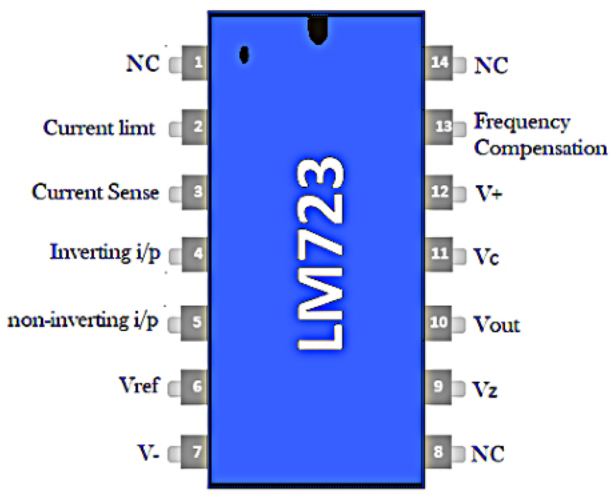
IC LM 723 Voltage Regulator

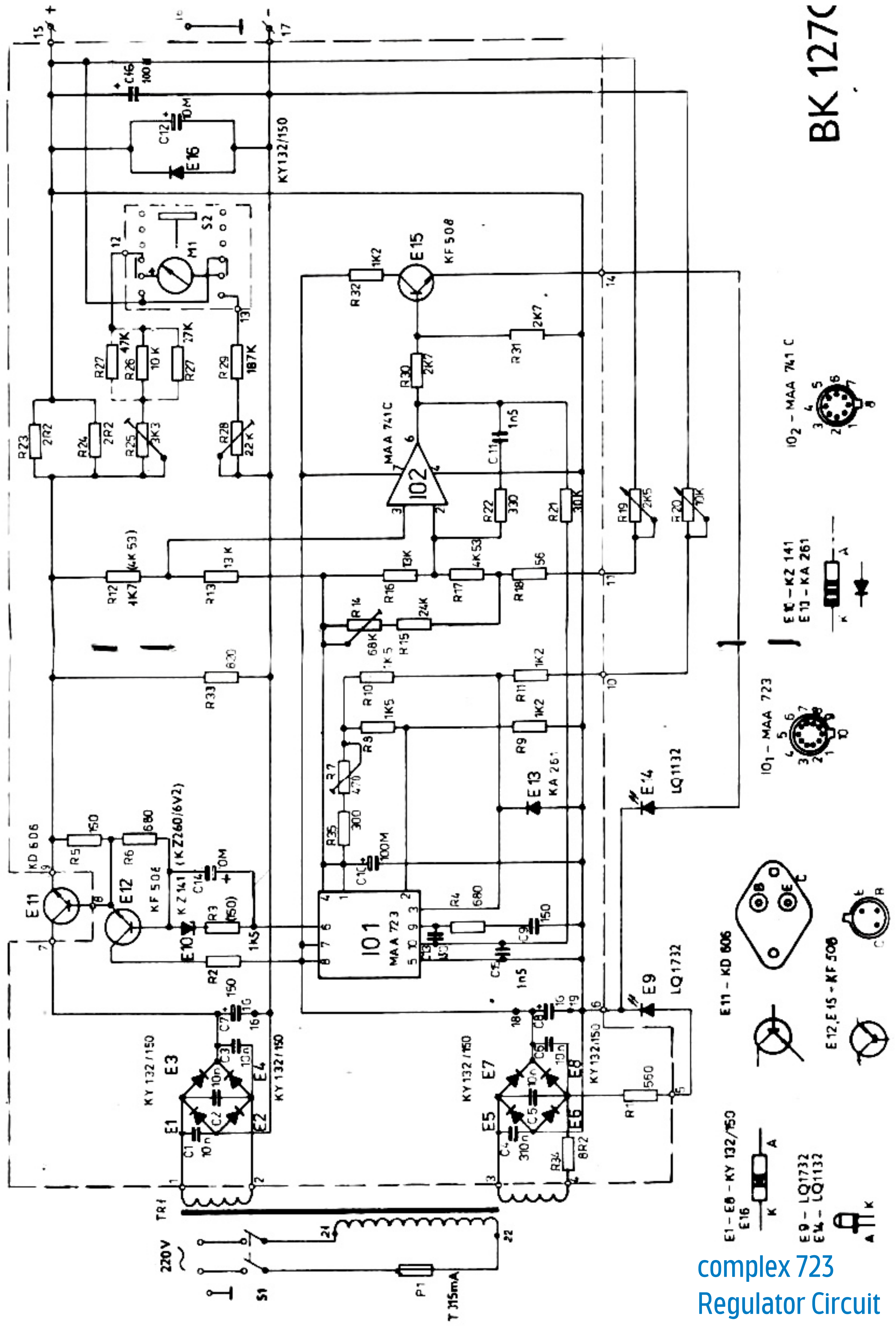
The 723 voltage regulator is commonly used for series voltage regulator applications. It can be used as both positive and negative voltage regulator. It has an ability to provide up to 150 mA of current to the load, but this can be increased more than 10A by using power transistors. It also comes with comparatively low standby current drain, and provision is made for either linear or fold-back current limiting. LM723 IC can also be used as a temperature controller, current regulator or shunt regulator and it is available in both Dual-In-Line and Metal Can packages. The input voltage ranges from 9.5 to 40V and it can regulate voltage from 2V to 37V.



