

Voltage Regulator for the Model T Ford.



Final version built into cutout housing.

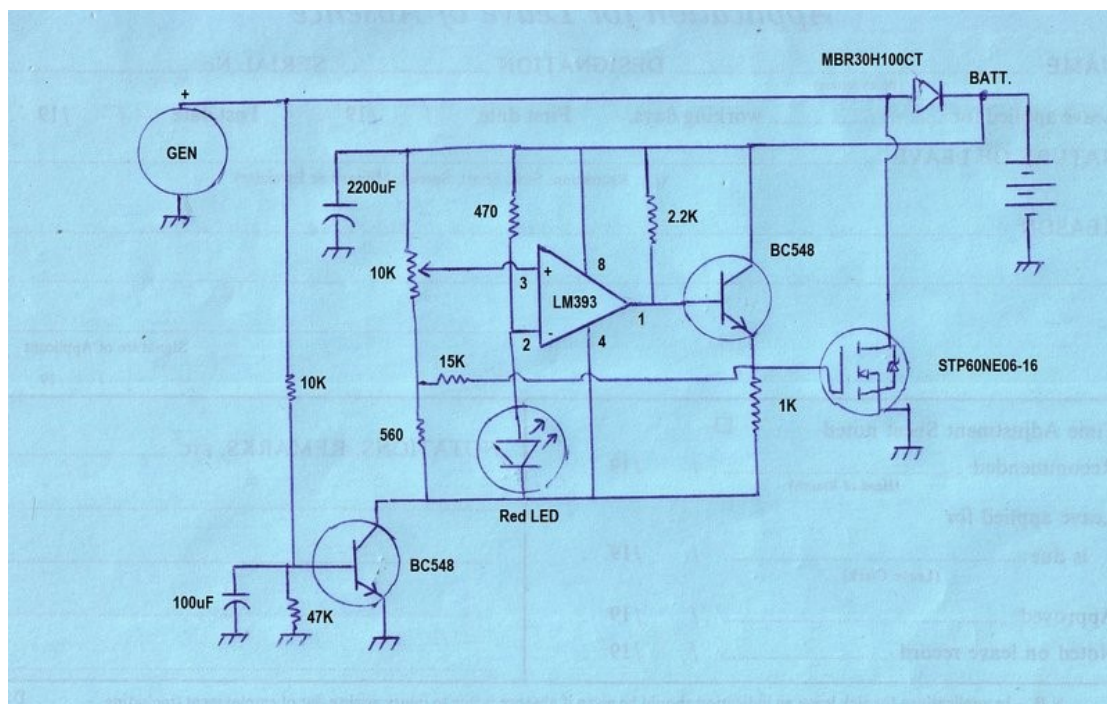
Prior to acquiring a Fun Projects voltage regulator for my Model T, I had often thought about building my own regulator. Its principles were going to use the grounding switch method, with a comparator to 'ground the generator' when the battery reached full charge.

The principles of this, and the regulation methods for the third brush generator, [have been described in this article](#).

Out of curiosity, I breadboarded a design on the bench which seemed to work well for what it was. At the time, I never proceeded any further by testing it in the car.

In recent times (end of 2021), there has been a lot of interest on the [MTFCA forum](#) about voltage regulators, since the Fun Projects regulator is in short supply. It has certainly been a popular accessory over the years, and from all reports, as well my own experience, it works very well. With some encouragement from forum members Mike Kossor (the designer of the [ECCT](#), [E-timers](#), and [I-Timers](#)), and Luke, a fellow electronics and Model T enthusiast, I decided to finish my project.

Let's Start at the Beginning:



First bench tested prototype. While it worked, it had a few problems.

Prior to examining the FP VR, I had assumed it used a comparator instead of a PWM controller. In this regard it would be like a regulator in a modern car, in that it switches off the generator when the battery reaches full charge, and then switches it back on as the voltage drops. This switching frequency and duty cycle would be dependent on the load; the off time being quite long if the battery was charged and lightly loaded. Experiments were made to see if my initial assumption was plausible, and the circuit above was constructed and tested on the bench. Like the FP VR, this circuit could also be built into the body of a mechanical cutout, and be used as a drop in replacement.

