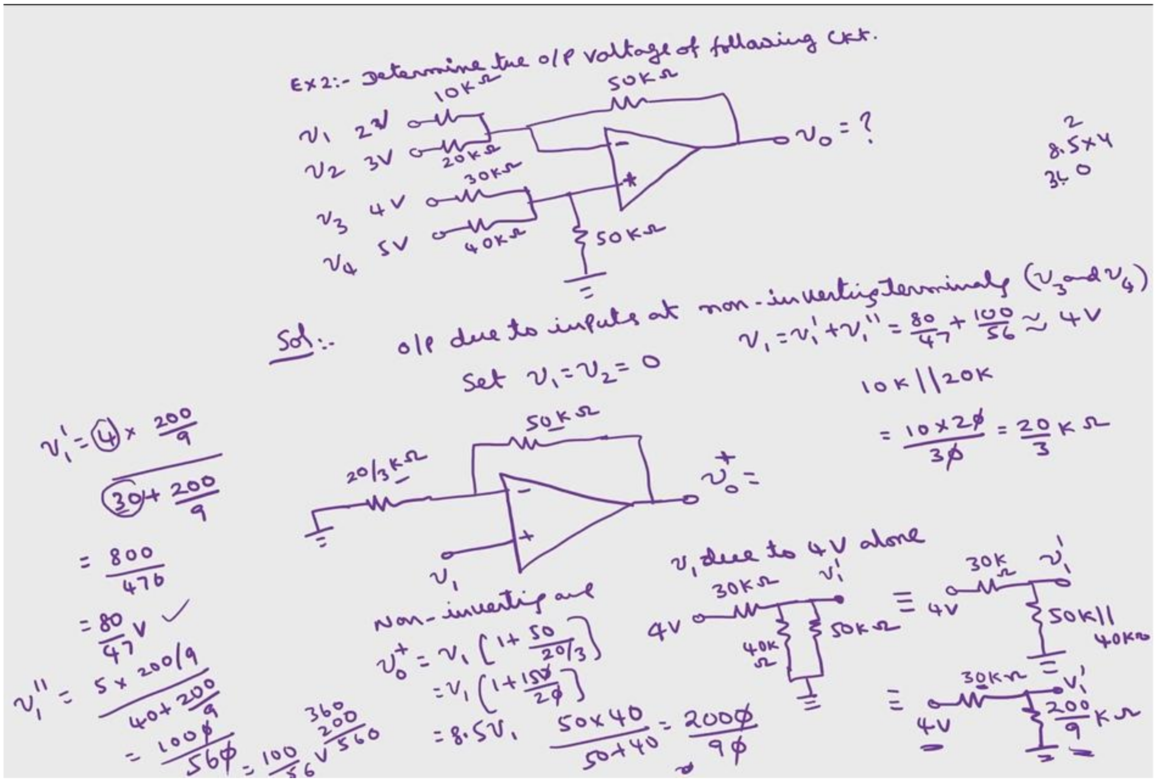

So, this will because there is no current through this one even if you have resistance that is that can be neglected. So, the equivalent circuit will be just this 2, 3V, 10, 20 and 50Ω. Here, there will be some equivalent resistance here, but this will not have any impact the value of this resistance is in fact, this is 30, 40, 50 parallel combination. But normally, this will be used to compensate the offset current and all because here the current is 0, there will be no voltage drop. So, this voltage is 0V, this is also 0V, and the remaining circuitry will be this 10k, 20k and then feedback resistance 50k.

Then this is standard non inverting amplifier. This is 2V, this is 3V. Let us call this output as v_0 due to the input the inverting terminal. So, we found that v_0 places approximately 30V, 34V. So, v_0 is, in fact, v_0 plus plus v_0 minus the output due to non inverting terminal inputs output due to inverting terminal inputs.

So, I have to find out now v_0 minus. So, if I short this 3V, then what will be the equivalent circuit output due to 2V alone? This is 2V; this is 10k. Here we will get this will be 20k will be grounded because this 3V will be 0. This is 20k will be grounded, this is 10k, this is 2V, this is 50 kilo ohms, and it positive terminal this will be a parallel combination of 30k, 40k, 50k. Let us call this one v_1^-. Now, what happens to this 20k? Because this is at 0V, because current is 0V is equal to RI. Even though you have some resistance voltage is equal to 0 this is also at 0V.