Features of 723

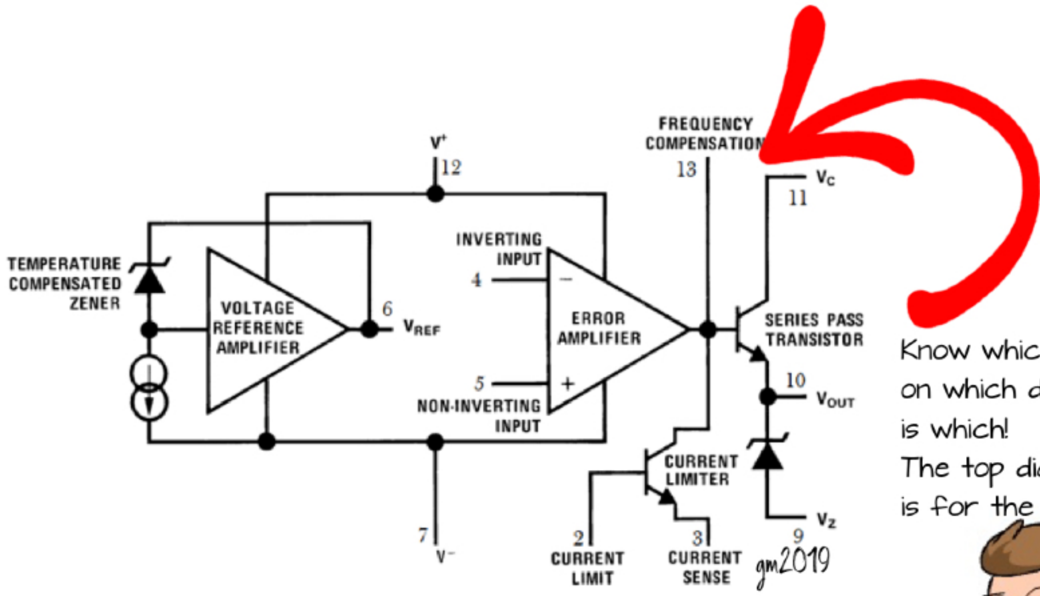
- 150 mA output current without external pass transistor
- Output currents in excess of 10A possible by adding external transistors
- Input voltage 40V max
- Output voltage adjustable from 2V to 37V
- Can be used as either a linear or a switching regulator

This is one of the most common linear regulator IC's on the market. It's been used in thousands of power supplies and temperature controllers over the past 40 years. We'll learn about it's functions.

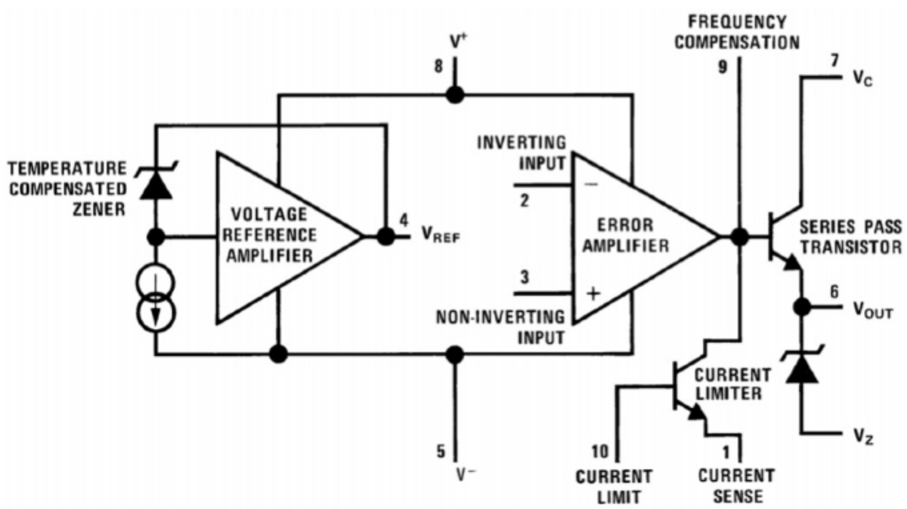


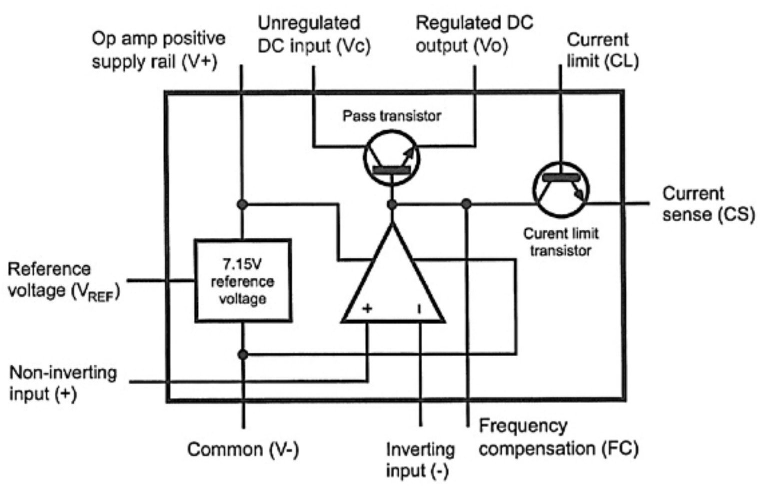
complex 723
Regulator Circuit

Here is what is on the inside of the 723 chip. On the left hand side you can see there is a constant current source feeding a zener diode in what is a current amplifier for the voltage reference. Being temperature compensated this forms a very stable and precision output voltage to use as a voltage reference in any design with this IC.



Know which Pin on which diagram is which!
The top diagram is for the DIL





Notwithstanding the quality of the precision reference, we still need to buffer the output current from this with a compensation resistor to the non-inverting input of the error amplifier.

From this lower diagram we can see that the LM723 contains the op amp, pass transistor, reference voltage circuit and current limit transistor needed for the circuits that we've looked at so far in this section. The reference voltage circuit is a little more sophisticated than just a resistor and zener diode connected in series and so it is simply shown as a functional block with a 7.15V output.

The sophisticated design provides for a more accurate and stable reference voltage which in turn provides for more accurate output voltages and better line regulation.