It uses the "grounding switch" method for regulation. A MOSFET was also chosen as the switching device because of the low "on" resistance (.013R) meaning that little heatsinking is required, and the high resistance gate is easy to drive. A Schottky diode was chosen for the cut out also due to the low voltage drop, and thus minimal heat generated.

The heart of the circuit is an LM393 comparator. The non-inverting input is held at a constant 2V by a red LED which is powered from a 470R resistor from the battery. Also across the battery is an adjustable voltage divider, comprising of a 10K pot and 560R resistor. When the voltage at the pot wiper (inverting input) exceeds 2V, the output at pin 1 goes high. The output drives the MOSFET gate high which then shorts out the generator. It can be seen that if the voltage divider is set so that pin 1 goes high when the battery reaches 7V, the battery will never be over charged.

Pin 1 is connected to the battery supply via a 2.2k resistor because the LM393 has an open collector output. Because of this, an emitter follower using a BC548 is used to drive the MOSFET gate. This is because the MOSFET must have a gate pull-down resistor to ensure it switches off completely when the LM393 output is low. If it wasn't for the emitter follower, gate voltage would be reduced because of the voltage division that would occur, and the MOSFET might not switch fully on. If this happens, it will overheat because of operating in its linear mode.

The switching would be unstable if not for one other component, the 15k resistor. This introduces hysteresis so that the turn off voltage is slightly less than the turn on voltage. When the output of the comparator goes high, the positive input of the comparator is raised slightly by means of the extra current flowing through the 560R. This means the turn off voltage must be made somewhat less than 7V (e.g. 6.5V). This provides a definite and clean switching point. Without it, the circuit oscillates at a high frequency around the comparator triggering point.

At this point the circuit is quite practical, but as the voltage divider, LED, and LM393 draw current, there would always be a drain on the battery. Unlike the FP design, the regulator circuitry here operates from the car battery; not from the generator directly. If the car was used every few days this would not be a problem, but we cannot count on this. This problem is eliminated with a second BC548. It will be seen that the earth return of the regulating circuitry is via this transistor.

When the generator is rotating, the BC548 is biased on by the 10k base resistor connected to the generator output, and thus the earth circuit is completed. When the generator is stopped, the BC548 appears as an open circuit, and there is no drain from the battery.

The 47k base resistor ensures the transistor is really off when it should be, although it is true the return path through the 10k, and the low resistance of the generator would do the same thing. The 100uF filters out generator noise that might interfere with the BC548 switching.

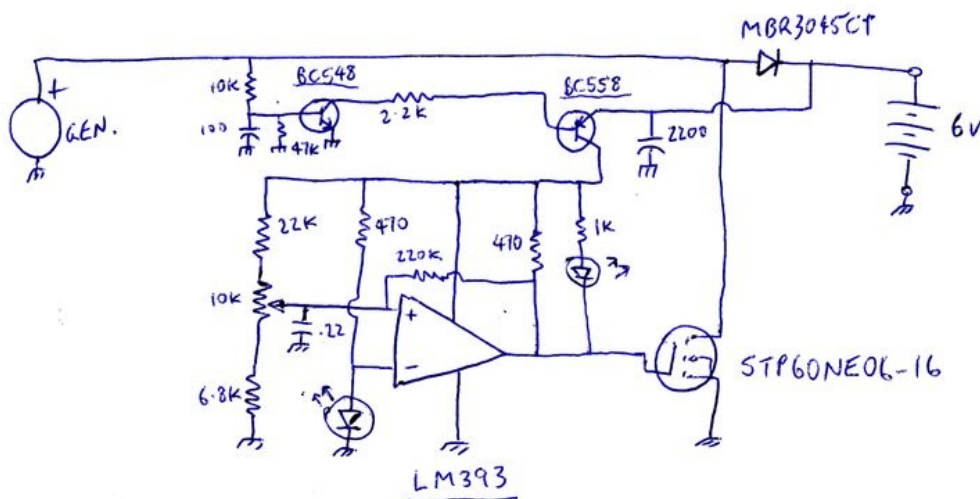
The circuit was bench tested and provided excellent results. With a 12V 5W lamp instead of the 6V battery, the circuit switched at about 100Hz. In this situation, the 2200uF simulated the battery time constant. No doubt with a proper battery the switching would be slower. The generator was simulated by a 10A variable power supply, fed into the regulator via a 12V 36W bulb for current limiting, which was in series with the secondary winding of a 14V transformer, to simulate generator inductance. Over voltage protection is inherent in this design, so that nothing is damaged if the battery is disconnected with the generator running. Output remained at 6.8V with the load disconnected, and the input increased to 16V.

