

The Fun Projects Voltage Regulator

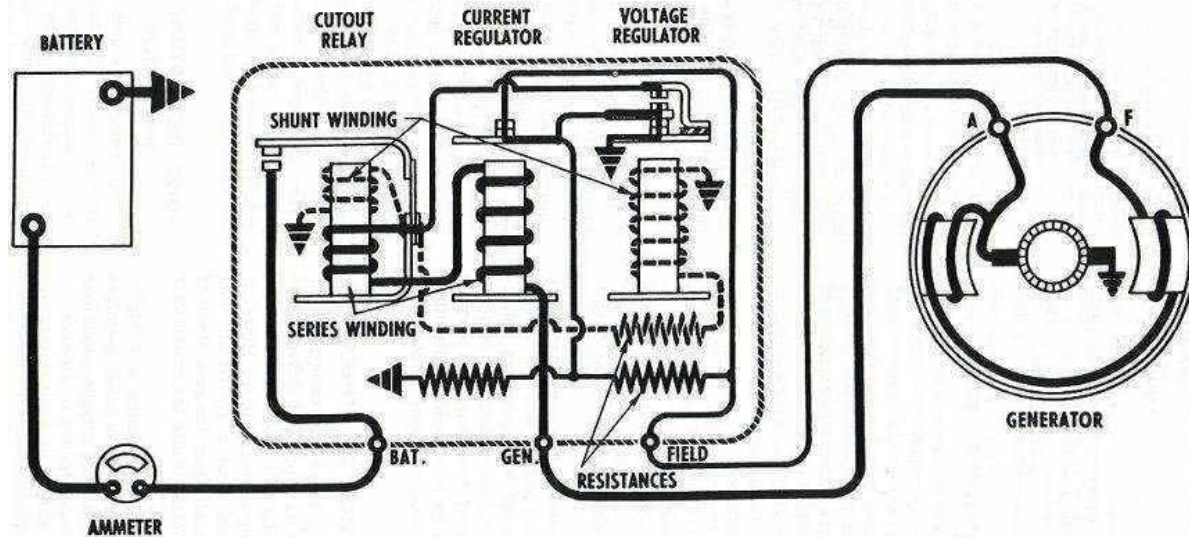
It is a known limitation that the Model T Ford can suffer from an overcharged battery because of the absence of any voltage regulation. While the 3rd brush generator allows one to set the charge current, which remains fairly constant over a wide generator speed, there is nothing to reduce the charge when the battery is full. So, if one has set the charge current to say 10A in order to run the headlights continuously, when the headlights are off the battery will receive this 10A, even after it is fully charged. That's not good for the battery, apart from it losing more electrolyte than normal. In practice, the best compromise with the stock standard set up is to set the charge current to 5A which won't damage the battery, and will allow moderate headlight usage.

Principles of Automotive Voltage Regulators.

The principles of voltage regulation for automotive electrical systems were known back in the 1920's, but Ford with its economy focussed ideals, ignored it.

The method used, which has remained to the present time, is to reduce the generator (or alternator) field current when the battery has reached full charge.

Until solid state regulators started to become common in the 1970's, the regulator was an electromechanical device built along the lines of a relay. One set of relay contacts was placed in series with the field coil supply. Shunted across the contacts was a resistor; the purpose of which set the minimum field current and also protected the contacts against the arcing that would result from the rapidly collapsing magnetic field of the field winding.



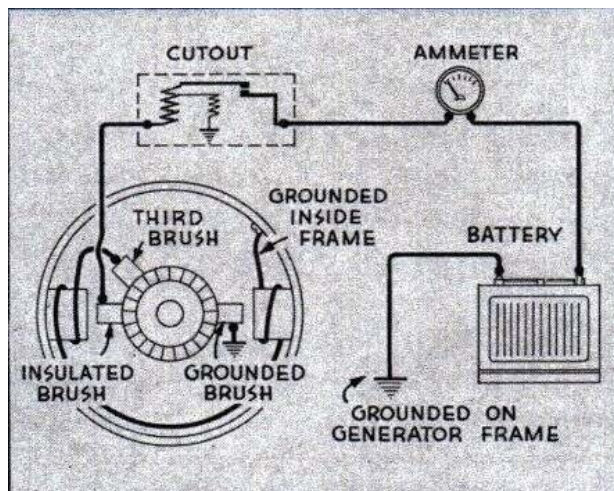
This set of contacts was pulled in by the voltage coil. Effectively, the voltage coil is connected across the battery and its pull in power is obviously dependent on battery voltage. Therefore, the contacts are set to open when the battery has reached about 7V for a 6V system, or 14V for a 12V system.

The charge current is severely reduced, and the battery does not overcharge. Along with the voltage coil and contacts, are also a current coil and cutout with their own sets of contacts. The current coil senses battery charge current and its contacts open, again reducing field coil current, if the charge current is too high - such as when the battery has a low charge. This is required to protect; a) the battery, b) the generator brushes and commutator, and c) the generator windings from excessive current. Finally, the cutout coil senses current direction. Its contacts are between the generator output and battery. If current flows from the generator to the battery the contacts close, and if the current from the battery tries to flow back into the generator (e.g., when the engine is stopped) then the contacts open. This prevents the battery discharging into the generator when the car is not in use.

The design of alternators is such that they are inherently current limited, by means of winding inductance and that they generate AC. The rectifier diodes used to change the three phase AC to DC automatically prevent the battery discharging when there's no output. Hence, alternators do not require the cutout and current coils in the regulator assembly.

Electronic regulators which replaced the earlier mechanical types use a power transistor to control the field current. This is controlled by a zener diode voltage reference and comparator circuit. As alternators were standard by this time, there was no need to provide current control or a cutout in the electronic regulator assembly.

Regulation and the Model T.



Third brush generator charging system.

Until 1939, Ford used a third brush generator. Current regulation is adjusted by the setting of the 3rd brush. In simple terms, this setting adjusts how much current flows in the field coils. The voltage is not regulated, being held only within safe limits by the loading of the battery.

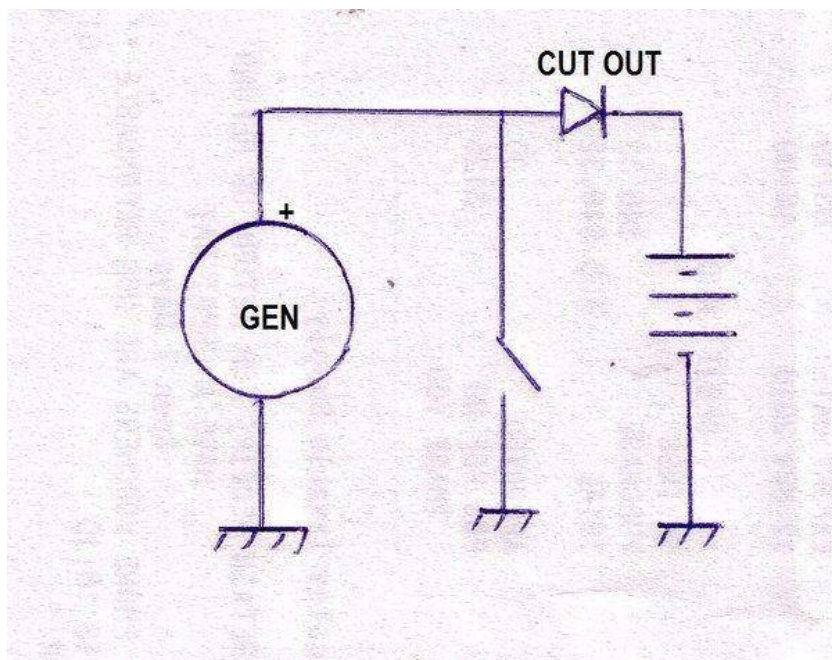
In essence, a third brush generator is a constant current source. A disadvantage with this set up is that once the battery is fully charged, it still receives full charging current. Setting the charge current is very much a compromise. It should not be so high to boil the battery electrolyte, but enough to replace the current taken by the electrical loads of the car. In practice, 5A has been found to be quite suitable.

Battery and generator life can be extended by including voltage regulation, since charge current decreases when the battery reaches full charge. In so doing, the mechanical drag and brush wear on the generator is also reduced.

An immediate problem trying to connect an accessory voltage regulator to the Model T, or any other car using a 3rd brush generator, is that there is only one terminal on the generator, which is for the output.

