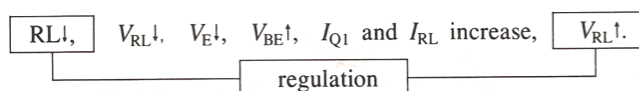
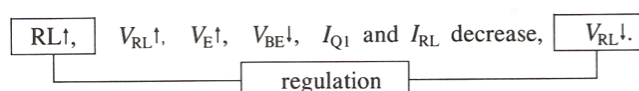


This is a screen shot of the circuit made with iCircuit, running on my Mac. You can think about purchasing this for iPad, or Windows systems too. About \$15 to purchase a licence online. But the oscilloscope trace numbers will be restricted



As V_{RL} tries to drop, it is held at its original value by an increase in current through it. If RL increased in value, the opposite would occur.

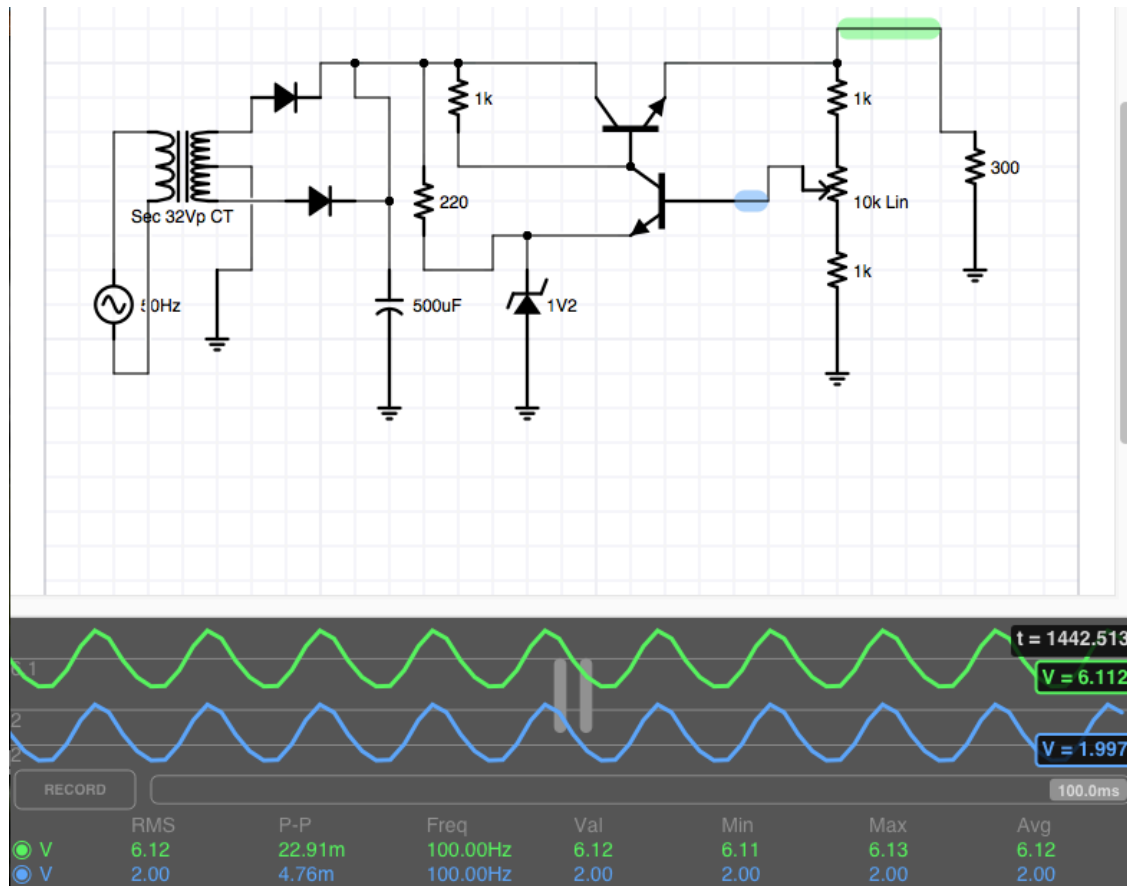


in the iPad version. For learning and for quick 'what if' ideas, an application like this is great.

Here is the mechanics behind why the regulation works. Just think about V_{be} increasing or decreasing and how that will cause more or less I_c which in turn shifts the value of V_e and of course V_{rl} .

The Edwards and Meyer notes which I handed out have many examples and notes about how this regulator works.

A simple regulator like this is very common in many products where a fixed voltage is required. However, if a variable output voltage is required, then some error feedback can be added to a series pass regulator and shunt some current away from the base of the main pass transistor to turn it off and allow a lower output voltage at it's collector.



The voltage divider set up with 1k and 10k variable resistor alters the current into the base of the error amplifier transistor and causes it to conduct harder or to be in cut off.