Thoughts were to simplify the circuit further, by removing the BC548 emitter follower, connecting the MOSFET gate directly to pin 1 of the LM393. The open collector output of the LM393 would take the MOSFET gate to earth when it needs to be switched off, and in so doing, the 1k gate resistor can be removed. The 2.2k load resistor is probably low enough to overcome the gate capacitance, and allow a rapid switch on for the MOSFET. If possible, the 2.2k should be reduced in value to allow a faster switch on. The lowest suitable value would depend on the current rating of the LM393, which appears to be 20mA. On this basis, the resistor could be as low as 350R with a 7V supply. 470R would be a good

Another point to consider if the emitter follower is not used, is the loading of the 15k hysteresis resistor. This is going to prevent pin1 of the LM393 rising to the full supply because of the voltage divider action between the 560R + 15k and the pin 1 load resistor. If we assume a supply voltage of 6V and a 470R load resistor, the gate voltage will be 5.8V, which is acceptable.

Second Prototype (December 2021).

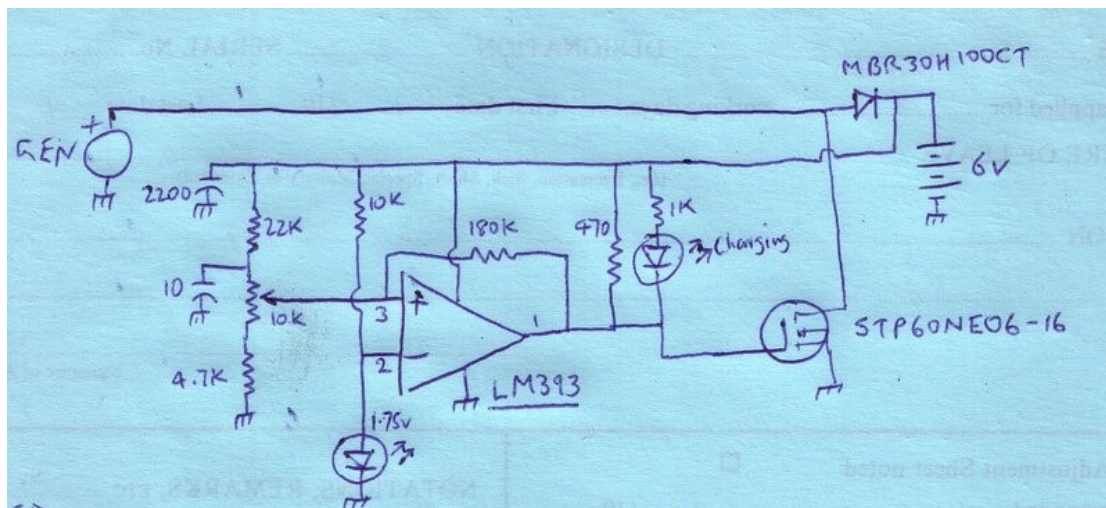
My original circuit was modified as shown. For development, I simulated the generator with a 12V 10A power supply in series with two 12V 36W light bulbs in parallel.



Finally, the hysteresis circuit has been simplified with just a 220k resistor between the LM393 output and the positive input.