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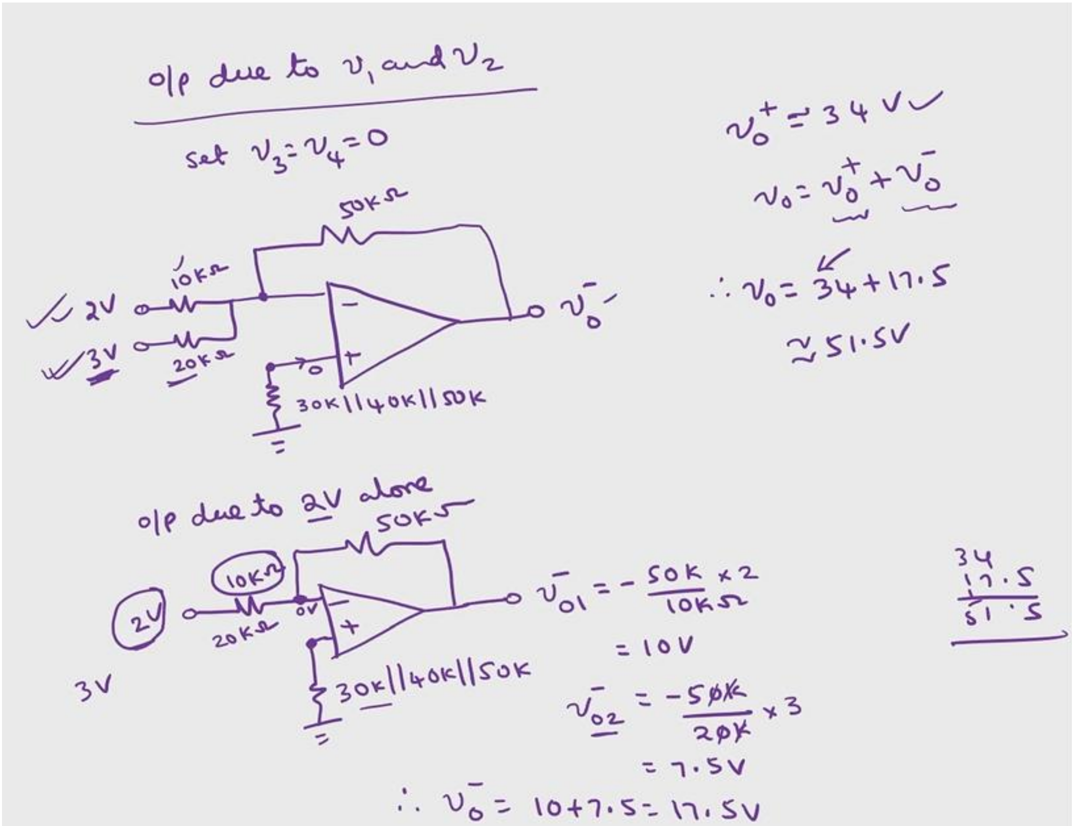

So, this 20k is between the 2 ground. This is also 0Vvirtually, this is also 0V. So, between 2 ground 20k is there that you can remove. So, this is standard inverting amplifier whose gain is equal to $-\frac{R_F}{R_1}$, $-\frac{50k}{10k}2V$. This is equal to $5 \times 2 = 10V$. Similarly, if you want to find out output due to 3V alone, this will be 3V, this will be $20k\Omega$, and the $10k\Omega$ path will be grounded. So, that can be removed because both the terminals of this 10k will be at 0 potential only.

So, as a result of that, what will be v_{02}^- this v_{02}^- is output due to only 3V. So, these 2V you have to ground the only difference is minus 50k divided by the resistance along this 3k is $20k\Omega$ into the input voltage is 3V this is equal to 7.5V, 0k, 0k get cancelled this is $v_{02}^- = \frac{50}{20} \times 3V = 7.5V$. So, the total $v_0^- = 10 + 7.5 = 17.5V$, the output due to the negative terminal inputs and the output due to the positive terminal inputs is 34 volts approximately.

So, total, therefore, $v_o = 34 + 17.5 \approx 51.5V$. This is how we can find out the output value given the resistances and input voltages. Then, the third example. So, I will give the example to find out the current ok.