Since the field winding is energised internally, it has no external connection. To use a standard regulator involves having to separate the field coil connection, and providing a second insulated terminal. Indeed, this has been done. However, it looks out of place and involves wiring modifications. For those who just want a drop in regulator with no wiring modifications, an electronic regulator was developed by Fun Projects.

First Principles - Grounding Switch.

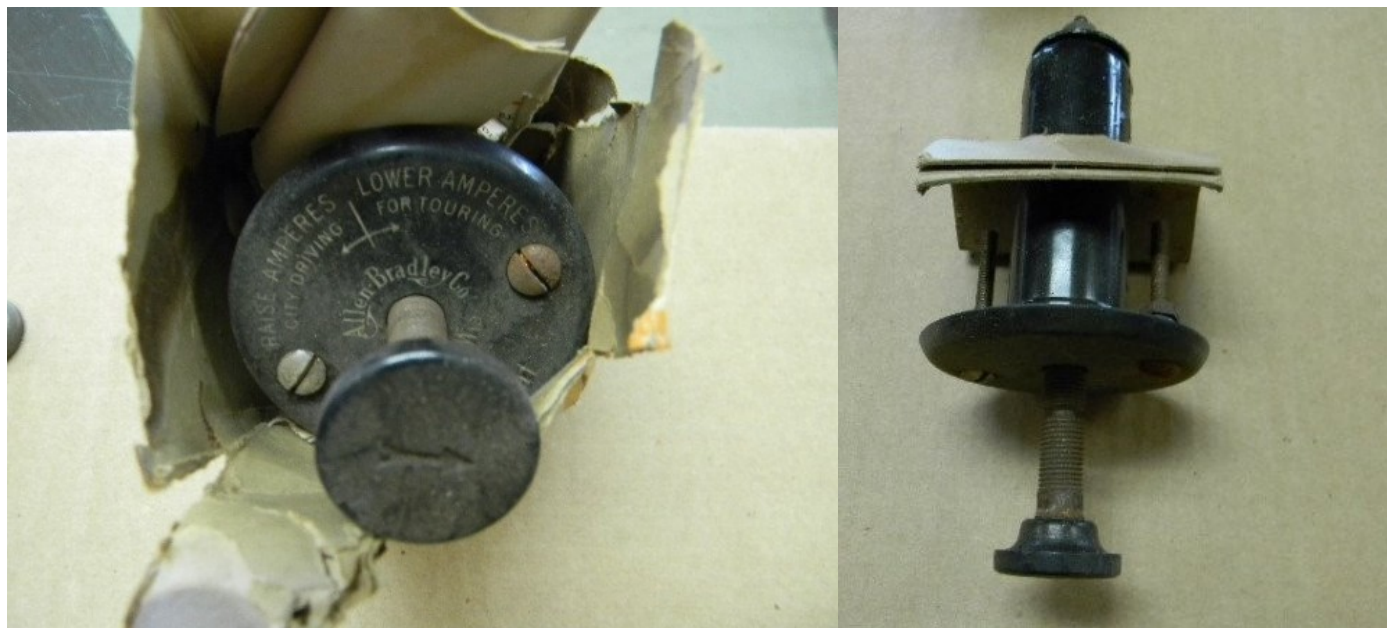


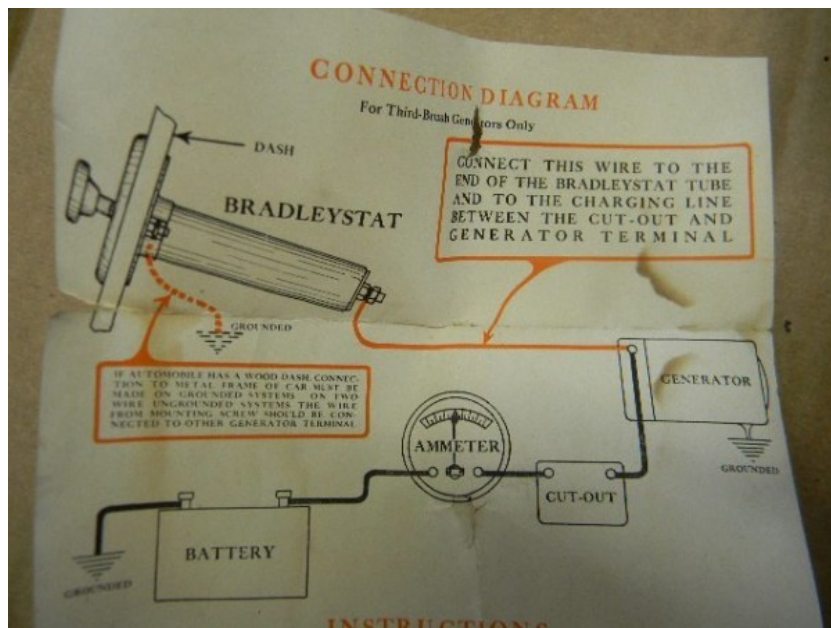
Switch short circuits generator output when no output is desired.

Well known in the Model T world is the so called "Grounding Switch". It made its appearance in an issue of "Tinkering Tips" many years ago. By means of this switch the generator could be shut off, if it was felt the battery did not require further charging. It was also thought that by shutting off the generator, some extra horsepower could be obtained from the engine. However, a theoretical analysis of the latter tends to make this claim suspicious. Assuming a charge current of 5A at 7V, that is a power of 35W. Assuming 50% efficiency for the generator, the input power would be around 70W. That is about one tenth of one horsepower! (1 HP = 746W).

To shut off the generator, we cannot merely open circuit the connection between the generator and battery, because it is a constant current source, meaning the output voltage will rise to a destructive level under no load, which can burn out the windings. But, because the generator is a constant current source, we can short circuit the output. Taking the output terminal to earth immediately robs the field coil of supply. It is perfectly safe to run the generator continuously this way, because since the field coil is not energised, the armature cannot produce any output. Shorting the generator output to earth would cause a huge current from the battery to flow if it wasn't for the cutout; shown as a diode in the above diagram. The diode merely becomes reverse biased when the switch is closed, and thus no current from the battery flows to earth. Importantly, when a grounding switch is installed, the cutout **must** be a diode type. This is because a mechanical cutout makes a direct connection to the battery when activated, and the switch would be shorting the battery current, limited only by the wiring resistance, until the cutout opened. Obviously, the switch and cut-out will not last long used like this. It is true that the switch could be closed prior to the engine coming up to full speed, before the cutout closes, but human nature being what it is, would eventually result in this point being forgotten.

Another method of controlling the charge rate is to simply divert more or less of the generator output to earth, as done by this period accessory:





(Photos courtesy MTFCA forum).

Here, a high power variable resistor is used to shunt the generator output. For example, assume the third brush is set to 10A. If the shunt resistor is set to draw 4A, then the battery will be charged at 6A. The resistor appears to be a carbon pile type. This is a tube filled with carbon discs (hence the term "pile"). If the pressure against the discs is increased, they are pressed more firmly together, and the resistance drops. In this case, the adjustment is made by a screw threaded plunger. While this method no doubt can save the battery from being overcharged, it is very inefficient, with all the diverted current going up as heat. Additionally, the generator output is not actually reduced. The input power from the engine remains the same, as does the rate of wear on the generator. However, unlike the grounding switch, this one can be used with a mechanical regulator.

Principle of Regulation.

Having acquainted ourselves with the grounding switch, we can see that if the switch was closed when the battery voltage increased to 7V, and was opened when it fell below this, the battery would remain fully charged without risk of overcharge. The concept of the regulator is to do this automatically. To take the generator output to earth, either a power transistor or a MOSFET could be used. To control this, a switchmode controller or a comparator could be used. A switchmode control would gradually increase its 'on' time (i.e. earthing the generator) as the battery reached 7V, and give the appearance of a variable current control when observed on the ammeter. A comparator would provide full charge until 7V was reached then shut the charge off altogether, until the battery voltage dropped to say 6.5V. This would show more of a pulsing type of indication on the ammeter.

Note that the charge current is still determined by the 3rd brush setting.

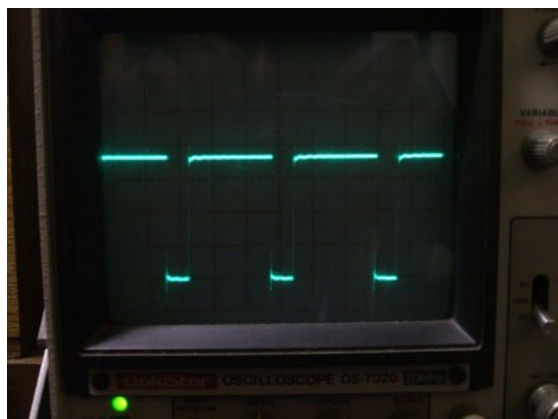
The Fun Projects Design.