When the error amplifier transistor is cut-off, the main series pass transistor is biased on hard by the 1k resistor wired directly to it's base. Series pass transistor on hard is providing the maximum voltage at the load.

When the error amplifier transistor is on hard, his collector voltage falls and pulls down the base voltage of the series pass transistor, turning it more off, consequently, the output voltage across the load resistor will be lower.

So the trick to remember is... the 10k variable resistor wiper UP = lower output voltage. The 10k variable resistor wiper DOWN = higher output voltage. Got it?

The use of a low voltage reference diode on the emitter of the error amplifier means we can have quite a low output voltage from the supply. The voltage divider across the output will need to be adjusted in resistance to ensure correct biasing of the error amplifier transistor.

Not only have we made a variable voltage power supply, but importantly, we have better voltage REGULATION also. We are now AMPLIFYING any changes to the output voltage so the V_{be} of the series pass transistor will have better control than it did in our simple single transistor circuit.

The reference circuit from our textbook.

We will practice building this circuit in Circuit Maker 2000 on the Windows computers.

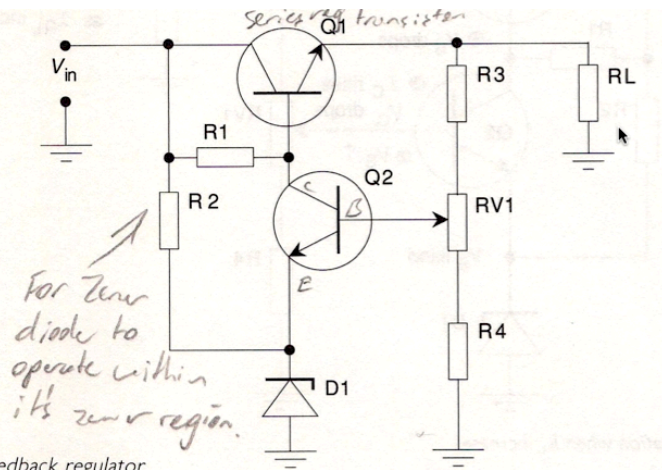


Fig. 18.28 Feedback regulator

- R1** is the base bias resistor for Q1. With Q2 and D1, R1 forms a voltage-divider bias network for Q1.
- R2** is the series resistor for the Zener diode D1. Its value is selected to ensure that D1 operates in the Zener region.
- D1** keeps the emitter of Q2 at a constant voltage level as long as D1 operates in the Zener region.
- Q1** is the series regulating transistor.
- Q2** is the feedback amplifier. Q2 amplifies any change in the output voltage and varies the bias on Q1 accordingly.
- R3, RV1 and R4** form a voltage-divider network across the output. The voltage at the wiper arm of RV1 will be directly proportional to V_{out} .
- RV1** may be varied in value to change the set level of V_{out} .

Refer to the Edwards and Meyer notes.

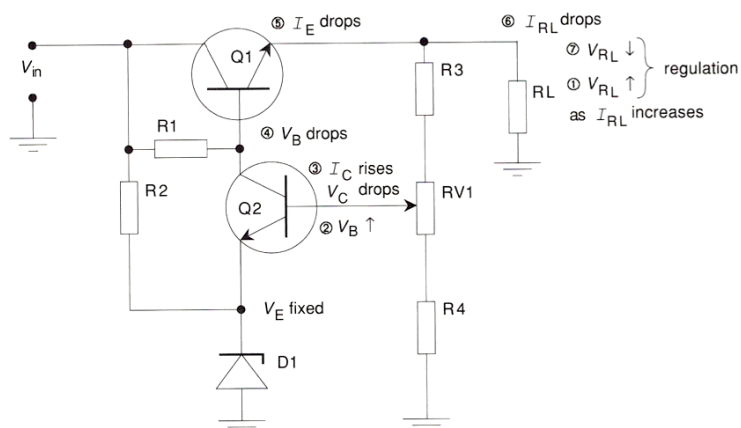


Fig. 18.29 Regulation when I_{RL} increases

****Don't forget, as I wrote, as RV1 wiper goes UP, $V_B(I_B)$ increases and Q2 progressively turns off Q1. Therefore the V_{RL} falls.**

If the wiper on RV1 goes down, the output voltage across RL will be greater!

But we need to take care that the wiper voltage does not allow Q2 to drop in cut-off. My circuit has a wiper voltage range of 1.11 to 2.01 volts.