Some important device specifications include:

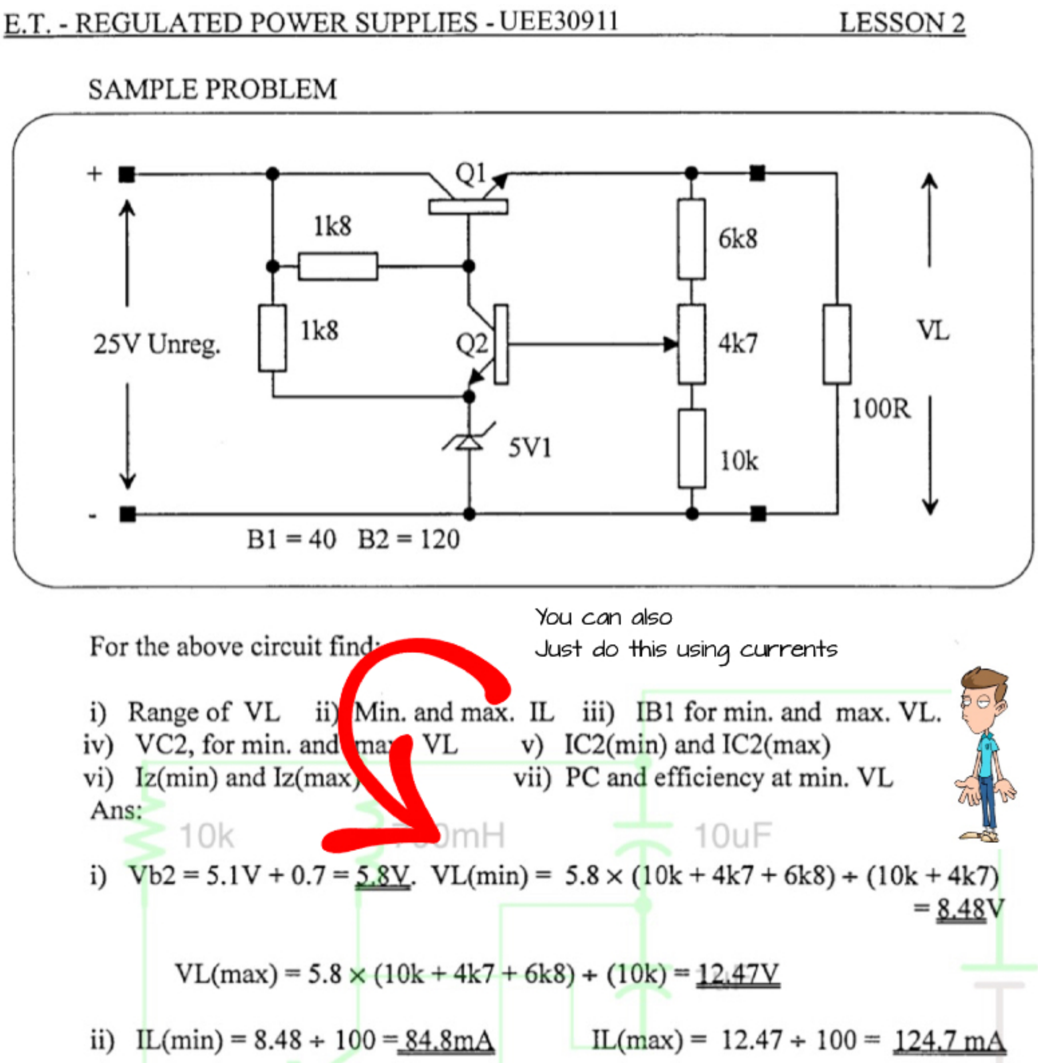
maximum output current: 150mA

maximum input voltage: 40V

maximum internal power dissipation (DIL package): 660mW

The following notes show how the LM723 is used to produce series regulators with error amplification and output voltages greater than 7.15V, equal to 7.15V and less than 7.15V.

From previous study, you will recall that the voltage reference value, added to any V_{be} drops limits our lowest output voltage from the supply. In my lesson 2 notes shown here, you can see how the output is derived. It's quite simple that if you have a voltage divider with a central voltage, you have a current in the bottom half of the voltage divider and using Kirchhoffs you can determine the potential across the entire voltage divider. I've shown in my notes a ratio method but note it's just as easy to use currents and Ω law.


E.T. - REGULATED POWER SUPPLIES - UEE30911 LESSON 2

SAMPLE PROBLEM

For the above circuit find:

i) Range of VL ii) Min. and max. IL iii) IB1 for min. and max. VL.
iv) VC2, for min. and max. VL v) IC2(min) and IC2(max)
vi) Iz(min) and Iz(max) vii) PC and efficiency at min. VL

You can also
Just do this using currents

Ans:

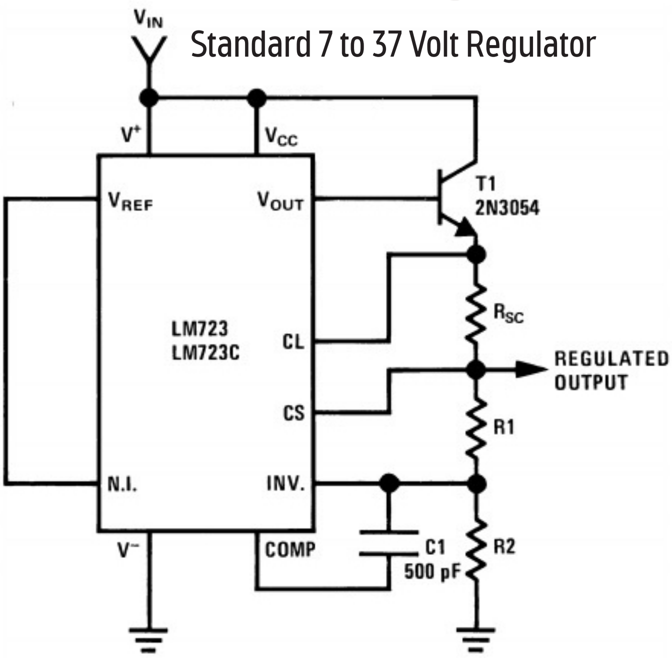
i) $V_{b2} = 5.1V + 0.7 = \underline{5.8V}$. $VL(min) = 5.8 \times (10k + 4k7 + 6k8) \div (10k + 4k7) = \underline{8.48V}$