- See this regulator being demonstrated on the bench <https://youtu.be/IO1u9mmLutk>

The above circuit had a problem in that the BC548-BC558 battery disconnect switch was not perfect. The supply rail for the LM393 fluctuated as the circuit switched, which affected the triggering point.



Third circuit worked well except for a high standby current. "Charging" designation on the LED should read "Charged".

So why not get rid of the battery switch altogether? Two things occurred to me; 1). The current through the 22k, 10k, and 4.7k was only 150uA. 2). A high brightness LED will work at less than 1mA, so why not use that as a voltage reference? And so the circuit was modified. The high brightness LED made a good 1.75V voltage reference, drawing about 450uA. With such a low current consumption, the circuit could be left across the battery all the time. The circuit would be drawing less than the self discharge current of the battery itself.

Regulation was good and the circuit looked promising. Alas, when the generator was disconnected, the current did not decrease as expected. It actually went up! This seemed illogical, until I thought about the operation of the circuit. With the battery not fully charged and the generator stopped, the MOSFET was switched off, as it should be. However, in order for this to happen, pin 1 of the LM393 has to go low. This in turn means there is a current of about 12mA flowing through the 470R resistor (slightly more with the "Charged" LED in circuit).

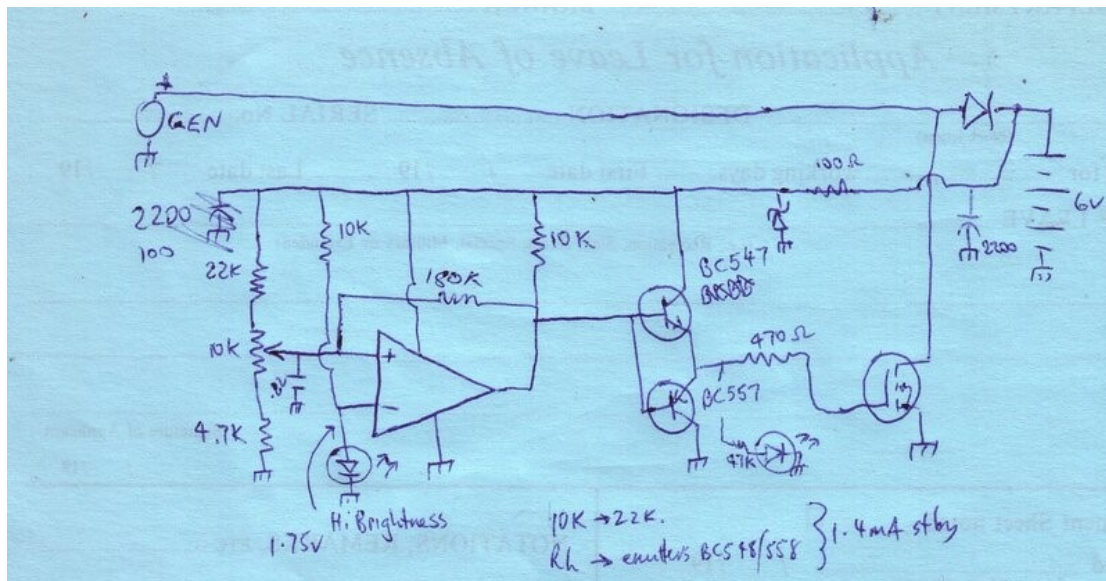
I thought about ways around this, using both sections of the comparator, one as an inverter - but always came back to the same problem: Battery at rest means the MOSFET has to be switched off, in readiness for when the generator next comes into operation - which in turn means the gate has to be earthed.

Increasing the pull up resistor at pin 1 to reduce the current draw would fix this, but it would be undesirable due to the MOSFET gate capacitance. There is a risk the MOSFET would operate in the linear mode at the switching on point. With the amount of current being switched this could cause undesirable overheating.

- See this circuit being demonstrated here <https://www.youtube.com/watch?v=pvCaxiRmzKM>

Fourth Circuit.

