Integrated Circuits and Applications
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Voltage Regulators
Lecture – 34
Fixed Voltage Regulator

In the last lectures, we have discussed about the some of the specialized ICs such as 555 timer, 565 and all. Today, we will discuss another special type of IC, which is called as voltage regulator. Voltage regulator, as the name implies, is a electronic circuit which provide the stable DC voltage for powering the electronic appliances. It is an electronic circuit which provides stable DC voltage for powering electronic appliances. So, we know that all the electronic devices require some power supply, and the power supply should be stable.

So, in order to provide this stable power supply to the electronic appliances we will use a voltage regulator. So, basically, there are two types of the voltage regulators. One is called the series voltage regulator, another is called switching mode voltage regulator. The series regulator also can be called as a linear regulator because here, we are going to use a power transistor which operates in the linear region.

Whereas, in a switching mode, we are going to use a power transistor, which will acts as the on off switch. So, this will acts as non-linear voltage regulator. In series again, we have two more types, which is called fixed voltage regulator variable output voltage. Whether the regulator provide the fixed voltage or the stable voltage can be varied over a range depends upon that we have two types of the series regulators. One is fixed voltage, another is variable voltage.

And again, this fixed, we can have two sub types of fixed voltage regulators. One is whether the fixed voltage is positive or negative. Similarly, the variable voltage is positive or negative. So, these are the different types of the voltage regulators. Now, if I consider the conventional voltage regulator using operational amplifier, also is called as regulator power supply RPS.

And basically, we will take a regulator power supply which is v in which will acts as unregulated power supply. This is the output resistance of this power supply. Now, this will be applied to a transistor, which will be derived by operational amplifier. And this is the output load. This is the basic circuit diagram of a regulated power supply using

operational   amplifier   and   discrete   components.

Here, v in is unregulated voltage, and v_0 is regulated voltage. If, due to changes in the load current, if v_0 fluctuates, then the difference between this v in and v_0 will be observed by this power transistor Q_1. Power transistor Q_1 absorbs the difference between if v_0 varies due to load current variations. This is the one use of this power transistor Q_1. So, whenever v_0 changes, then the difference between this v_0 and v in will be observed by this Q_1.

In addition to that, Q_1 also will acts as a emitter follower, Q_1 also acts as an emitter follower, whether it will supply the sufficient current to the load. So, coming for the operation of this regulated power supply, a part of the output will be sampled here beta into v_0 where beta is given by using the voltage divider expression $\frac{R_2}{R_1+R_2}$. This is v_0; the voltage across this will be $v_0 \frac{R_2}{R_1+R_2}$. So, βv_0, β will be $\frac{R_2}{R_1+R_2}$. Now, this will be fed back to the positive terminal of operational amplifier; this will acts as a error amplifier.

This is the output of this one is v_0', and the second input of this operational amplifier will be connected to the v_0 diode, which supplies a reference voltage. Now, error amplifier will amplify the difference between the βv_0 and v_{ref}. So, this βv_0 will be supplied to the negative terminal, whereas the positive terminal will be supplied with a v_{ref} voltage which will be supplied by the v_0 diode. Now, the error amplifier will amplify the difference between the v_{ref} and βv_0. v_{ref} minus beta v_0 will be amplified by error amplifier.

Let us consider that if v_0 increases due to fluctuations in the load. So, this v_0 has been increased. How to nullify this increase in the v_0 using this regulated power supply? So, we can see that as v_0 increases, βv_0 also will increase. Then what happens to $v_{ref} - \beta v_0$? Because this is a minus sign, if this value is large, then the overall value will be less this will decrease. Then v_0' is the output of the error amplifier whose input is $v_{ref} - \beta v_0$.

So, v_0' also decreases because this is the input to the error amplifier. This is the output of the error amplifier. If input decreases, output also decreases. So, this v_0' will drive this emitter follower. So, as a result of that because this Q_1 will acts as emitter follower. So, v_0 also   decreases   nearby,   nullifies   the v_0 variation.