$VL(max) = 5.8 \times (10k + 4k7 + 6k8) \div (10k) = \underline{12.47V}$

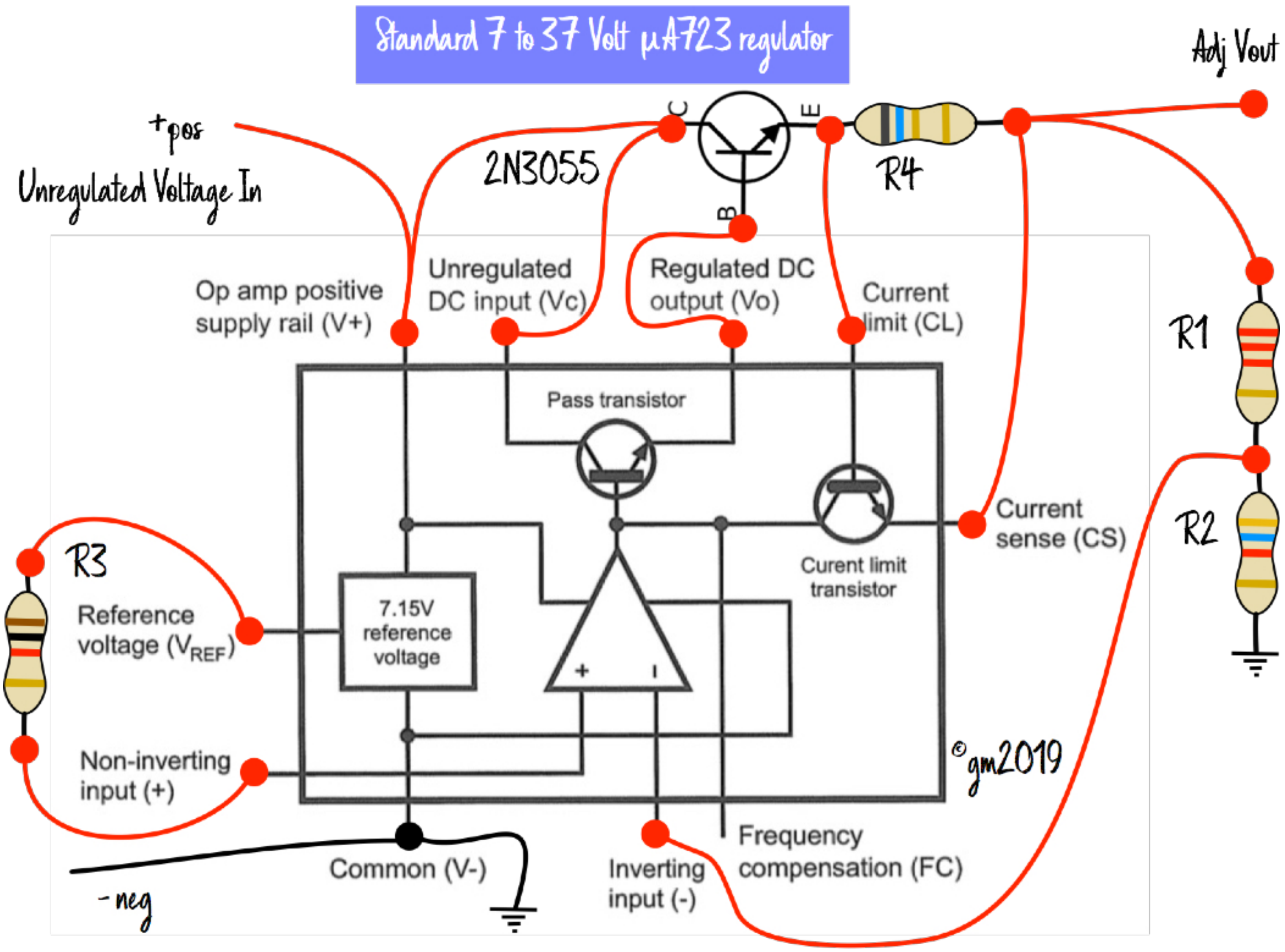
ii) $IL(min) = 8.48 \div 100 = \underline{84.8mA}$ $IL(max) = 12.47 \div 100 = \underline{124.7\ mA}$

For this reason the 723 running 'barefoot' wil have a lower voltage in it's output range which is above $7.15V_{DC}$ and we need to employ special steps to change our design circuit if we intend to use a lower voltage. There was a very good article way back in 1978 Elektor magazine showing how this can be achieved. Also, once you understand this, the complex 723 circuit on page 2 can be read more easily.