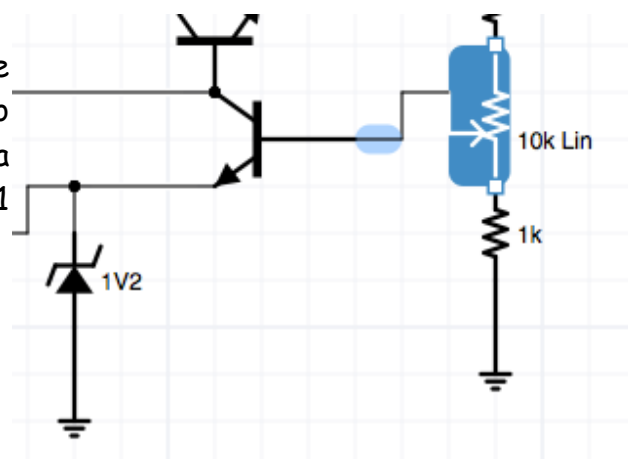
0% of travel = 1.11V

5% of travel = 1.66V

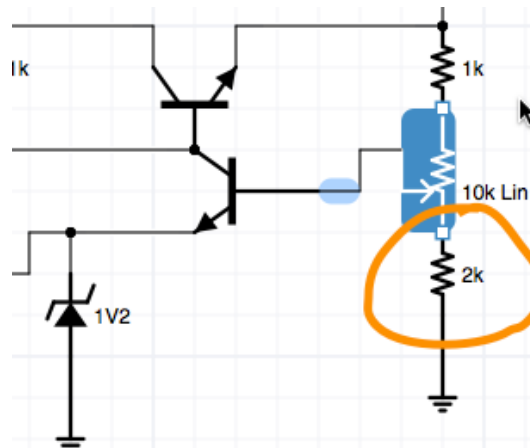
10% of travel = 1.95V

20% = 1.99V

40% = 2.0V



You see.... the zener... is clamping the emitter of Q2 at 1.2Volts in my circuit. That means that about 1.8V needs to be at the base of Q2 to cause it to be in the active region of operation.



So how to fix this problem? A more focussed attention to the choice of resistors in the error sampling resistor network.

With 2kohms in the bottom of the voltage divider network...

0% of travel = 1.93V

100% of travel = 2.01V

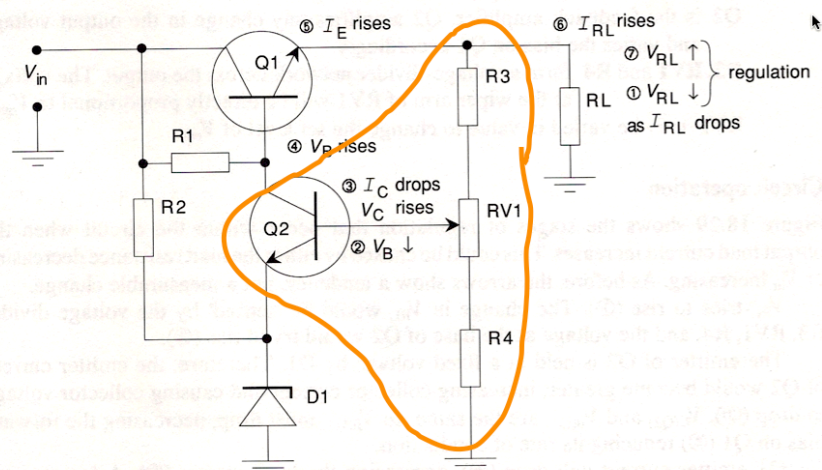
So now the circuit is properly balanced. Q2 goes from on, to hard on. The value of I_b goes from 1uA to about 24uA

BJT Transistor (NPN)	
fwd active	500.000
beta	903.108
I_c	1.806 μA
I_b	573.148 mV
V_{be}	-11.346 V
V_{bc}	11.919 V
V_{ce}	

BJT Transistor (NPN)	
fwd active	500.000
beta	11.264
I_c	22.529 μA
I_b	636.238 mV
V_{be}	-816.318 mV
V_{bc}	1.453 V
V_{ce}	