A well known and popular accessory for the Model T is the Fun Projects Voltage regulator. It was available from various Model T parts suppliers. It eliminates the potentially unreliable mechanical cutout, and prevents battery overcharge. It is a drop in replacement for the original cutout, looks identical, and needs no additional wiring. A further advantage is the crowbar protection to prevent generator burn out, if the battery should be disconnected.



However, there is no technical information available on how it works, or the internal design. As I'm often asked about the Model T electrical system, it was necessary to investigate and provide my own information.

The particular regulator in my possession was given to me on the premise that it was faulty, and could I fix it? As I discovered, the regulator was actually quite OK, but other things in the car were at fault. Nevertheless, I had been curious about the design and wanted to confirm my theory as to how it worked. So what better way than to examine the unit, and trace out the circuit. It could be of use for others who have a faulty regulator, or just want to build their own. Opening the unit simply involved a slight grind into a couple of spot welds. The cover then slips off. I used a variable, current limited power supply, in series with the secondary winding of a 14V power transformer (primary not connected), to test the unit, which indicated it was functional. Upon raising the input voltage, a high frequency tone could be heard from the power supply, and connecting a CRO showed that indeed it was rapidly switching on and off.



Waveform at generator terminal. As battery voltage rises, the pulse width shown here decreases so that the generator output is earthed for a longer period. Frequency is about 6kHz.

Inside the unit, the cutout diode and switching device (both TO220 packages) are mounted on the chassis, the diode between the generator and battery terminals, and the switching device between the generator terminal and earth. This immediately confirmed the regulator is based on the well known 'grounding switch'. Mounted above, is the PCB with the other components, including a 16 pin IC. Remarkably, the IC, diode, and switching device were devoid of type numbers. Thankfully, that need not present a serious obstacle.



Component side of the PCB.

The Cut-out Diode.

Obviously, the diode was a dual Schottky type. I've serviced enough switchmode power supplies to have recognised it as such. Plus, logic tells that this would be the ideal type to use here. The reason being that a Schottky diode has less of a voltage drop across it than a silicon type. This means less heat dissipation for a given current, and less heatsinking is required. In fact, the body of the regulator housing is sufficient for this purpose. Typical types would include MBR30H100CT, rated at 30A and 100V.

The Switching Device.

A bipolar power transistor could have been used, but given the current it would have to switch, and the lack of heatsinking, a MOSFET was the likely candidate. As the 'on' resistance of a MOSFET is a fraction of an ohm, it means very little voltage drop, even at high current. Hence, low power dissipation. Besides, MOSFETs are easy to drive straight from regulator IC's, as this one was. A further clue was the 470R gate pull down resistor between gate and source terminals. A bipolar transistor would not need such a low value of base resistor because the base is current driven. With a MOSFET however, the gate presents as an open circuit, and the drive source needs to be low impedance to switch off the MOSFET very rapidly. A slow turn off will cause overheating due to operation over the linear part of the curve.

Indeed, a quick test confirmed it was a MOSFET. A good choice would be a type such as IRF640 or STP60NE06-16. One important specification of the MOSFET used is that the gate voltage required to turn the device on is no more than about 5V.

The Integrated Circuit.

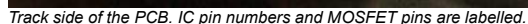
As to the IC, several options suggested themselves. But first, before getting carried away with guessing, it was necessary to trace out the circuit. As there are few external components, this was straightforward. Having done this, several clues became apparent. Two things indicated it was a switchmode regulator IC - this being gleaned from the .0047uF and 49.9K resistors - obviously the time constant of an RC oscillator. The one and only zener diode was 15V, and with a voltage that high, was clearly part of the crowbar protection. It was obvious that the voltage reference was internal to the IC; another feature of purpose designed switchmode regulator IC's. And of course, with my previous testing of the unit, the high frequency oscillation present was another confirmation.

Now, to get a block diagram of this IC to analyse operation requires knowing the exact type number. 16 pins immediately narrows it down to a few types. Then by looking at the function of the pins we can match them up. For example, the timing resistor and capacitor need to be on pins 6 and 7 respectively.

Also the output to drive the MOSFET needs to be pin 14, and/or 11. We can also see the output voltage is monitored at pin 2 via a voltage divider - obviously the input to the error amplifier.

Using the values of resistors connected to this terminal, and knowing the regulation should commence at about 7V, the reference voltage of this IC was calculated to be around 5V. This immediately eliminated several types from the list of possibilities. Pin 9 would appear to be able to shut down the IC should the 15V zener conduct.

The 3524 family of regulator IC's fits these specifications.



The MOSFET and Schottky diode have already been discussed. The IC receives supply to pin 15 via the chain of diodes D1 to D3. These are type 1N5819 Schottky diodes. Apart from reverse polarity protection, this chain of diodes, and their associated 100uF 50V capacitors, also function as a voltage multiplier. Once the battery voltage reaches about 7V and the MOSFET starts switching, there is effectively an AC component present at the generator terminal. By multiplying this, we can get sufficient voltage for the IC to perform properly. Apart from increased drive to the MOSFET, the internal voltage reference is more accurate. There is about 13V present at pin 15 once regulation commences. The charge retained in the 100uF connected to pin 15 would keep the IC powered up during 'dead time'; i.e., when the MOSFET is switched on.

The battery voltage is sensed via a voltage divider feeding pin 2; the non inverting input of the error amplifier. This is compared to the reference voltage (5V) internally generated in the IC, and made available at pin 16. Note that the input to the voltage divider is not the actual battery voltage, but the battery voltage plus the drop across the Schottky cutout diode and D1. We can work out the voltage at which regulation commences. With 5V across the 240R resistor, there will be 7V at the junction of D1 and D2. Adding 600mV onto this gives 7.6V at the generator terminal, and losing about 400mV across the cutout diode (Schottky) means about 7.2V at the battery, which is what we want. It would appear D1 and the associated 100uF decouple the voltage sensing input from commutator noise, and again provide reverse polarity protection to this part of the circuit.

One obvious way around this limitation is to use remote sensing; i.e. run a separate wire to the battery from the error sensing input, or alternatively to locate the regulator right at the battery. However, both options require wiring modifications. In practice, the scheme works well enough, and battery charge voltage is not that critical. Just make sure your wiring is in good condition so as to minimise the voltage drop when charging.

Crowbar protection for the generator (and the IC) is performed by the 15V zener. If the battery should be disconnected, the generator voltage will rise to an excessive figure. The zener conducts, and pin 9 starts to go high. This then forces the MOSFET to switch on and short the generator to earth. It may be wondered why pin 10 is not used despite being the official shutdown pin. This is because taking pin 10 high actually turns off the switching device, as would be required in the conventional kind of regulator circuit. Here, we want it to turn on the MOSFET to shut everything down. Pin 9 is the inverse of pin 10.

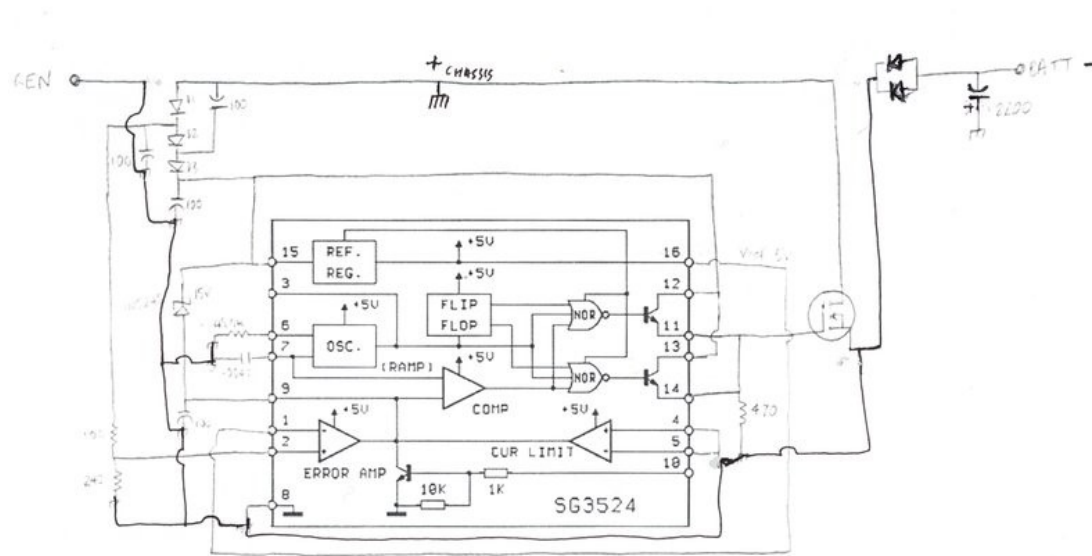
Likely Faults.