The load current in the following circuit. This is load this current you call as I_L. This is the output v_0. This is the input v_i. Let us assume that all the resistors are equal R, R, R, R. Let this is v_1 let $R = 10k\Omega$, $v_1 = 1V$, and here we are going to apply v, this is grounded $v_i = 5V$. So, for these values, what is I_L? This is the problem. Similarly, this particular circuit is called as voltage to current converter V-I converter. Because the input is voltage, output is current will be delivered to the load because this is v_1, this is also v_1. So, what is v_0? Simply, you can tell this $v_o = 2v_i$. So, this current, if I call this one as I the same, I will flow through this one also. So, from here to here, I expression is $\frac{0-v_1}{R} = \frac{v_1-v_o}{R} \Rightarrow -v_1 = v_1 - v_o \Rightarrow v_o = 2v_1$, and $v_1 = 1V$ So, $v_o = 2V$. Now coming to this node, we have to find out I_L the load current. So, what is I_1? I_1 and I_2 are entering I_L is leaving. So, what is I_1? $I_1 = \frac{v_i-v_1}{R} = \frac{5-1}{10k\Omega} = 4mA$.

Then $I_2 = \frac{v_o-v_1}{R} = \frac{2-1}{10k\Omega} = 0.1mA$. And if I apply the KCL here, I_L is leaving $I_L = I_1 + I_2 = 4mA + 0.1mA = 4.1mA$.

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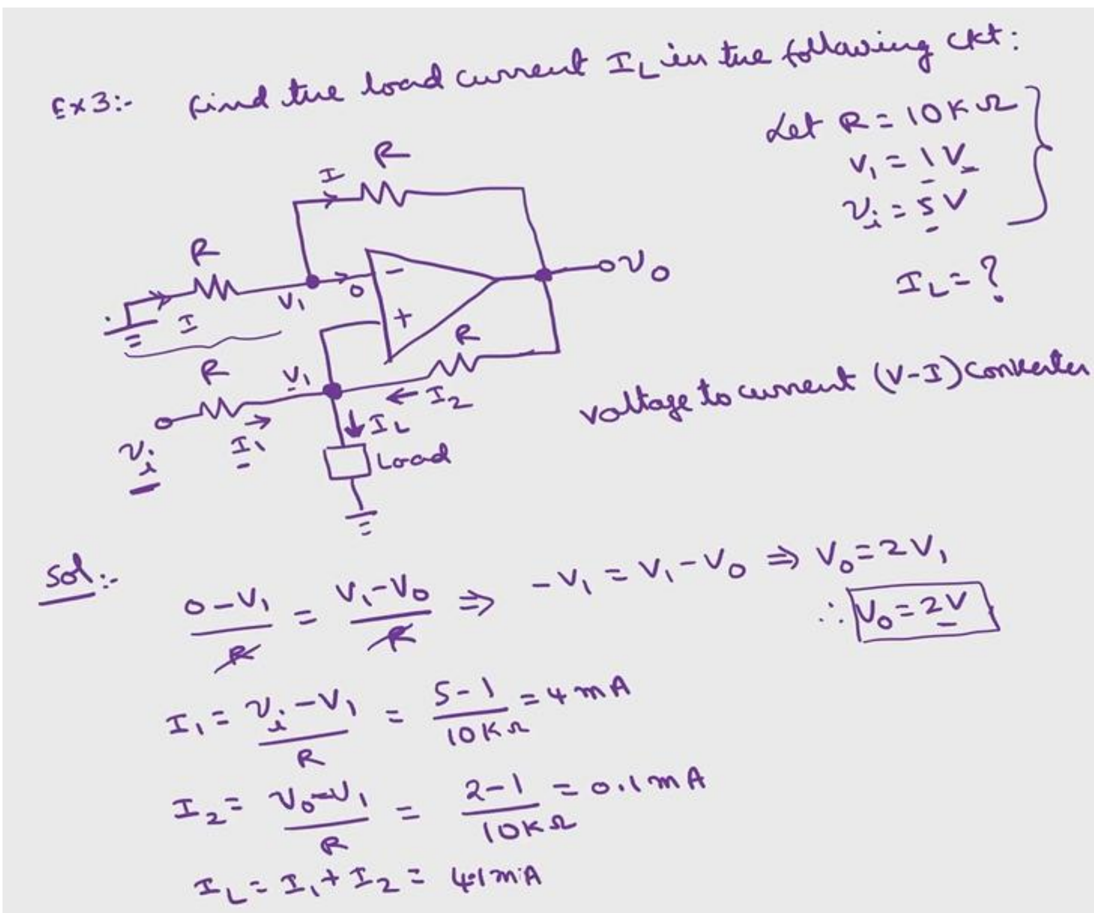

So, here, we can find out the load current. So, this circuit is called as voltage to current converter. So, I will discuss some more examples in the next lecture. Thank you.