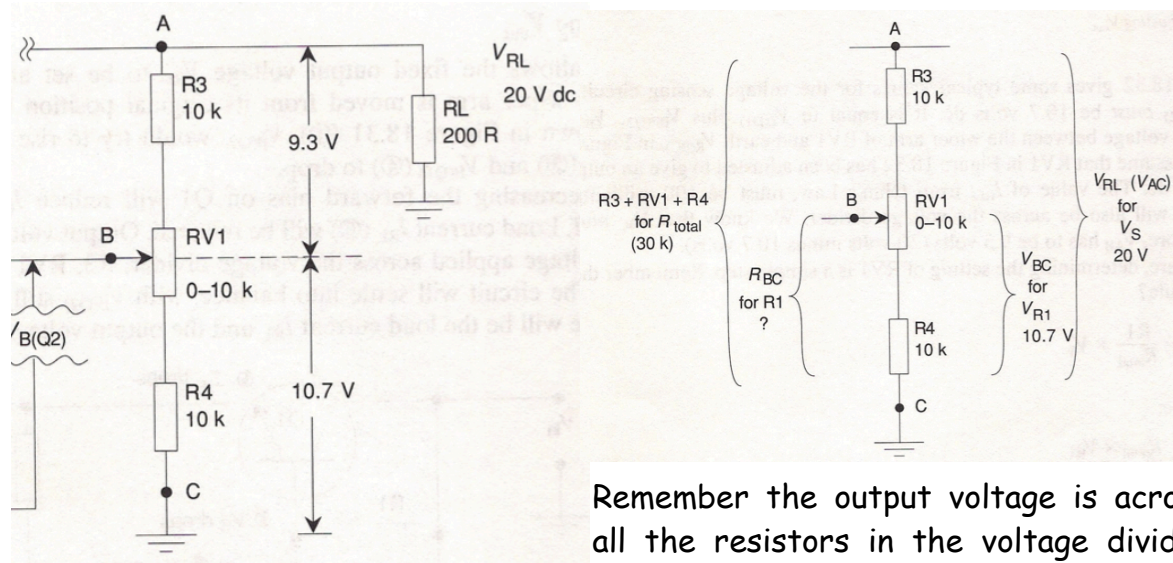
And as I wrote, the key advantage in a regulator circuit like this is that the output **VOLTAGE REGULATION IS SUPERIOR** to the simple regulator we first viewed.

Any changes in the load will affect the voltage on the base of Q2 and cause a very fast correction to maintain the voltage at the set point of the voltage divider.



The range of output voltages from a supply as this is also controlled by the correct selection of voltage divider components.

Sometimes we want a supply which is adjustable from 10 to 12 Volts only, quite precision adjustment indeed. At other times, we want a much wider range of voltages, and that is what I designed my network to give. (2.7 to 12 Volts)



Remember the output voltage is across all the resistors in the voltage divider network.

So, we can determine a current at any particular output voltage. In Edwards book, he shows 20V across the load R. So by using just ratios we can get the value of the resistance needed at the base to give us 20 Volts of output. (instead of R3,RV1,R4, I simply used two resistors to simplify the maths)

$$20V \times \frac{R_2}{R_1 + R_2} = 10.7$$

$$20V \times \frac{R_2}{30K} = 10.7$$

$$\frac{R_2}{30K} = \frac{10.7}{20}$$

$$R_2 = \frac{10.7}{20} \times 30 = 16050\Omega$$

Solution 18.22

(a) $V_{out} = 16.05 \text{ V dc}$

$$V_{B(Q2)} = V_{Z(D1)} + V_{BE(Q2)}$$

$$= 10 \text{ V} + 0.7 \text{ V}$$

$$= 10.7 \text{ V}$$

$$V_{out} = V_B \times \frac{(R3 + RV1 + R4)}{RV1 + R4}$$

$$= 10.7 \text{ V} \times \frac{30 \text{ k}}{20 \text{ k}}$$

$$= 16.05 \text{ V}$$

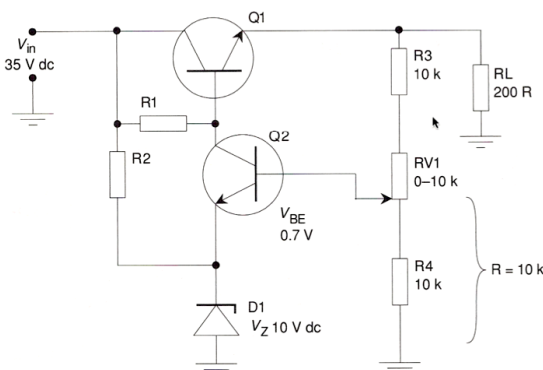
(b) $I_{RL} = 80.25 \text{ mA}$

$$I_{RL} = \frac{V_{out}}{R_L}$$

$$= \frac{16.05 \text{ V}}{200 \text{ R}}$$

$$= 80.25 \text{ mA}$$

just R1, R2 as I did and then go to your box of available components and choose the appropriate parts to build a circuit. And here below... based on the wiper at the lowest extremity.