Similarly, if v_0 decreases also. So, this βv_0 decreases whereas $v_{ref} - \beta v_0$ will increase. So, that will nullify the decrease in the v_0. So, you see, the basic operation of a regulated power supply, regardless of the variations in the load or temperature effects. v_0 remains constant or stable because of this power transistor Q_1. Now, because of the advancements in   the   microelectronics.

So, this entire circuitry can be fabricated on a monolithic silicon IC. So, what are the advantages of this IC based voltage regulators when compared with the discrete voltage regulators? The main advantage is low cost and the second advantage is it occupies the less area. So, third one is it will give better performance when compared with the discrete type voltage regulator, and fourth advantage is more reliable. Because of these four advantages, the IC voltage regulators are very commonly used in many of the applications. As I have told, the voltage regulators are two types; basically, one is a series type, another is a switched-mode power supply.
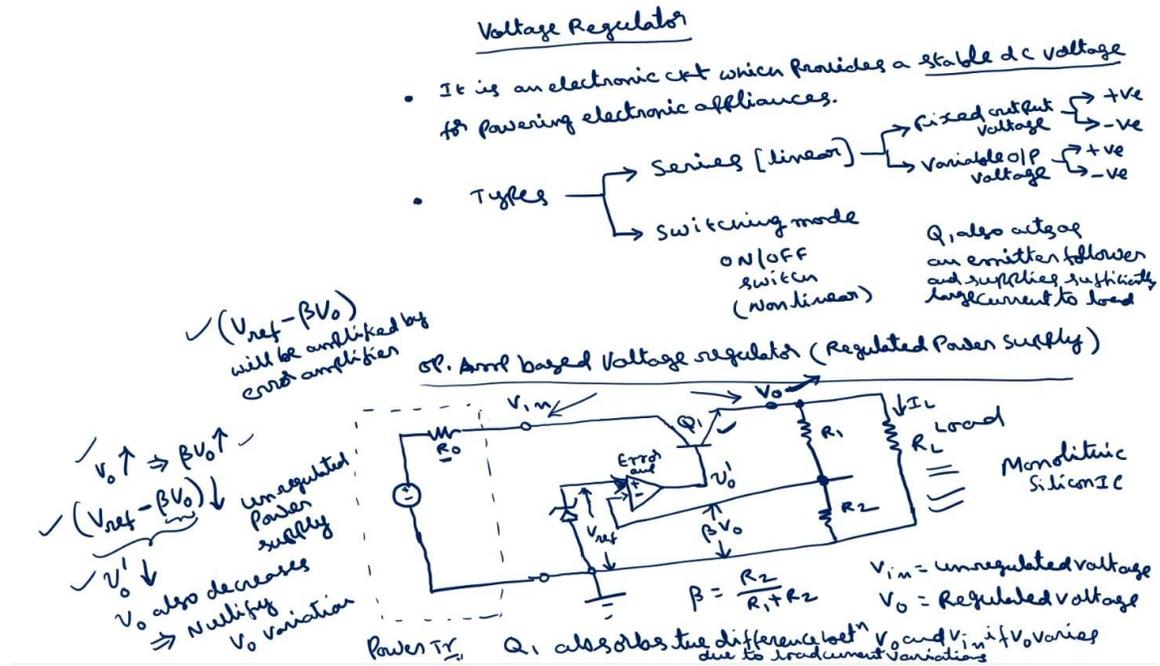
First, I will discuss about the fixed voltage regulators monolithic. So, this fixed voltage regulators are available in 78XX series 79XX series. So, here, this 78XX series are the positive voltage regulators, whereas 79 are negative voltage regulators, and the last two digits XX represent the output voltage. For example, if I give 7805 that means, so, this 7805 will give the output stable voltage of $+5V$. If I give 7905, this will give output stable voltage of $-5V$, and this 78 series can have 7 different output voltages.