Another scenario is if the generator should be 'flashed' after this regulator has been installed. If the MOSFET should be conducting when the battery and generator terminals are bridged out, the MOSFET will be blown apart internally.

When installed correctly, neither a short circuit to earth at either the generator or battery terminal will harm the regulator.

Positive Earth Regulator.

For the Model A owners, Fun Projects also produced a positive earth version of the regulator. I have not had a 6V type to reverse engineer, but I would expect it to be as per the circuit below. In essence the circuit is flipped upside down in the electrical sense.



Theoretical circuit of the 6V positive earth regulator. This has not been confirmed in practice.

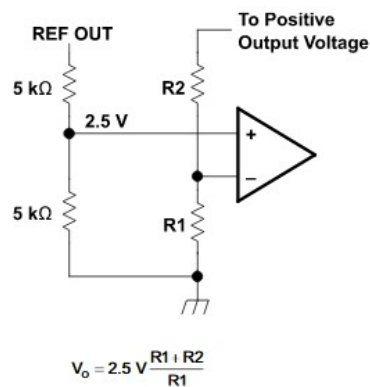
A positive earth 12V regulator has been reverse engineered, and its details appear further down.

What is the IC?

Subsequent experimentation to reconstruct the regulator on a breadboard revealed that the IC is not an SG3524. Trying an SG3524 in the actual FP voltage regulator was not successful either. The problem is largely to do with the error amplifier. The unknown IC has about 3V at pin 9 (the error amp output), whereas there is nothing with the SG3524. Aside from that, it was found that the internal oscillator operated with a level of 3V p-p at pin 7 with the unknown IC, and oscillation started when pin 15 reached 3V. The SG3524 required pin 15 to be at 5.4V for the oscillator to start, and the oscillation level was only 2V p-p. There was no gate drive to the MOSFET unless pin 9 was taken slightly high with a resistor, but there was no regulation. The crowbar circuit does work with the SG3524.

There are a few other pin compatible types such as the LM3524D and NTE1720 but these have not been tested.

Update Feb. 2019: A reader has drawn my attention to the LM3524D, in that the common mode voltage range of the error amplifier has been raised to 5.5V to eliminate the need for a resistive divider for the 5V reference. Interestingly, the Fun Projects circuit does not have the resistive divider that appears in the SG3524 application notes. The LM3524D therefore fits this description. I have not actually tried an LM3524D, since I had difficulty obtaining one at the time I did the reverse engineering. It seems the DN suffixed IC is more readily available, and this also has the appropriate characteristics.



It appears this modification is required to use the SG3524.

Update May 2019: Another reader has confirmed that the SG3524 works as a replacement, by including the resistive divider at the error amp input, and readjusting the divider at pin 2. This was for the 12V version of the regulator. See above circuit.

An Experimental Voltage Regulator.

Using the grounding switch method of control, I have developed a voltage regulator which may interest those who are unable to obtain the Fun Projects regulator. It uses easily available parts.



Homemade regulator uses comparator controlled grounding switch.

- [See the article here.](#)
- [See also the experimental TL494 based regulator here.](#)

Fun Projects Regulator for the Model A Ford (Positive Earth).

As has been mentioned, Fun Projects also made a regulator for the Model A Ford. Originally, the Model A used the same mechanical cutout as the Model T. Even though the Model A was the first Ford to use positive earth, this was of no consequence, since the mechanical cutout is not polarised.

When this is replaced with a modern diode cutout or regulator, one designed for positive earth must be used.

As is the case with Model T's, a lot of Model A owners have installed a 12V battery. Again, the third brush generator used in the Model A can charge a 12V battery, since it operates as a constant current source.

Thus, Fun Projects produced two regulators for the Model A; one for 6V positive earth, and one for 12V positive earth. The same housings are used as with the Model T versions.

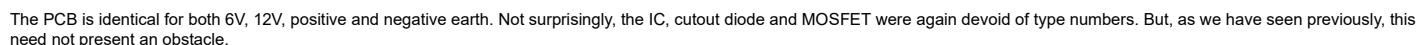
Reverse Engineering the Model A Voltage Regulator.

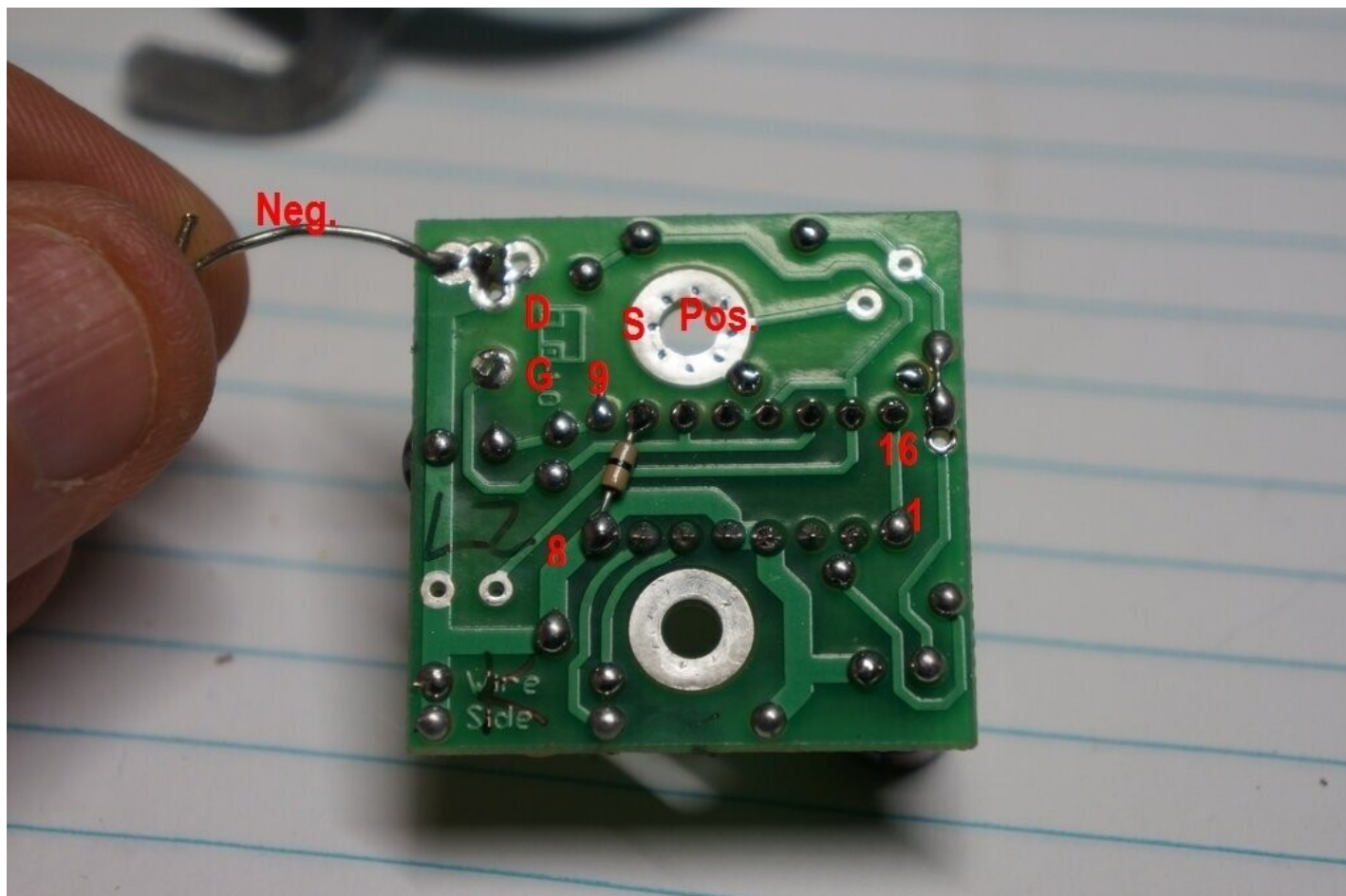
A new Model T owner contacted me regarding a cutout - it was the last thing he needed to complete his car.