Solution 18.23

(a) $V_{out} = 32.1 \text{ V dc}$

$$V_{B(Q2)} = 10.7 \text{ V (as before)}$$

$$V_{out} = V_B \times \frac{(R3 + RV1 + R4)}{R4}$$

$$= 10.7 \text{ V} \times \frac{30 \text{ k}}{10 \text{ k}}$$

$$= 32.1 \text{ V}$$

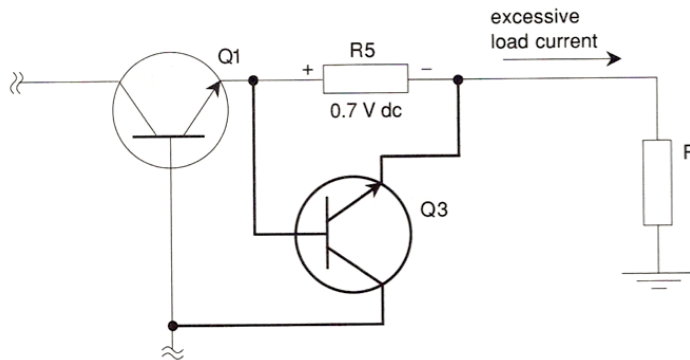
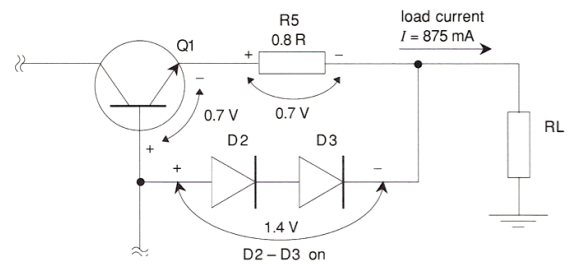
(b) $I_{RL} = 160.5 \text{ mA}$

$$I_{RL} = \frac{V_{out}}{R_L}$$

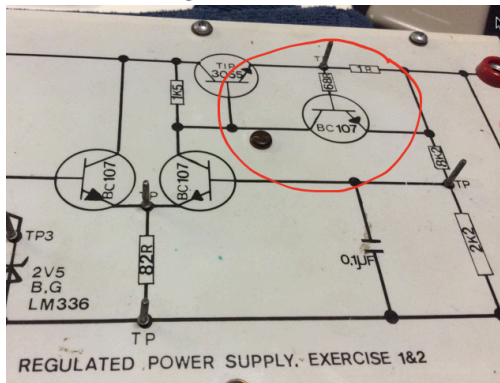
$$= \frac{32.1 \text{ V}}{200 \text{ R}}$$

$$= 160.5 \text{ mA}$$

Over current protection in regulated power supplies can be provided by various means. In this circuit, the 0.8ohm resistor will drop 700mV when 875mA flows through it. That would bias on D2 and D3. In turn, they will now cause the base voltage to be lower and prevent further

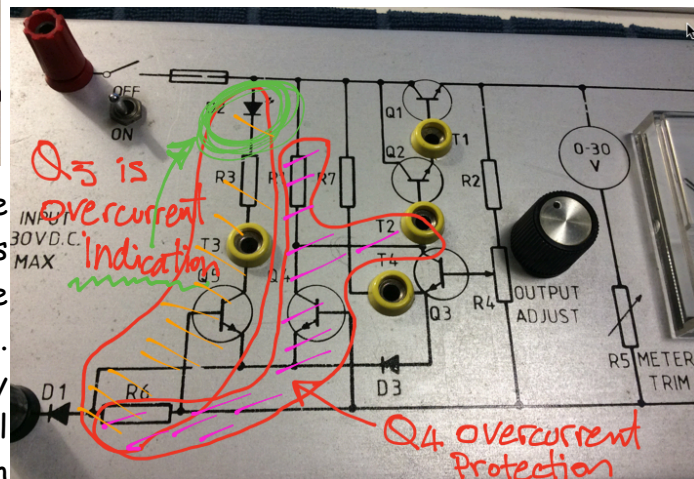


increases in output voltage. The more common and frequently seen method is shown here. The use of a BJT, which will turn on, V_{ce} becomes very low resistance and the base on Q1 voltage is then prevented from rising higher.



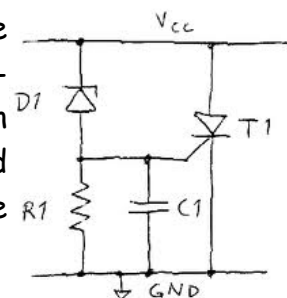
We saw this power supply board in last weeks class. The little BC107 is providing overcurrent protection.

This power supply board to the right is a curiosity in as much as it uses the sense resistor in the negative side of the supply. (which means you cannot safely connect the -ve output terminal to other grounded and common connections!) The Q5 is providing a switching to the LED to let the user know it's in overload. Q4 is using the same R6 to get the voltage drop in higher current conditions and then pull down the voltage on Q3 collector- therefore lowering the output voltage to a level just below the threshold of the point of overcurrent.



Over Voltage protection - Crowbar circuits.

By incorporating a silicon controlled rectifier...SCR in the little circuit I have drawn, once the voltage of V_{cc} is sufficient to turn on Zener D1, current flows in R1 and when enough flows to 'trigger' the SCR gate, the Anode and Cathode will lock into the 'on' state and short circuit the



output of our supply. WHY? To cause the fuse to blow and open circuit the power supply. Brute force... hence Crow Bar. You know... you do not want a PSU designed to work at 5 Volts giving out 15 Volts.. no no no. Kill it before it kills your other circuits!