Advantages of IC voltage regulators

(i) Low cost
(ii) occupies less area
(iii) Better performance
(iv) More reliable

Fixed Voltage regulator (Monolithic)

✓ 78 XX   Series ⟹ +ve ; XX can be 5V, 6V, 8V, 12V,
  79 XX   "   ⟹ -ve ⟹ 15V, 18V and 24V
                              -2V

XX represents output voltage

7805 ⟹ output stable voltage of +5V
7905 ⟹   "   "   "   -5V

XX can be $5V$, $6V$, $8V$, $12V$, 15 1 $18V$ and $24V$. This is capable of supplying 7 different output voltages. Accordingly, the IC number will vary from $5V$, $6V$, $8V$, $12V$, 15, 18 and 24. This, 79 series also will give all these 7 ranges. In addition to this, it can provide two more extra voltages. One is $-2V$, another is $-5.2V$. So, if I take this general diagram of this fixed voltage regulator, this is a 3-terminal device; we have an input terminal, we have an output terminal, and we have one ground, which is pin number 1, pin number 2, pin number 3.

So, normally, at the input terminal, we will connect a capacitance of the order of $0.33\mu F$, and between this output terminal and ground, we will connect an output capacitance of $1\mu F$. So, the use of this input capacitor is to cancel inductive effects due to long distribution leads. So, if I take the equivalent circuit of any wire, it will have some inductance, some capacitance, lumped parameters, distributed parameters that you might have studied in your circuit theory.

So, to cancel this inductive effects, which are caused by the long distribution leads, we will use a input capacitance of the order of $0.33\mu F$. Similarly, the output capacitance C_0 is used to improve the transient response. So, we will be having two responses: like

transient response and a steady state response. So, this C_0 will be used to improve the transient response.

3- terminal fixed voltage regulator

C_i = To cancel Inductive effects due to long distribution leads

C_0 : Used to improve the transient response
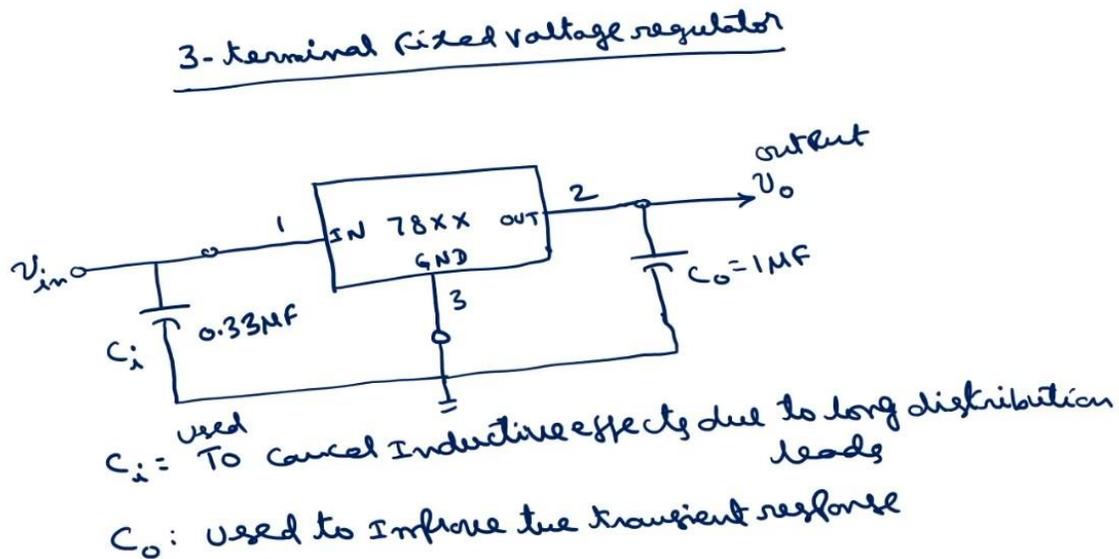
(Refer   to   the   slide   at   20:25)

Now, we have some applications of this fixed voltage regulators. So, fixed voltage regulators can be used as a constant current source. In addition to providing the stable output voltage, this can also be used as a constant current source. So, if you want to use this fixed voltage regulator as a constant current source, what are the external components required? So, I will take the example of 7805, which gives the output voltage of $5V$, and 78 series means positive voltage 7805. So, there are three terminals IN, OUT and GROUND. This is terminal 1, terminal 2, terminal 3. This is the standard voltage regulator. Now, in order to add this as a constant current source you have to connect at the output two resistors. So, let us call this one as R_1, this is V_{R_1}, this has R_L, this is V_L.