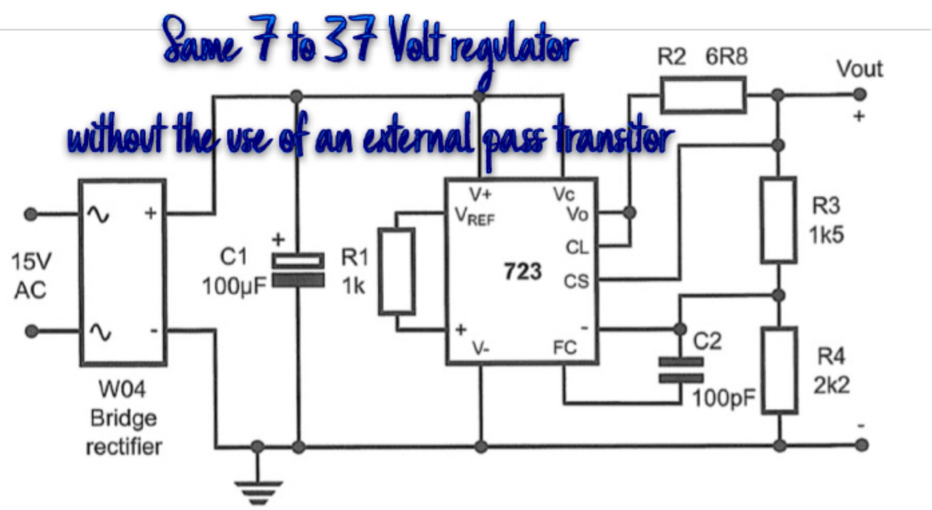
I'll get to that shortly. First of all let's have a look at how the 723 design circuit works. In the adjacent circuit taken from the Texas Instruments data sheet (application data) the 7.1V reference voltage is tied directly to the N.I. input of the opamp in the output of the chip which forms the error amplifier. The INV. input of the opamp is tied to voltage divider R1 and R2. This is the error voltage coming back and being compared to the reference voltage. This error output voltage is used to drive the base of the series pass transistor. V_{out} pin 10 on the 723 DIL is the output from the series pass emitter and is used to drive an external power transistor, creating a darlington output.In practice a resistor is used between V_{ref} and N.I. and I have drawn this in my colour hook up plate no. 1 on the next page.While design circuits can be a little dull to look at with an idea to actually build the circuit, I have shown a wiring diagram for this standard regulator in colour with resistors in actual body shapes.



In this simple circuit we see R1 and R2 as a ratio to set the output voltage from the overall circuit. R4 is used for current limit. The 2N3055 is used as a high power partition to the internal 723 pass transistor and of course is a power darlington which can be bolted to a heatsink. There is an equation given by the manufacturer to choose the value of R3. Commonly though it's just put as 1kΩ. This is the 7 to 37 volt regulator as there is no voltage divider used in the Reference / Non Inverting input. If a voltage divider is used where I have positioned R3, then a new equation must be used for the output voltage divider and the reference voltage divider to obtain the output voltage. Using a voltage divider in the reference side of the chip, a lower 2 Volt output can be obtained. (the 7.15V is proportioned down before going into the N.I.terminal) At the bottom right of this page I have shown essentially the identical circuit to my colour plate but without an external pass transisor. In this circuit, R2 at 6.8Ω is the current limit and R3 with R4 set the output voltage.



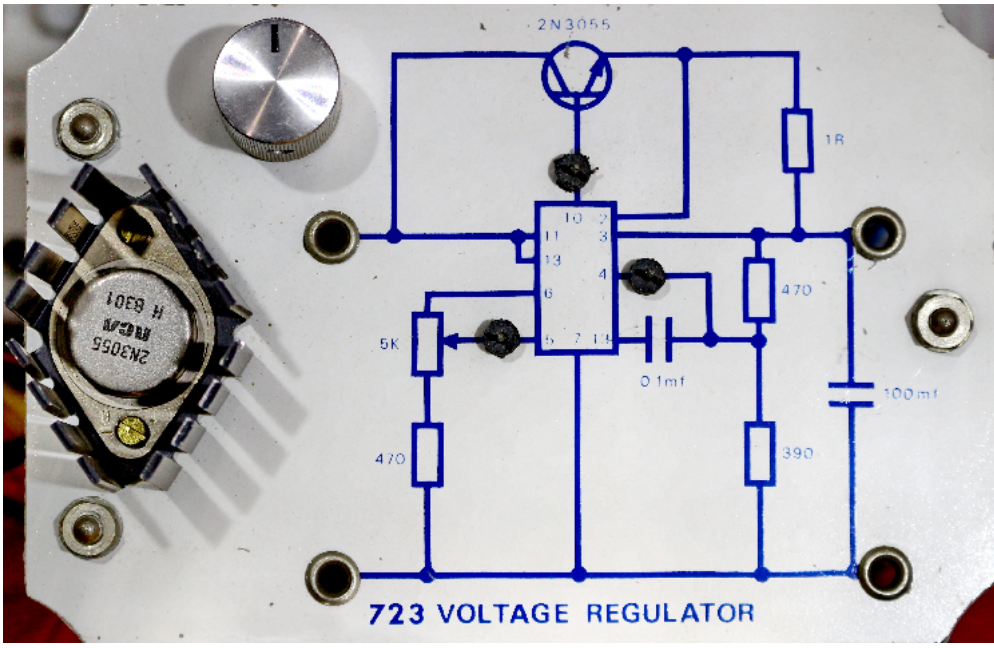
See Elektor Magazine for better ripple rejection by using buffered OpAmp Positive



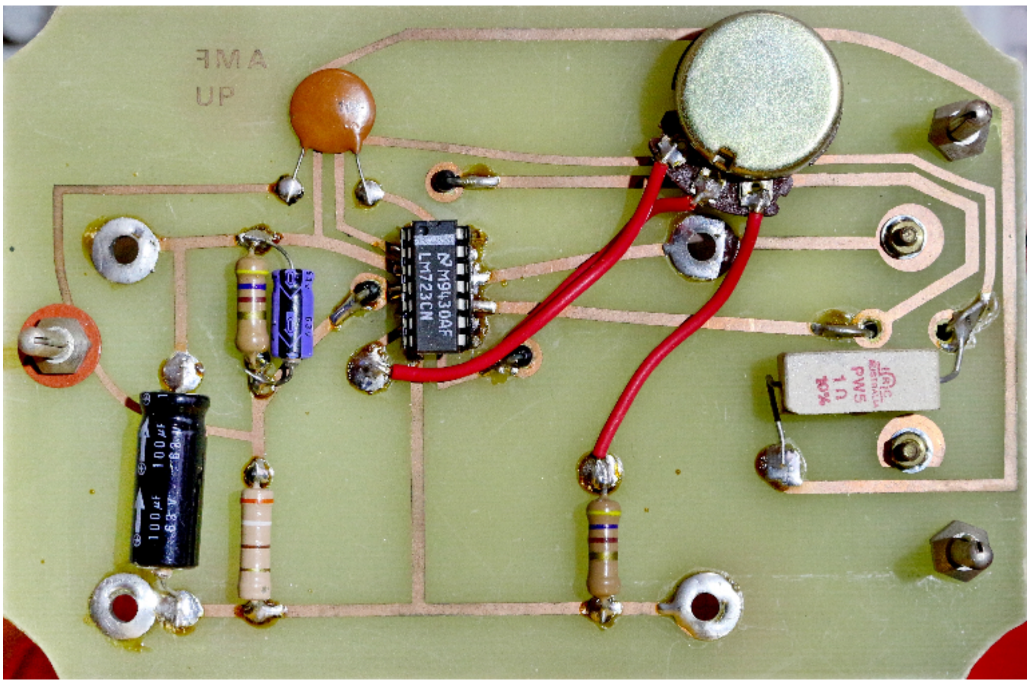
Note: $R3 = \frac{R1\,R2}{R1 + R2}$
for minimum temperature drift.
R3 may be eliminated for minimum component count.