As it happened, the local parts supplier just happened to have what he thought was a Model A cutout. I suggested that this be purchased, and that I could convert it to negative earth. The Model T owner mentioned he was using 12V, but being a diode cutout this would not be important. All that needed to be done was to reverse the diode.

In due course, the 'cutout' arrived. A very nice surprise was that it actually turned out to be a Fun Projects voltage regulator! So he definitely got his money's worth, and all to the better. It was the 12V positive earth version of the regulator. My job was to convert it to 12V negative earth for his Model T.

And here things became interesting, once all was revealed inside. It turned out to be exactly as I had assumed previously. The voltage multiplier used in the 6V version was absent, and the circuit was as I had assumed it would be, as shown previously. It was 'flipped upside down' in the electrical sense, but was otherwise the same as the negative earth version. Nevertheless, the circuit was traced out to confirm this.





PCB from the 12V positive earth regulator.

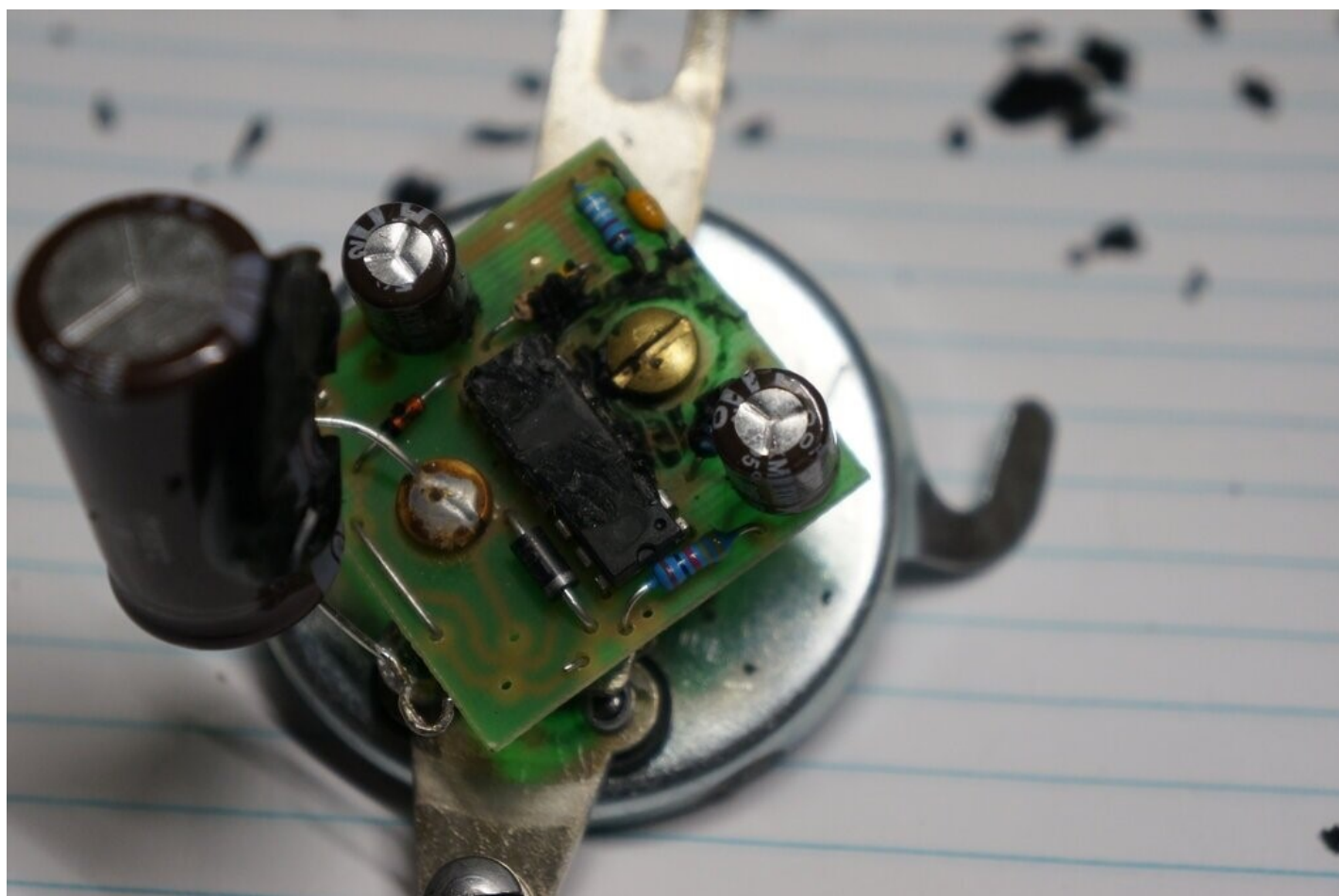
Comparing the negative and positive earth regulators, we can see all the same parts there, but rearranged. Interestingly, in this regulator, pin 10 of the IC has been earthed (note the zero ohm link between pins 8 and 10). In my 6V negative earth regulator, pin 10 is not connected. This is the shutdown pin which is not used anyway. Internally, the shutdown transistor base is already loaded with a 10k resistor. I assume this zero ohm link was just added to make sure the shutdown would not be triggered. Possibly a later improvement.



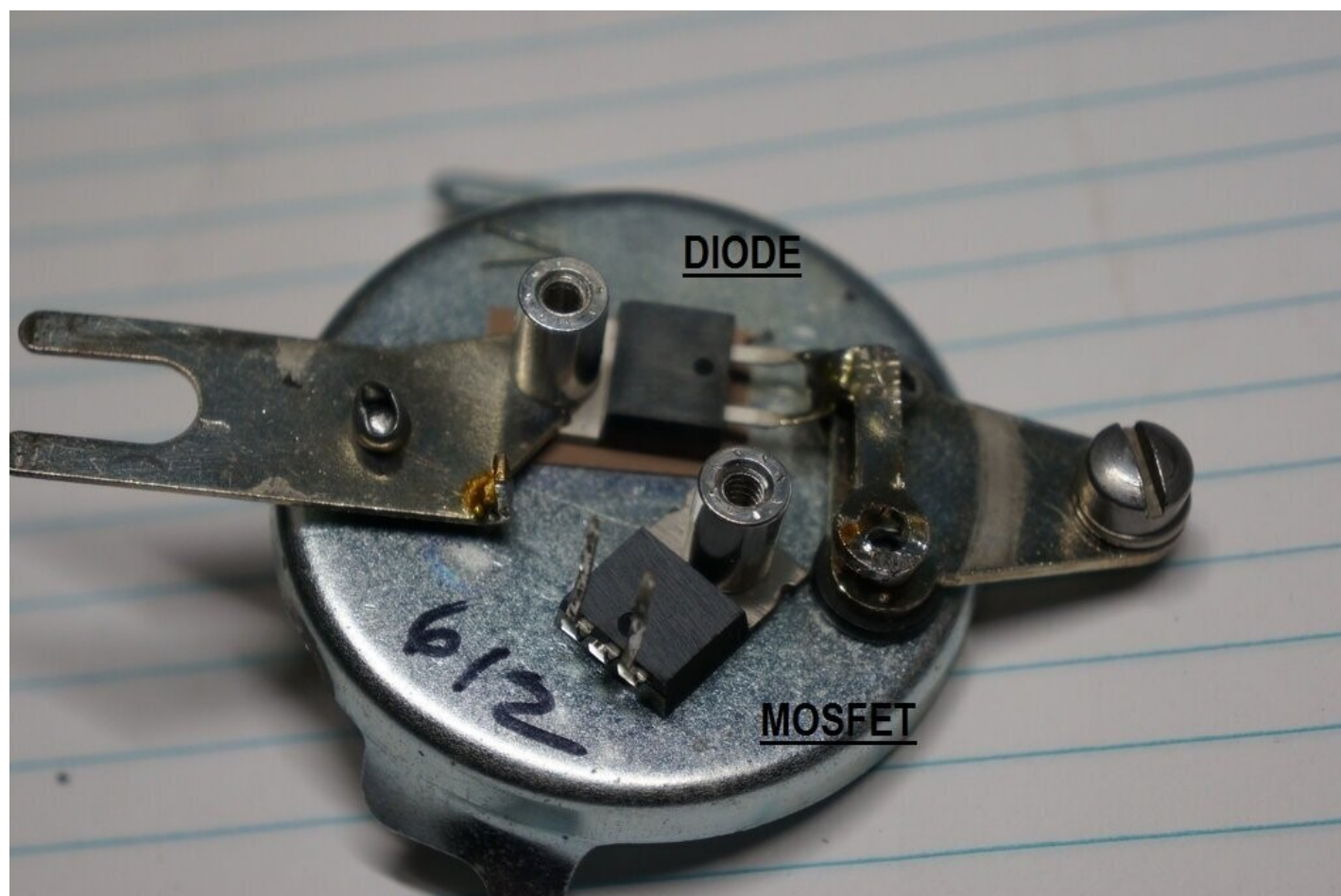
Note the PCB is rotated 180 degrees.