So, this current is I_Q; this current is I_L, this current is I_0. So, our intention is you have to make this as a constant current source. Let us assume that I have this 10Ω resistor here; it should draw $10W$ of power, and it has to operate with 1-ampere constant current. So, in order to do this, the KCL at this node will be I_Q is entering, I_0 is entering, I_L is leaving,

$I_L = I_Q + I_0$.   And   what   is I_0?   This $\frac{V_{R_1}}{R_1} + I_Q$.

So, normally, this I_Q is very, very small for 7805; $I_Q \approx 4.2mA$, which is much, much less than I_0. So, we can neglect this. So, this is approximately equal to $\frac{V_{R_1}}{R_1}$. To supply a

constant current of $1A$, so for I_L to be $1A$ what is the value of the resistance R_1 is required? What is the value of resistance R_1 required? Which will provide constant current of $1A$ to the load.

So, from here this is equal to $1A = \frac{V_{R_1}}{R_1} = \frac{5V}{R_1}$. But what is V R_1? This is equal to $5V$ because this is 7805. So, v_0 is $5V$. So, this is equal to $\frac{5V}{R_1} \Rightarrow R_1 = 5\Omega$. If I choose this R_1 value 5Ω, then this will supply a constant current of $1A$ to the load.

fixed voltage regulator as constant current source
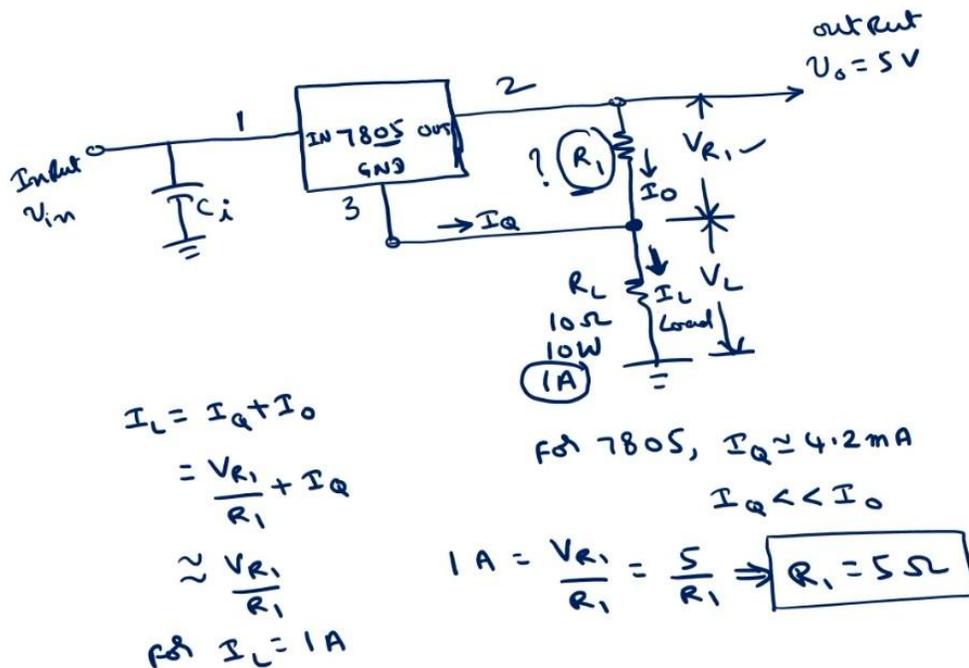
This is how we can use this fixed voltage regulator as a constant current source. This is one of the application. Second application is you can use this fixed voltage regulator to boost the load current. Fixed voltage regulator as current booster. So, basically, here I am going to take a fixed voltage regulator.

Again I will consider the same 7805. This output is connected to the load resistor R_L. So, this output will be because this is 05, this will give $+5V$. This is terminal 3, which is ground, this is out, this is in, and the in, we are going to connect through the resistor.