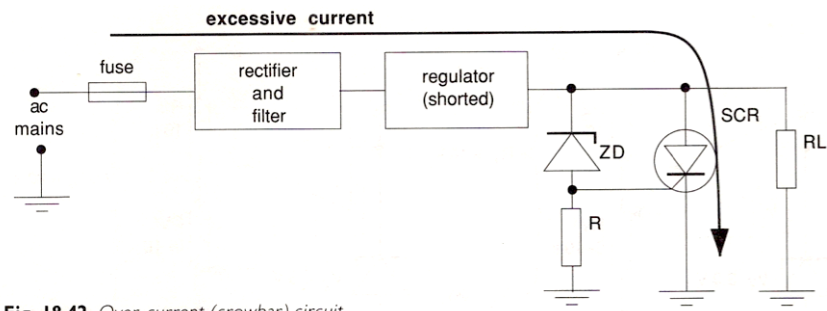
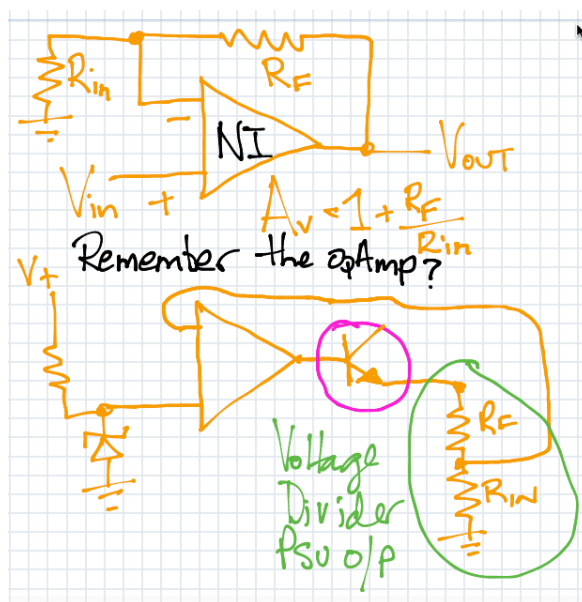


Fig. 18.42 Over-current (crowbar) circuit

If an over-voltage condition develops, the Zener diode will conduct. Voltage developed across the series resistor will gate the SCR on, providing an immediate current path for the excessive current. The current will flow only until the fuse blows.

This type of over-voltage protection circuit is called a crowbar circuit. It is like throwing an electronic crowbar, capable of handling very large currents, across the output when a fault develops.

Using OpAmps in power supply error correction circuits.



in the non-inverting mode the gain will be as I have drawn in the left hand picture.

The input to the opamp is the zener voltage. Edwards shows a 3.3V zener, and if we calculate the gain of the opamp feedback circuit and multiply it by the zener voltage we can know the output voltage of that opamp.

Note the circuit equivalent i drew. The base emitter resistance is negligible and all we see mathematically are Rf and Rin.

Overpage, the maximum and minimum gains for this opamp feedback circuit.

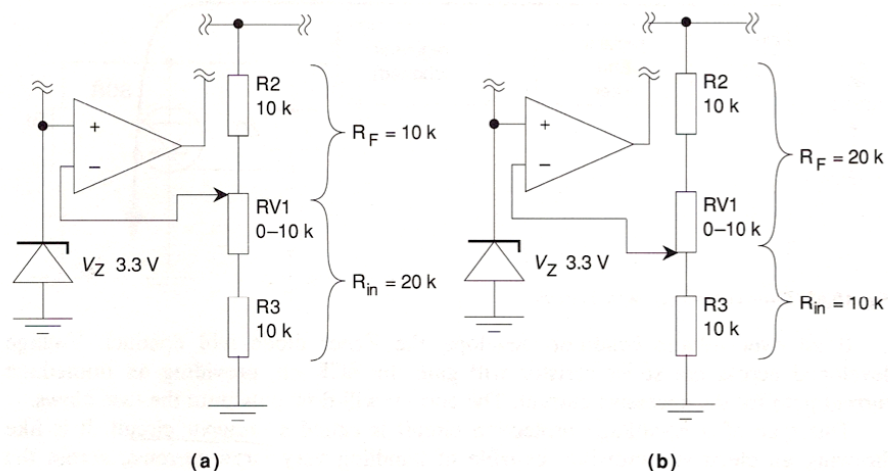


Fig. 18.44 Maximum and minimum voltage gains for the opamp

Solution 18.24

(a) $V_{out(min)} = 4.25 \text{ V}$

$$\begin{aligned} A_{V(min)} &= 1 + \frac{R_{F(min)}}{R_{in(max)}} \\ &= 1 + \frac{R_2}{RV_1 + R_3} \\ &= 1 + (10 \text{ k} \div 20 \text{ k}) \\ &= 1.5 \end{aligned}$$