The 12V regulator PCB is a lot less cluttered, since two diodes and two 100uF electrolytics are no longer required. In the 6V version, these components are used as a voltage multiplier to increase the supply voltage for the IC. The IC supply comes from a single 1N5819 diode fed from the generator, and is filtered by a 100uF. The shutdown zener diode is still the same 1N5245. And, as before the RC time constant for the oscillator is the same; .0047uF and 49.9k.

Of course, being 12V, there is some variation in the feedback circuit to the error amplifier. The 240R remains the same, but the other resistor is now 440R.



Component layout for 12V positive earth version. The voltage multiplying diodes and capacitors are not used.



Looking at the chassis, the diode is reversed, as expected. However, the diode position has been swapped with the MOSFET.

Converting to Negative Earth.

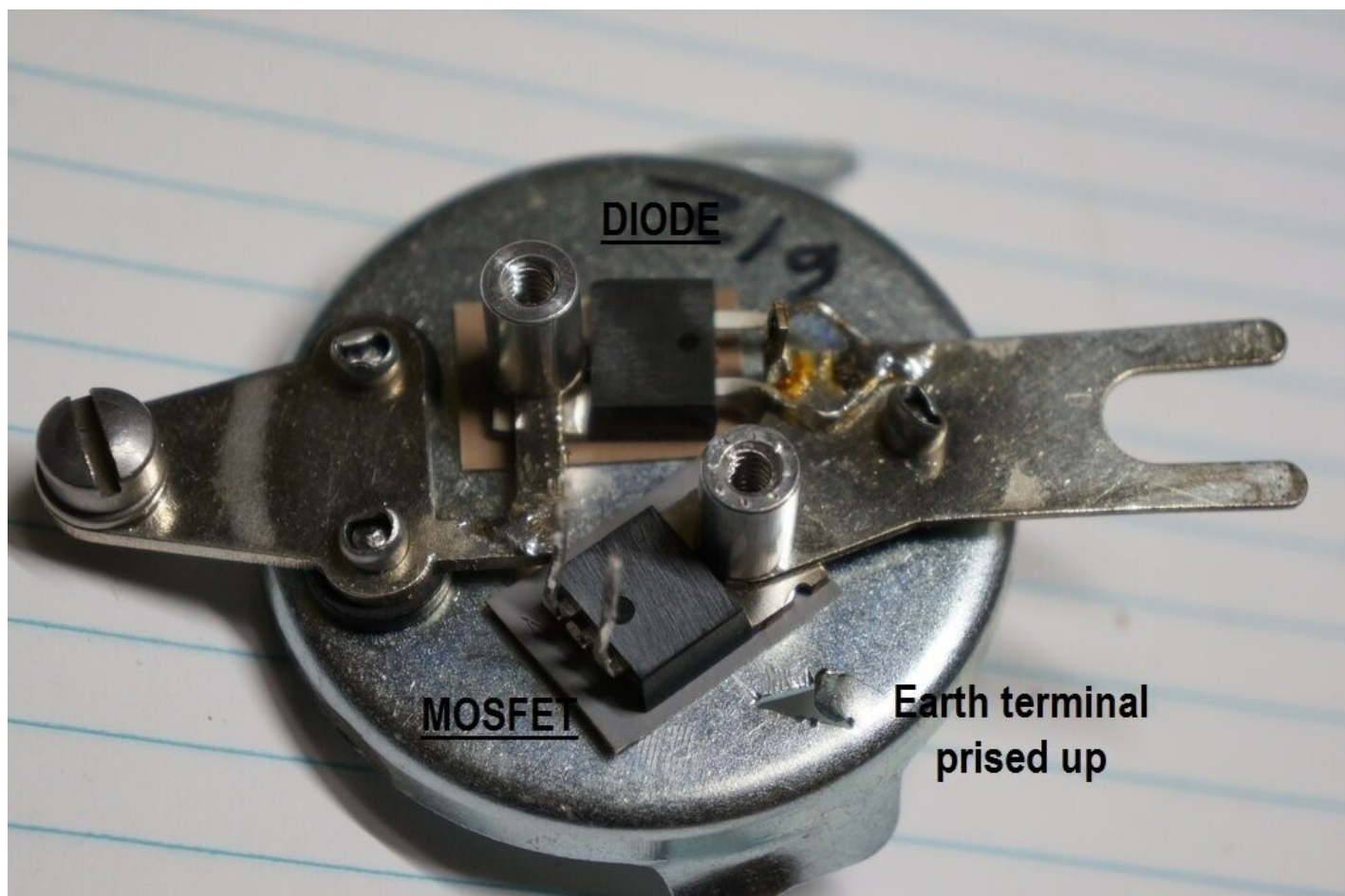
The design is actually quite ingenious in that for the positive and negative earth version, the parts used are all the same. Essentially, it is a matter of how they are physically arranged and connected.

First thing to deal with is the chassis.

The diode and MOSFET were swapped.

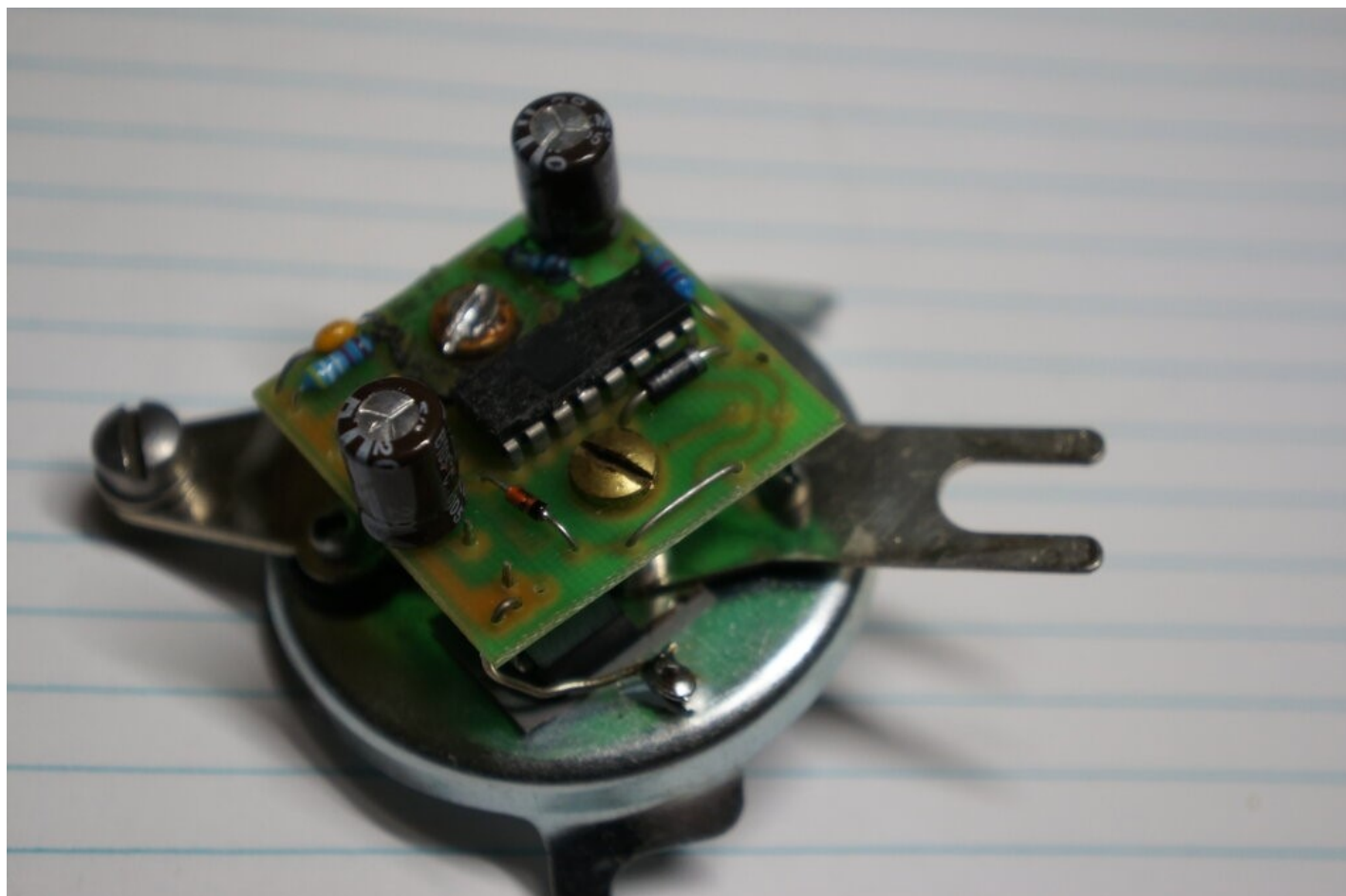
To connect the diode, the connection arm from the battery terminal, which had been bent over for the positive earth version, had to be bent back. It connects to the diode cathode (the tab of the TO220 case). The two outer anode leads were then connected to the generator terminal. At this point we had a negative earth cutout.