One way around this problem to provide a low impedance drive to the MOSFET, and to have a high value pull up resistor, is to use an emitter follower.



Circuit has a 1.4mA standby current.

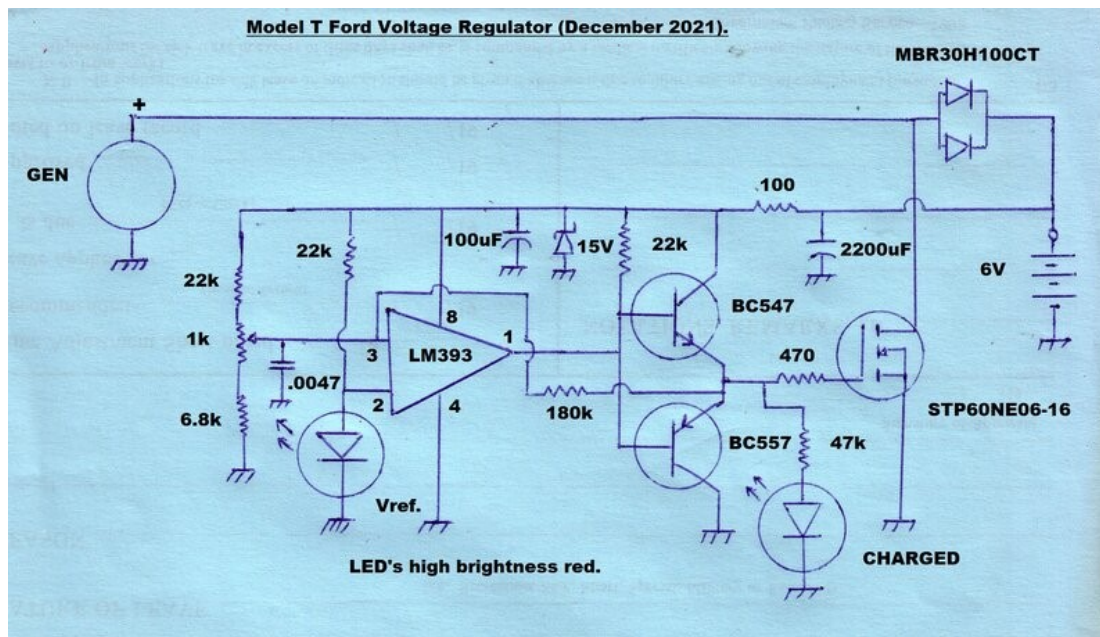
A complementary-symmetry emitter follower circuit drives the MOSFET gate. With a 10k pull up resistor, the standby current was reduced to 1.4mA which is very acceptable. Some high frequency oscillation was visible at the switching point, and this was largely removed by the 470R gate resistor - standard practice for this kind of circuit. In simple terms, the 470R in conjunction with the gate capacitance works as a low pass filter. The "Charged" LED was changed to a high brightness type, which in turn allowed its series resistor to be increased substantially, to 47k.

This was important, because the lower the output current of the emitter followers, the lower their base current can be, which in turn allows a higher pull up resistor - now 10k.

To give an idea of how the hysteresis resistor affects operation, with 180k, the switching occurred at 6.77V and 7.19V. Increased to 220k, the switching points were 6.86V and 7.14V. It can be seen that the higher the resistor, the narrower the voltage range, and thus the faster the switching frequency. Lowering the resistor lowers the switching frequency, but also means the battery voltage drops further before charging recommences.

Final Circuit.

A few minor improvements resulted in the final circuit which went into the car for real world testing.



Final circuit has further reduced standby current and supply filtering.

In the previous circuit, it can be seen that the base voltage of the BC547/BC557 pair won't get to the full supply voltage, because of the voltage divider action of the 10k being loaded down by the 180k hysteresis resistor. The answer to this is to simply drive the 180k from the output of the emitter follower. Furthermore, this allowed the pull up resistor to be increased to 22k. Now the standby current was a very acceptable 1.2mA. The high brightness LED seems to work well as a voltage reference. With a range of battery voltage from 6.82 to 7.2V, the LED Vref is 1.747 to 1.741 which is a change of only 6mV.