This is V_{BE} transistor Q_1, this is I_C collector current, this is emitter, this is a R_1. Here we are going to apply the input voltage v_{in}.
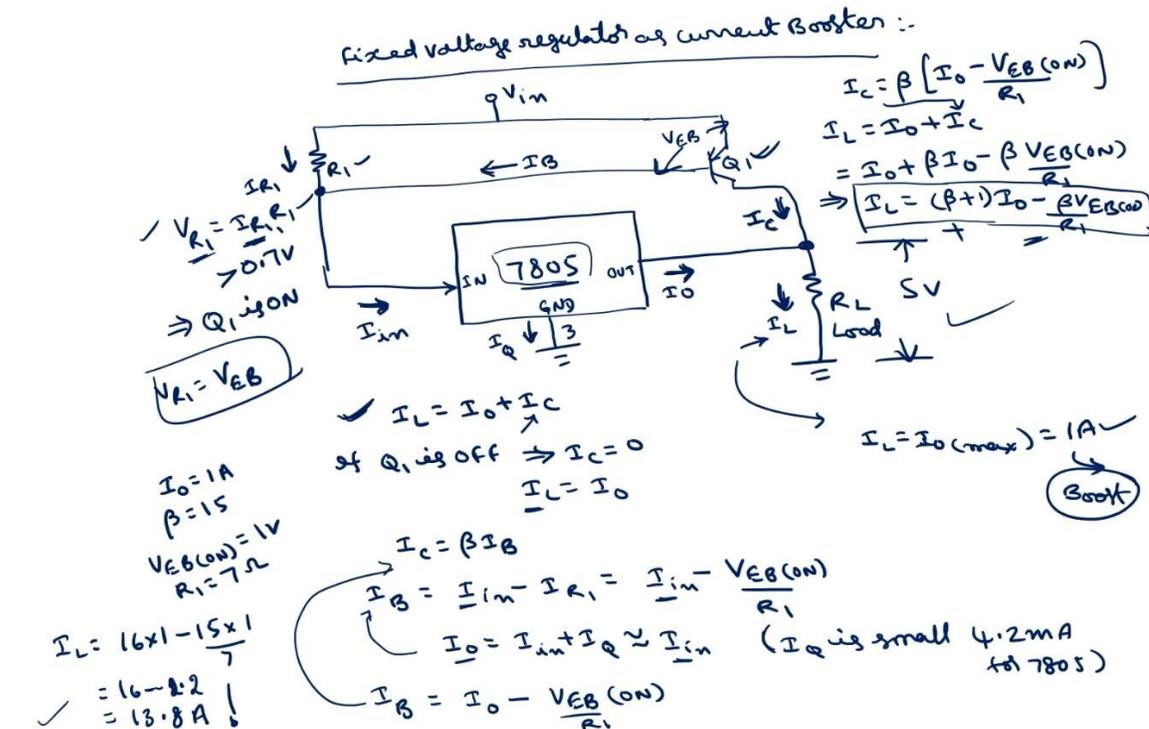
So, this current you call as I_{R_1}, this will be I_{in}, this is I_Q, this is I_0, this is I_L. Our intention is to boost this current. If I take 7805 IC, the maximum current that can be supplied by in 7805 I_L or $I_{O\ (max)} = 1A$ only. If I want to boost this, I have to connect this circuitry. It is clear that this $I_L = I_0 + I_C$.

So, this current I_0 is entering, I_C is also entering, I_L is leaving. So, at this point if you apply the KCL, $I_L = I_0 + I_C$. Assume that if this Q_1 is off, implies $I_C = 0$, simply I_L and I_0 will be same. You see without current boosting. So, in order to boost this current, we have to make this I_C non-zero ok.

Means we have to operate the transistor Q_1, we have to ON this transistor Q_1. So, for that, we are going to choose this R_1 such that the voltage across this one is $V_{R_1\ max} = I_{R_1}R_1$, this slightly greater than $0.7V$. Then transistor Q_1 is on. You have to choose the value of the R_1 such that if the V_{R_1}, which itself is $V_{EB} > 0.7V$, then Q_1 will be ON, thereby it supply some I_C. So, the total current through this load will be $I_0 + I_C$. So, current will be increases or boosted by some amount, ok. So, how much current will be boosted? For that we will do some simple mathematical analysis. So, this is expression for I_L, but what is $I_C = \beta I_B$.