Next, the MOSFET had to be installed with an insulator, since the drain (the body) was now connected to the generator terminal, and not the chassis. Additionally, the screw also required an insulator.

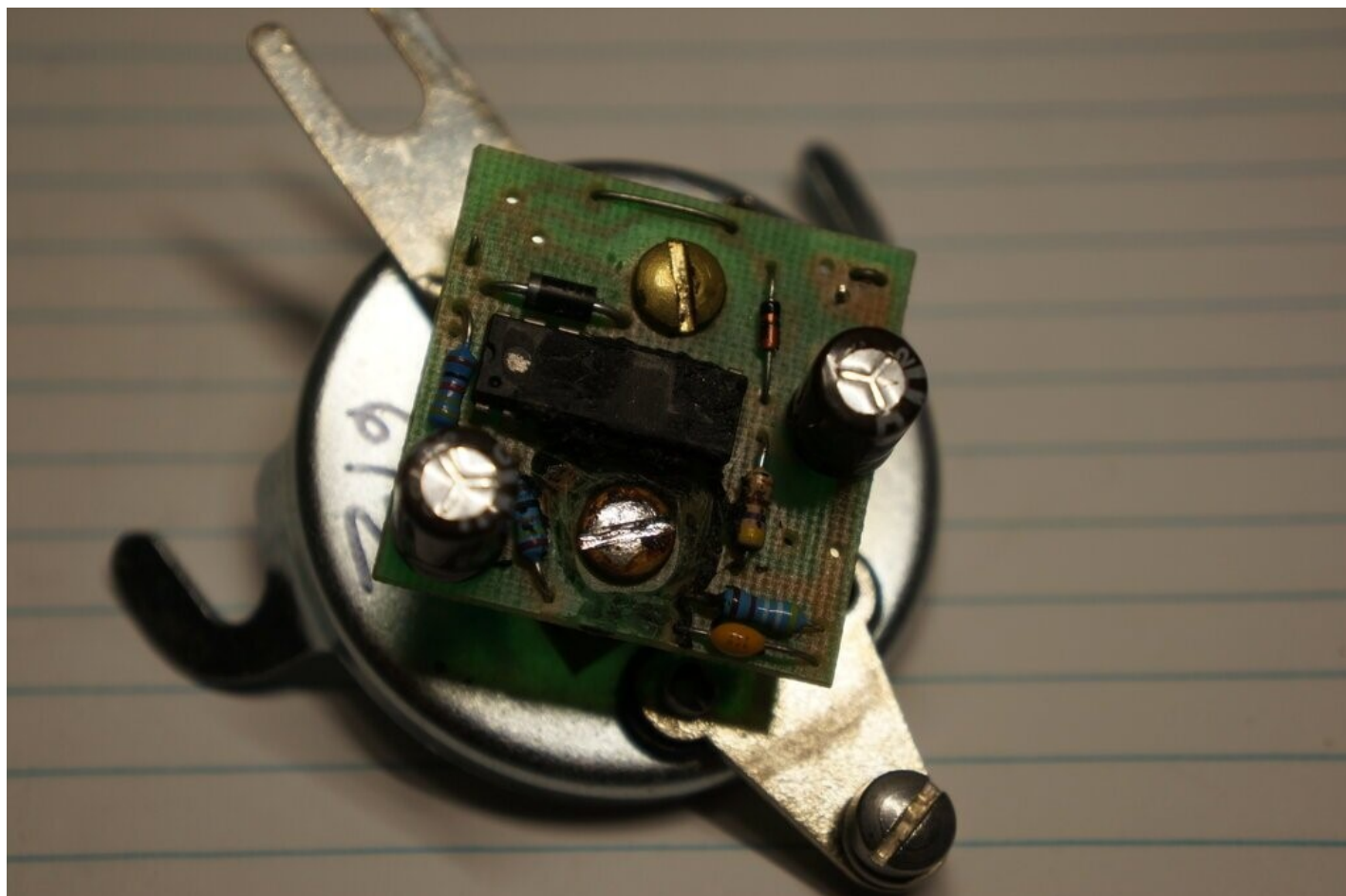


Diode and MOSFET positions swapped.

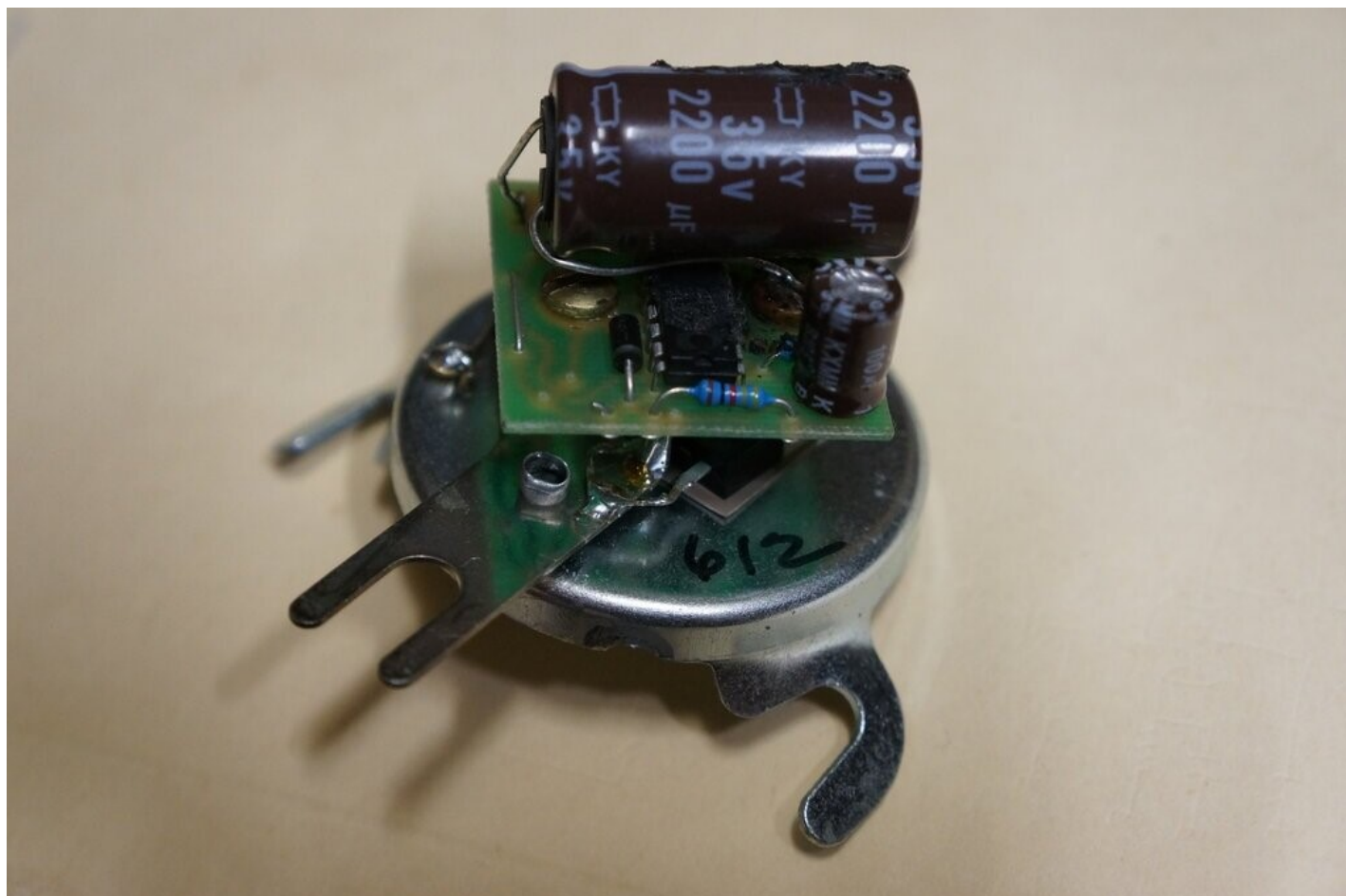
There is a "V" shaped stamping in the chassis. In the negative earth version, this is the earth terminal. Thus, it was prised up from the chassis. Since the MOSFET is now in the other position, it follows that the PCB is now mounted 180 degrees around from where it was before. Everything lines up perfectly.