In view of restricted space in the final unit, the capacitor at pin 3 was reduced to .0047uF without any ill effect.

The preset pot was changed to 1k to make adjustment less sensitive. Having said that, it's possible that given the spread of LED characteristics, one of the resistors either side of the pot might need to be changed for other individual constructions of this circuit.

A final modification was the inclusion of a 15V zener diode to protect against spikes from the ignition system, or external battery chargers that might be connected. In addition, a 100R provides current limiting for the zener, and noise filtering in conjunction with the 100uF.

By default, the zener also provides reverse polarity protection for the IC and transistors, should the battery be connected in reverse.

- See this circuit demonstrated here <https://www.youtube.com/watch?v=H1PyqnpTBdU>

Over Voltage Protection.

A danger for the 3rd brush generator is that if it is run into no load, such as with the battery disconnected, its output voltage will rise to a possibly harmful level, which then puts excessive current through the field coils. For this reason, the Ford manual shows the generator terminal earthed if the car must be run without the battery.

Open Circuits

1107 An "open" in the charging circuit is a condition to be guarded against, as running the car for any length of time with the charging

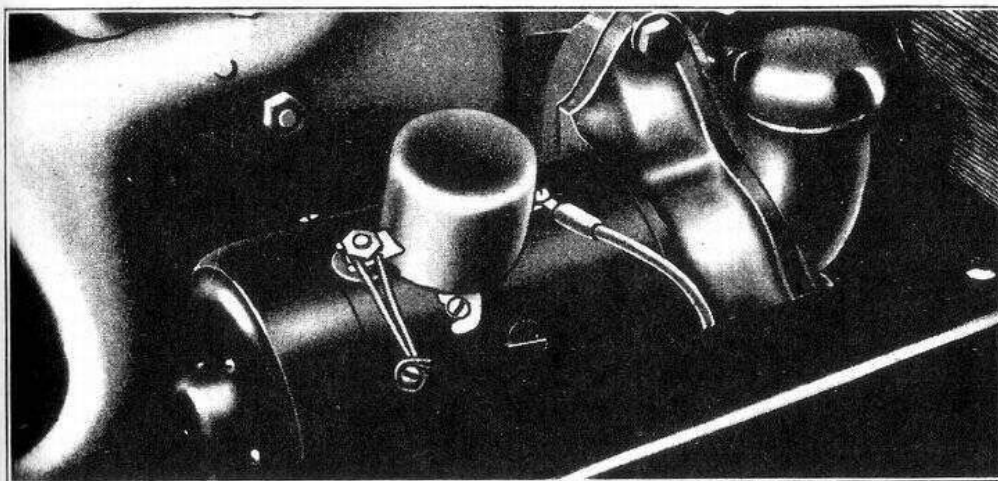


Fig. 520

circuit open will result in a burned out generator. While the engine is running at a fair rate of speed an open is indicated by the ammeter showing no charge and a decided hum in the generator. When this condition occurs the trouble should be located and corrected immediately. If it is necessary to run the engine while the charging circuit is open, the generator should be grounded. This can be done by running a piece of wire from the generator terminal to one of the brush end bracket screws, (See Fig. 520).