$$\begin{aligned} V_{min} &= A_{V(min)} \times V_{in} \\ &= 1.5 \times 3.3 \text{ V} \\ &= 4.95 \text{ V} \end{aligned}$$

$$\begin{aligned} V_{out(min)} &= V_{min} - V_{BE(Q1)} \\ &= 4.95 \text{ V} - 0.7 \text{ V} \\ &= 4.25 \text{ V} \end{aligned}$$

(b) $V_{out(max)} = 9.2 \text{ V}$

$$\begin{aligned} A_{V(max)} &= 1 + \frac{R_{F(max)}}{R_{in(min)}} \\ &= 1 + \frac{R_2 + RV_1}{R_3} \\ &= 1 + (20 \text{ k} \div 10 \text{ k}) \\ &= 3 \end{aligned}$$

$$\begin{aligned} V_{max} &= A_{V(max)} \times V_{in} \\ &= 3 \times 3.3 \text{ V} \\ &= 9.9 \text{ V} \end{aligned}$$

$$\begin{aligned} V_{out(max)} &= V_{max} - V_{BE(Q1)} \\ &= 9.9 \text{ V} - 0.7 \text{ V} \\ &= 9.2 \text{ V} \end{aligned}$$

Using his components, Edwards has given us the calculated values.

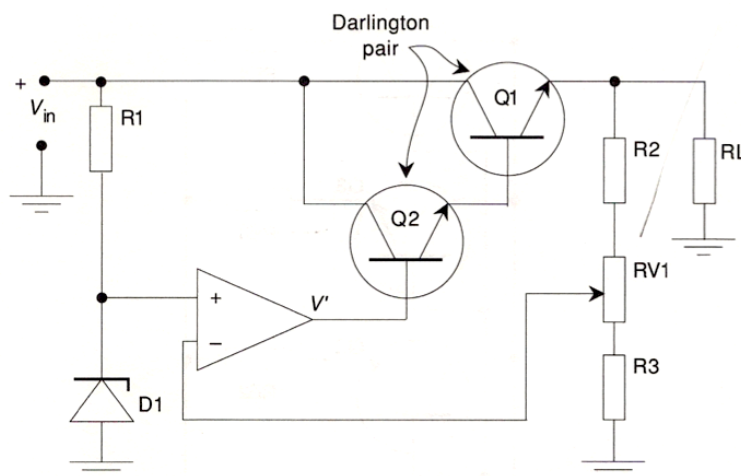
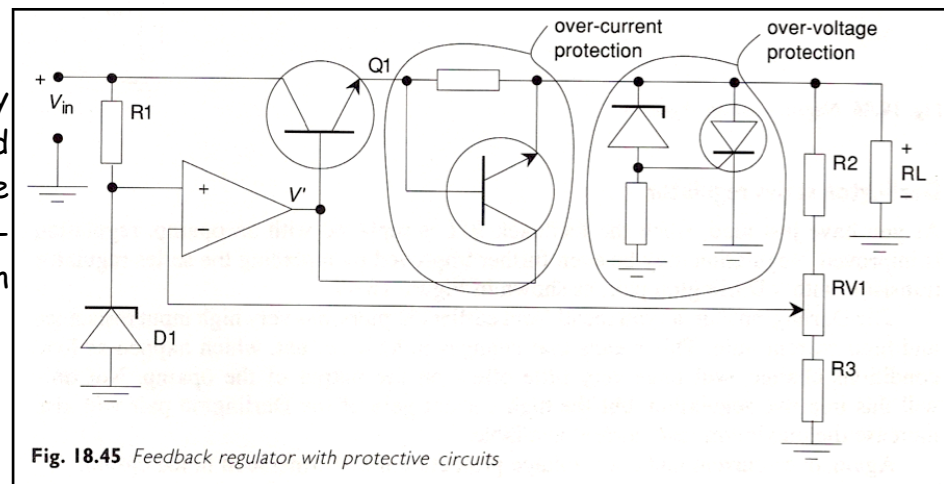
Case #1 A_v is 1.5

Case #2 A_v is 3

★★

so.. like an earlier model with the BJT error amplifier... the VR1 wiper at the bottom gives us the greatest output voltage from the power supply.