This is I_B, but what is I_B? At this node I_B is entering, I_{R_1} is entering, I_{in} is leaving. So, this is equal to $I_{in} - I_{R_1}$. This is equal to $I_{in} - I_{R_1}$ is nothing, but V_{EB} divided by V_{EB}, which is on divided by R_1. From this $V_{R_1} = V_{EB}$.

So, this $I_R = \frac{V_{EB}}{R_1}$. This is one expression, and if I consider this, I_0, I_Q, and I_{in}. So, this I_{in} is entering into this regulator, I_Q is outputted, I_0 is outputted. $I_0 = I_{in} + I_Q$, but this is approximately equal to I in itself because I_Q is very very small, only order of $5.2mA$ for 7805. If I substitute this here, I_B will be I_0 because this I in is equal to approximately equal to $I_0 - \frac{V_{EB}}{R_1}$. And if I substitute this I_B here, then what is I_C? Right here, $I_C = \beta I_0 - \frac{V_{EB}}{R_1}$. But we are interested in I_L from this $I_L = I_0 + I_C$. If I substitute this I_C here, this is equal to $I_0 + \beta I_0 - \beta \frac{V_{EB}}{R_1} \Rightarrow I_L = (\beta + 1)I_0 - \beta \frac{V_{EB}}{R_1}$. If I choose say I_0 of $1A$ and β is say 15, V_{EB} on is say $1V$, R_1 is say 7Ω, then what will be I_L from this? $I_L = 16 \times 1 - \frac{15 \times 1}{7} = 16 - 2.2 = 13.8mA$, you see this how large value is this, ok.

Fixed voltage regulator as current Booster :-

$$I_c = \beta \left[I_0 - \frac{V_{EB}(ON)}{R_1} \right]$$

$$I_L = I_0 + I_c$$

$$= I_0 + \beta I_0 - \frac{\beta V_{EB}(ON)}{R_1}$$

$$\Rightarrow \boxed{I_L = (\beta+1) I_0 - \frac{\beta V_{EB}(ON)}{R_1}}$$

V_{in}

$I_{R_1} \downarrow \quad R_1$

$\leftarrow I_B$

$V_{EB} \quad Q_1$

$I_{R_1} = I_{R_1} R_1$

$V_{R_1} = I_{R_1} R_1$

$> 0.7V$

$\Rightarrow Q_1$ is ON

$V_{R_1} = V_{EB}$

IN $\boxed{7805}$ OUT

GND

I_{in}

$I_Q \downarrow \boxed{3}$

$I_c \downarrow$

$I_O \rightarrow$

$I_L \downarrow \quad R_L$ Load $\quad 5V$

$I_L = I_{0(max)} = 1A$

$I_0 = 1A$

$\beta = 15$

$V_{EB}(ON) = 1V$

$R_1 = 7\Omega$

$I_L = I_0 + I_c$

if Q_1 is OFF $\Rightarrow I_c = 0$

$I_L = I_0$

Boost

$I_c = \beta I_B$

$I_B = I_{in} - I_{R_1} = I_{in} - \frac{V_{EB}(ON)}{R_1}$

$I_0 = I_{in} + I_Q \approx I_{in} \quad (I_Q$ is small $4.2mA$ for $7805)$

$I_B = I_0 - \frac{V_{EB}(ON)}{R_1}$

$I_L = \frac{16 \times 1 - 15 \times 1}{7}$

$= 16 - 2.2$

$= 13.8 A$!

(Refer to the slide at 34:36)

So, the maximum of 1 amp that will be provided by this 7805. If I use this external circuitry, I can increase this current to a value of 13.8 amperes. This is called the current boosting ok. So, we can use this fixed voltage regulator as a current booster, ok. So, next we will discuss about the other types of the voltage regulators in the next lecture. Thank you.