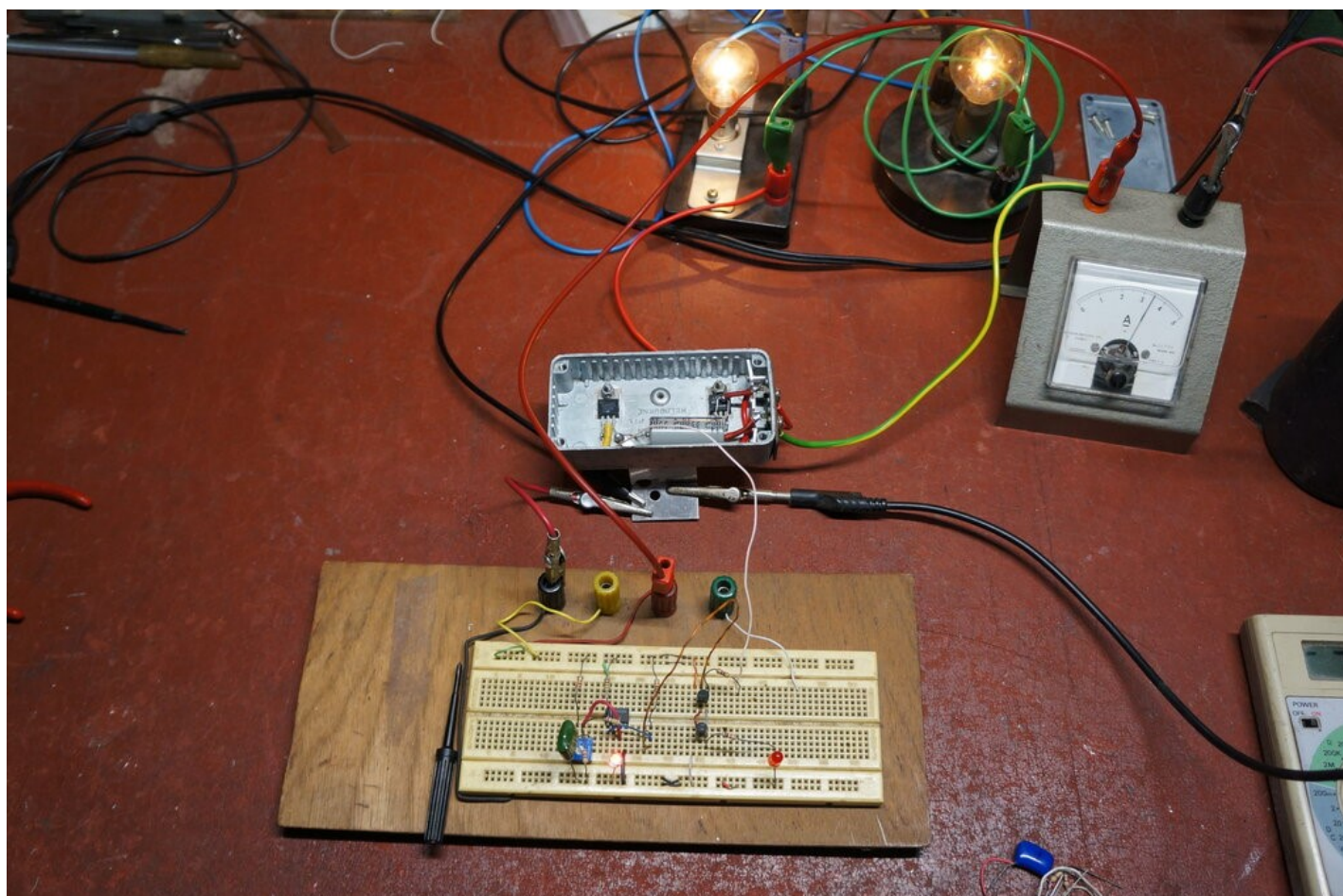
The regulator circuit provides inherent protection for the generator, should the battery become disconnected with the engine running. The regulator immediately senses the terminal voltage as being above 7.2V, and shorts out the generator. Due to the time constant formed by the 100R and 100uF, the circuit begins to oscillate at about 29Hz. This is because the supply to the regulator is lost when the MOSFET conducts. The duty cycle of the MOSFET conduction is so high that no harmful voltage is developed.

Construction of the Prototype.