R3 in my colour plate and R1 in the inset is optional according to the Texas Instruments notes.

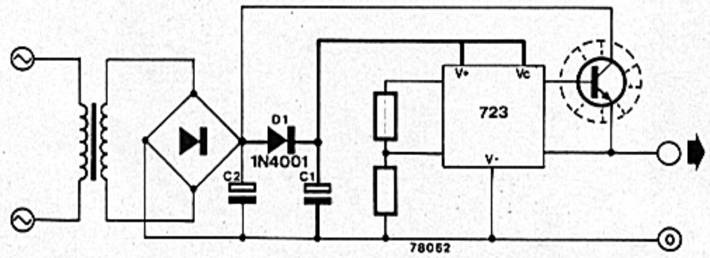
Here is our Lab board with a voltage divider set up between the V_{Ref} and N.I. input of the error amplifier. So you see there are two

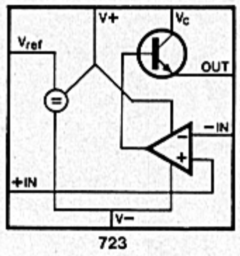


voltage dividers used in this arrangement to obtain the output voltage. The variable component being a 5kΩ potentiometer in the Reference side of the 723. The 470Ω and the 390Ω form a voltage divider to set the output maximum voltage. There is 1Ω of current sensing resistor to set the maximum output current before fold-back occurs. I've shown the the bottom of the PCB also. The LM723 IC is clearly visible in the centre of the board. The colour bands on each resistor are also easy to read and identify the values against the circuit diagram. Note the 1Ω current sensing resitor is rated at 5W. This indicates that the output current is limited at (600mV ÷ 1Ω) say 0.6A. The 1Ω resistor is oversized for this application. I^2R shows just 360mW of dissipation. It probably could have been rated at 1W. The regulator circuit is very basic. Extra ripple rejection has not been accounted for by decoupling of the rail voltage to the LM723 IC. It's ok for low power applications only, with low dynamic loads attached to the supply. (ie output resistance not varying rapidly and with sudden deep transitions). On the next page, I've added two key articles from the 1978 edition of Elektor magazine. In the first article the need to supply the LM723 with a minimum of 8.5V is discussed and the problem with series pass transistor excessive power dissipation under load. For example, if you only want 5 Volts DC out of the transistor, it is necessary to normally power the series pass transistor collector with the same supply of a minium 8.5Volts. Why not supply it with a more modest supply and supply the just the LM723 with 8.5 Volts? This is a little cunning and a little strange. To use a smaller value of filter capacitor C2 to increase the ripple and to push down the average voltage to the series pass transistor, thereby reducing it's power dissipation. Meanwhile, C1 has a bigger reservoir



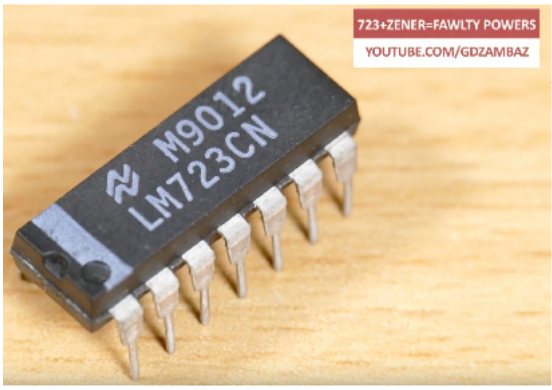
improved 723 supply 29





The 723 is a very widely used IC regulator. Hence the following circuit, which is intended to reduce power dissipation when the 723 is used with an external transistor, should prove very popular.
According to the manufacturer's specification the supply voltage to the 723 should always be at least 8.5 V to ensure satisfactory operation of the internal 7.5 V reference and of the IC's internal differential amplifier.
Using the 723 in a low-voltage high-current supply, with an external series transistor operating from the same supply rail as the 723, invariably results in excessive dissipation in the series transistor.
For example, in a 5 V 2 A supply for TTL about 3.5 V would be dropped acorss the series transistor and 7 W would be dissipated in it at full load current. Furthermore, the reservoir capacitor must be larger than necessary to prevent the supply to the 723 falling below 8.5 V in the ripple troughs.
In fact the supply voltage to the series transistor need be no more than 0.5 V above the regulated output voltage, to allow for its saturation voltage.
The solution is to use a separate 8.5 V supply for the 723 and a lower voltage supply for the external transistor. Rather than using separate transformer windings for the two supplies, the supply to the 723 is simply tapped off using a peak rectifier D1/C1. Since the 723 takes only a small current C1 will charge up to virtually the peak voltage from the bridge rectifier, 1.414 times the RMS voltage of the transformer minus the voltage drop of the bridge.
The transformer voltage thus needs to be at least 7 V to give an 8.5 V supply to the 723.
However, by suitable choice of reservoir capacitor C2 the ripple on the main unregulated supply can be made such that the voltage falls to about 0.5 V above the regulated output voltage in the ripple troughs.
The average voltage fed to the series transistor will thus be less than 8.5 V and the dissipation will be greatly reduced.
The value of C1 is determined by the maximum base current that the 723 must supply to the series output transistor. As a rule of thumb allow about 10 µF per mA. The base current can be found by dividing the maximum output current by the gain of the transistor. A suitable value for the main reservoir capacitor C2 is between 1500 and 2200 µF per amp of output current.