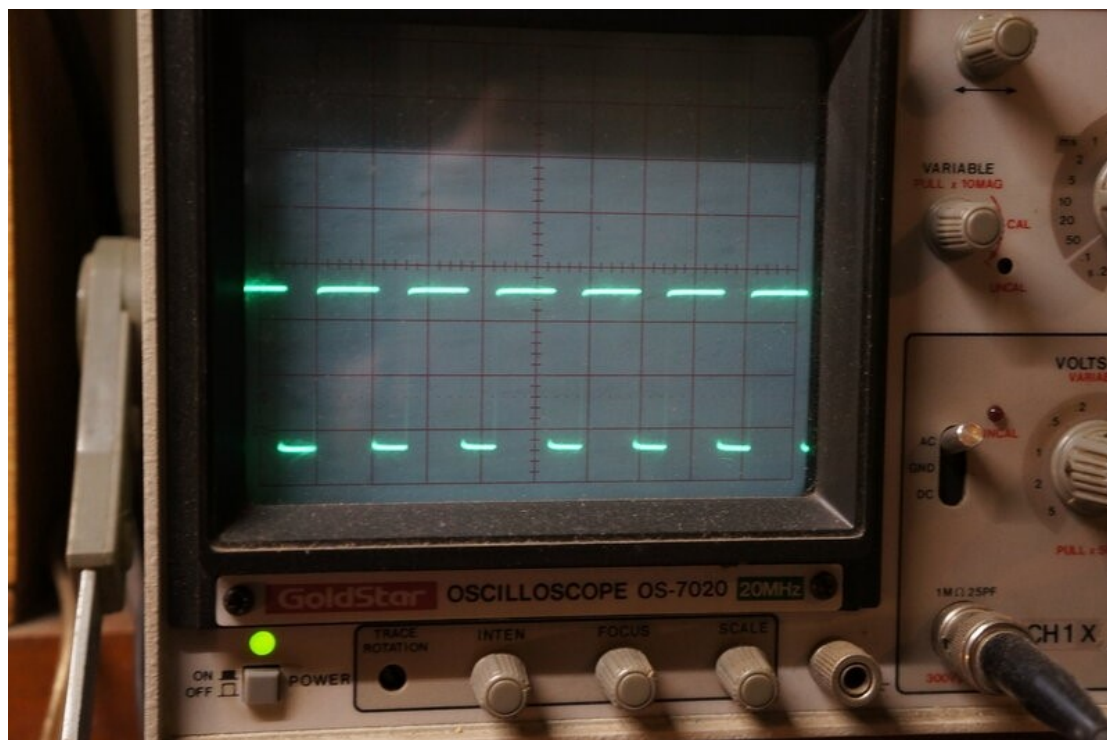
Earth terminal of PCB soldered to chassis via prised up "V" shaped terminal.



Resistor at left of IC is 440R. Under that to the right is 240R. The 470R gate load resistor is to the right of the IC, and the oscillator RC components in the bottom right corner. At the top left of the IC is the 1N5819, and to the right is the 1N5245.



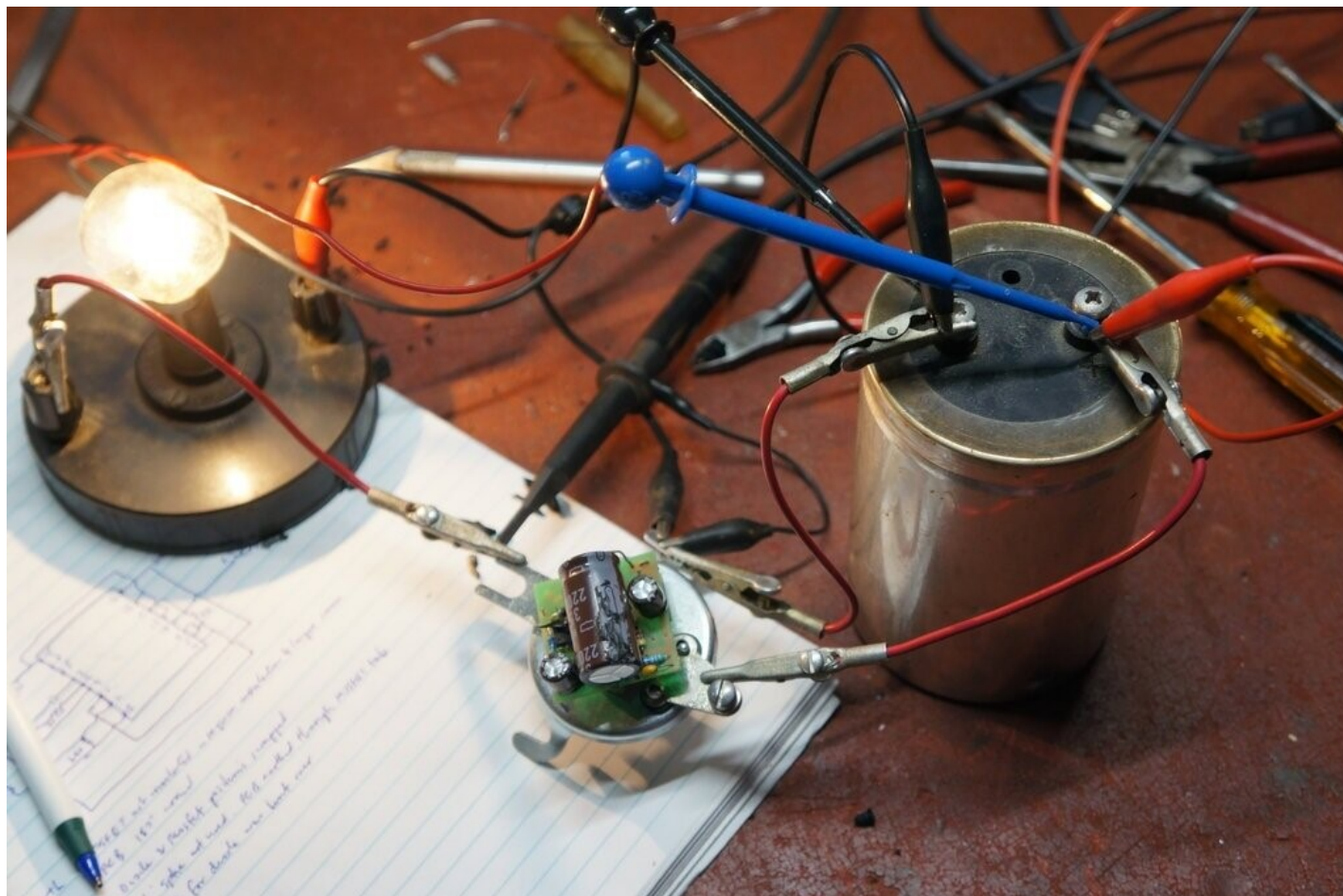
Regulator is now negative earth.



Regulation waveform at generator terminal.



13.93V charge voltage into simulated load of a 60,000uF capacitor and 12V 5W lamp.



Test setup is a 16V power supply in series with a 12V 36W lamp to simulate the generator.



2.5mm screws replace spot welds.

The final part of the job was to secure the cover. Holes were drilled and tapped to take 2.5mm screws. This will allow ease of future servicing if required.

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