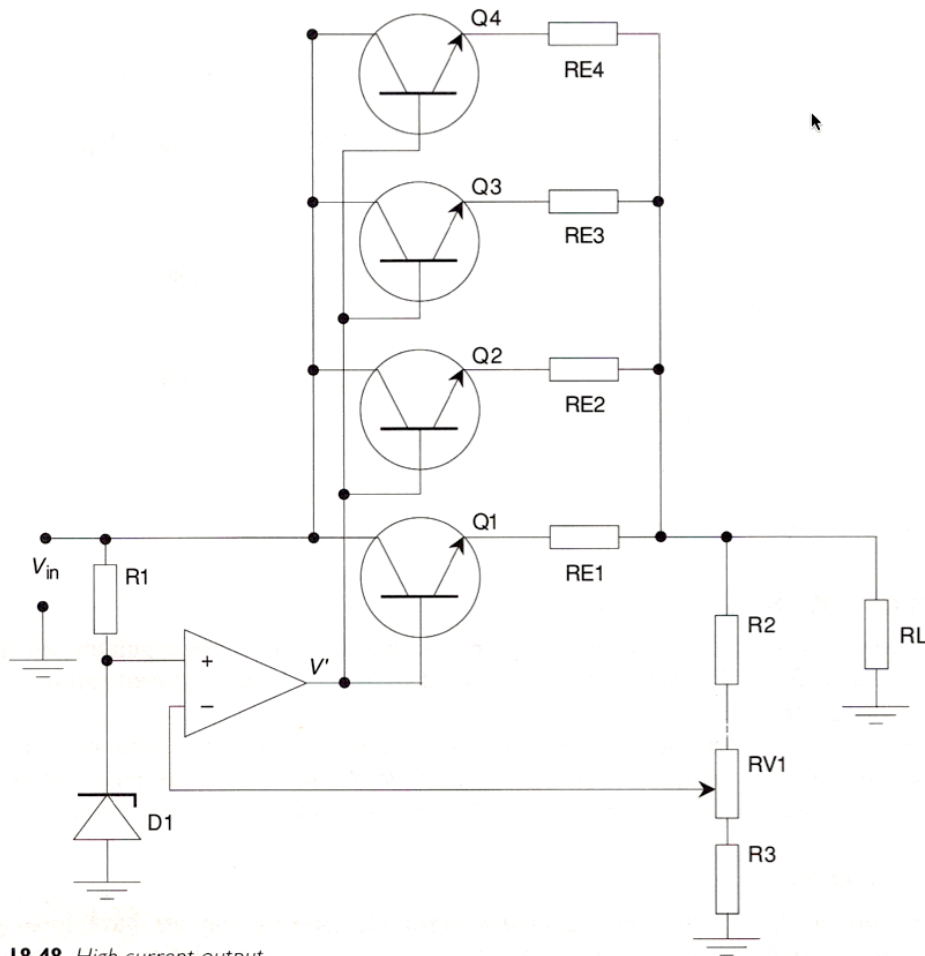
The whole study is presented here. All of the components discussed are shown in this circuit.



Darlington output transistors are common. Regulation may be even further improved by replacing the series regulator transistor with a Darlington pair, as shown in Figure 18.47.

The Darlington pair, as you recall from earlier chapters, has very high input resistance and high

current gain. This means that changes in load current, which happen as load conditions change, will have very little effect on the output of the opamp. Not only will this improve regulation, but the high current gain of the Darlington pair will also increase the maximum load current available.



Often we need very high current power supplies, this is done by paralleling up many power transistors in the output stage.

Fig. 18.48 High current output

Current Regulators

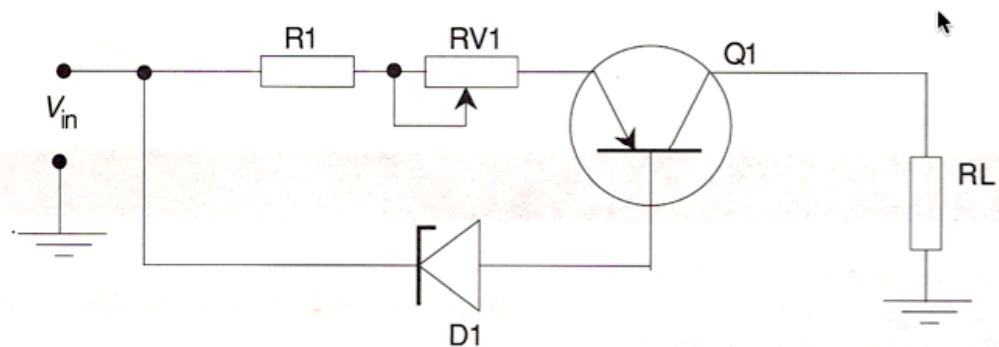


Fig. 18.51 Adjustable current regulator

This circuit will allow the output voltage to change and keep the current at a constant value. The amount of current limit setting is done with RV1. R1 is for protection if RV1 was adjusted to minimum value.