capacitance and maintains a higher peak voltage of +8.5 Volts DC. The LM723 does not draw very much current but the base current of the series pass has to be supplied by the pass transistor in the



LM723. As the author here says, allow enough reservoir to provide the base current. Often we see an additional supply for the output series pass, the regulator circuitry and as we shall see, the 'lift' voltage to put the LM723 above rail if the output voltage is needed to go down to zero volts. (it's easy with a Voltage Reference voltage divider to get the output down to +2Volts, but down zero is a whole different situation. **There is a video to watch**. Really well made video about lowering the voltage in the LM723 at the expense of highter load regulation
https://youtu.be/2w4cR8D8WJ4

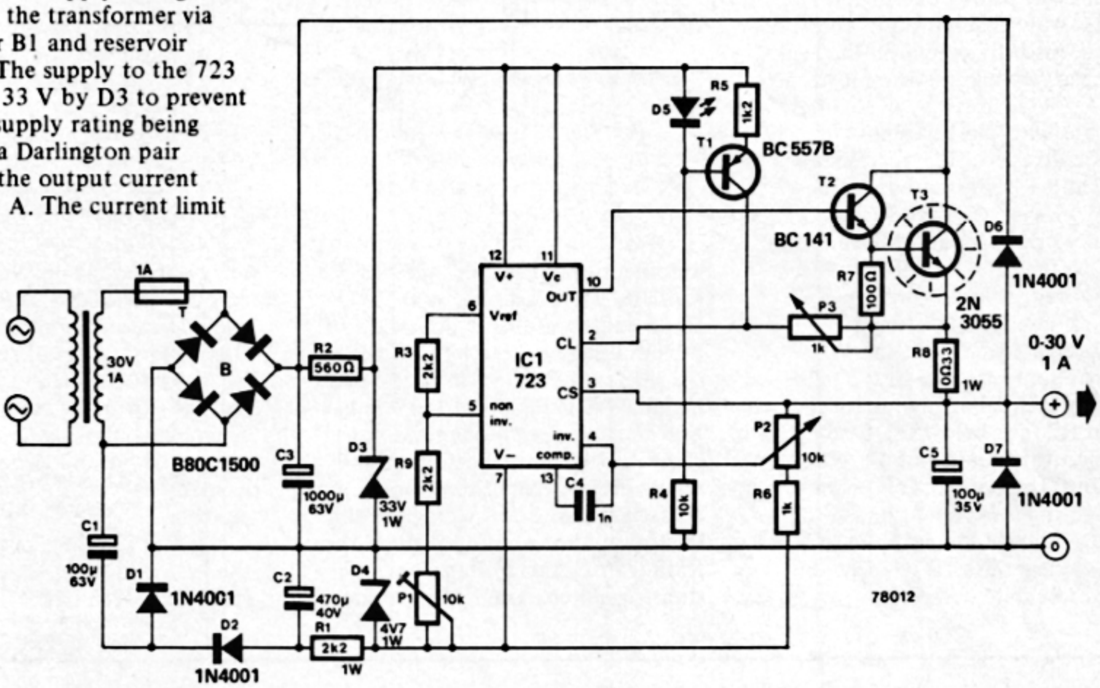
The load regulation of the barefoot LM723 is excellent and is not matched by many newer IC's on the market today. The reason for this is the embedded (buried) zener diode. A subsurface Zener diode, also called 'buried Zener', is a device similar to the Surface (normal) Zener, but with the avalanche region located deeper in the structure, typically several micrometers below the oxide. The hot carriers then lose energy by collisions with the semiconductor lattice before reaching the oxide layer and cannot be trapped there. The Zener walkout phenomenon therefore does not occur here, and the buried Zeners have voltage constant over their entire lifetime. Most buried Zeners have breakdown voltage of 5–7 volts. Several different junction structures are used. (**wikipedia**)
On the next page, the second article from Elektor 1978 magazine is reproduced for educational pur-

poses and it is just what we need to know about how many 0 to 30 Volt LM737 supplies have been built. Again a cunning mix of decoupled 33 Volt zener biased supply to the LM723 and then R1 and D4 giving a nice minus 4.7 Volt supply to the bottom of the LM723 IC. By lifting the 723 up by 4.7 Volts and using a 50/50 voltage divider bias in the Reference circuit of the 723, the output voltage can be carefully tailed to zero volts. But is there a disadvantage to doing this? After watching *Goran Dzambazov's YouTube video* you should have a fairly good understanding of what has gone wrong with doing this. It's only a minor technical thing, but you are defeating the whole beauty of the buried zener and ad-

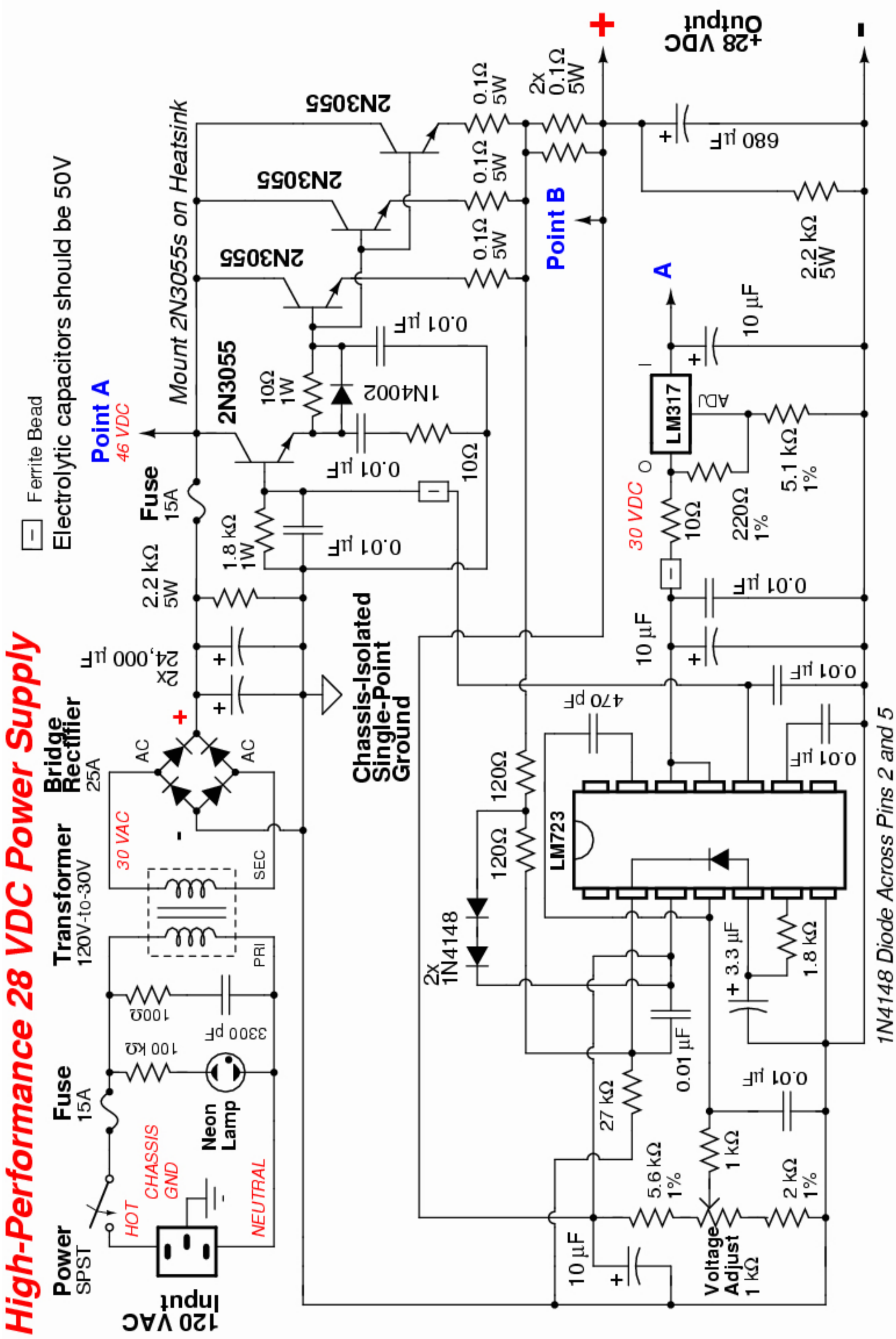
77 0 – 30 V regulated supply

This laboratory power supply offers excellent line and load regulation and an output voltage continuously variable from 0 to 30 V at output currents up to one amp. The output is current limited and protected against output fault conditions such as reverse voltage or overvoltage applied to the output terminals.
The circuit is based on the well-known 723 IC regulator. As readers who have used this IC will know, the minimum output voltage normally obtainable from this IC is +2 V relative to the V– terminal of the device (which is normally connected to 0 V). The problem can be overcome by connecting the V– pin to a negative potential of at least –2 V, so that the output voltage can swing down to +2 V

relative to this, i.e. to zero volts.
To avoid the necessity for a transformer with multiple secondary windings the auxiliary negative supply is obtained using a voltage doubler arrangement comprising C1, C2, D1 and D2 and is stabilised at –4.7 V by R1 and D4. The use of –4.7 V rather than –2 V means that the differential amplifier in the 723 is still operating well within its common-mode range even when the output voltage is zero.
The main positive supply voltage is obtained from the transformer via bridge rectifier B1 and reservoir capacitor C3. The supply to the 723 is stabilised at 33 V by D3 to prevent its maximum supply rating being exceeded and a Darlington pair T2/T3 boosts the output current capability to 1 A. The current limit is continuously variable by means of P3.
The output voltage may be adjusted using P2, while preset P1 is used to set zero output voltage.
The supply is protected against reverse polarity being applied to the output terminals by D7, and against overvoltages up to 63 V by D6.
To set the output voltage to zero P2 is first turned anticlockwise (wiper towards R8) and P1 is then adjusted until the output voltage is zero.
With P2 turned fully clockwise the output voltage should then be approximately 30 V. If, due to component tolerance, the maximum output is less than 30 V the value of R6 may require slight reduction.
When constructing the circuit particular care should be taken to ensure that the 0 V rail is of low resistance (heavy gauge wire or wide p.c.b. track) as voltage drops along this line can cause poor regulation and ripple at the output.



ding a common garden variety of surface zener with a large resistive region and subject to the voltage change as the current rises and falls through the zener. I've added a 723 circuit on this page. Try redraw-



ing the circuit to show what the LM723 is doing. When looking at this circuit it's awkward to know what is happening. For example: Look at the LM317 regulator. Is the output going to point A? No it is not! Point A is the input to the LM317 and it is being used like the circuits we already saw, to supply the LM723 with a steady regulated voltage supply of $30V_{dc}$. Why are so many 2N3055 transistors used? You can read more about this supply here: 28 Volt Supply Is the voltage adjustment done on the Reference voltage side of the LM723 or on the output side with a standard voltage divider? **Redraw the circuit in a better way that is more understandable.**

Study the circuit I have provided on page 2 of this handout. Analyse the circuit. Can it go down to zero volts? It's an old commercial power supply unit, one which is typically encountered in the servicing of older equipment or Audio equipment where power supply radiation is not allowed. Think about eavesdropping with a switching supply, the audio would faintly modulate the oscillations in the power supply, which are radiating and can be eavesdropped on with electromagnetic spectrum equipment. Supplies which do not radiate RF are still very much in use today.

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