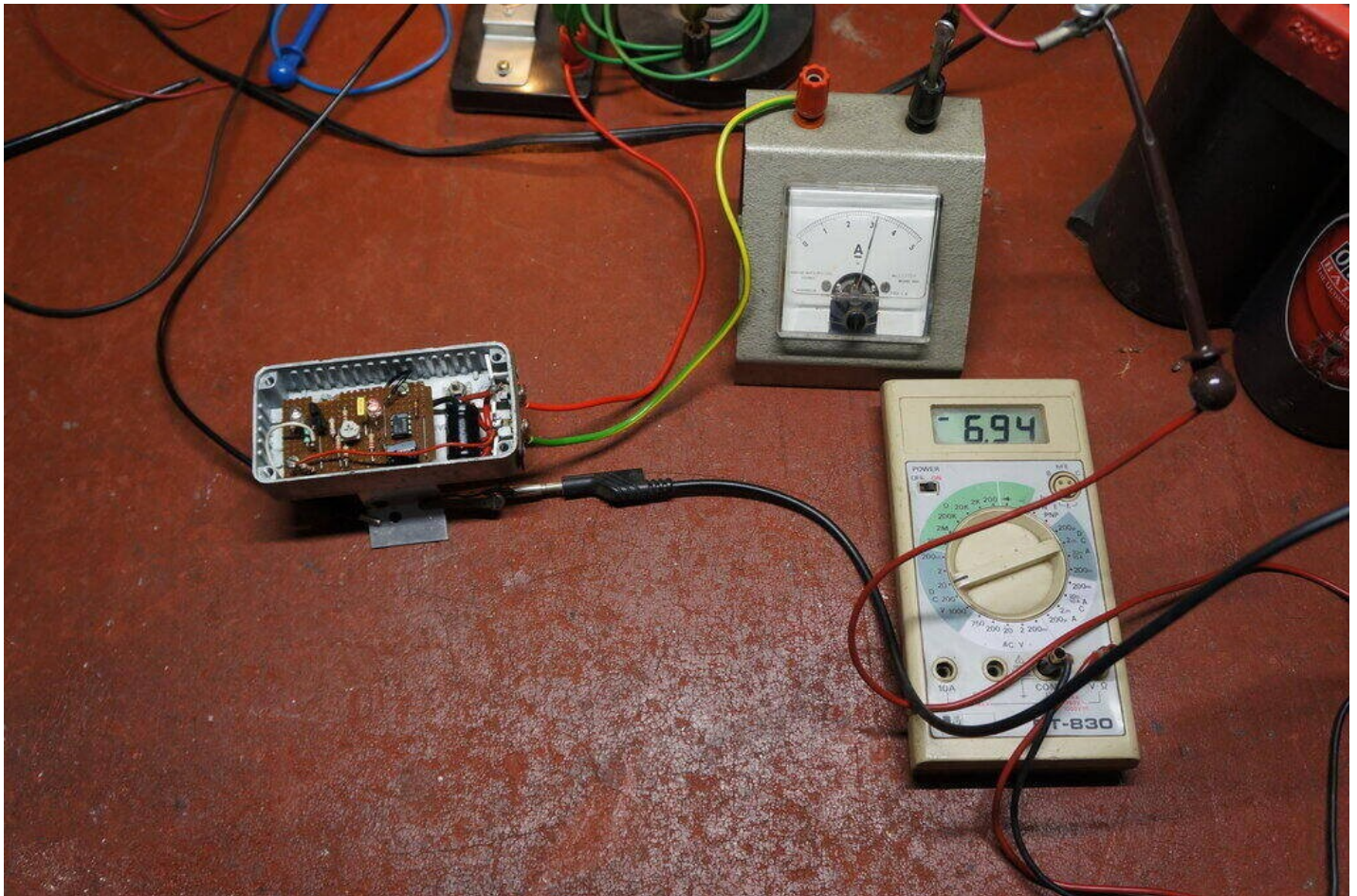
At this stage of the design, I wasn't ready to make a PCB, and nor did I have an empty cutout housing for the regulator. Instead, the circuit was built on a piece of Veroboard mounted inside a diecast alloy box. This in turn was riveted to an aluminium bracket which was screwed to the generator.



How the regulator mounts to the generator in place of the original cutout. MOSFET and cutout diode have been screwed to the box for heatsinking.



MOSFET and cutout diode mounted in diecast box. Circuit in its final form before assembling on Veroboard.



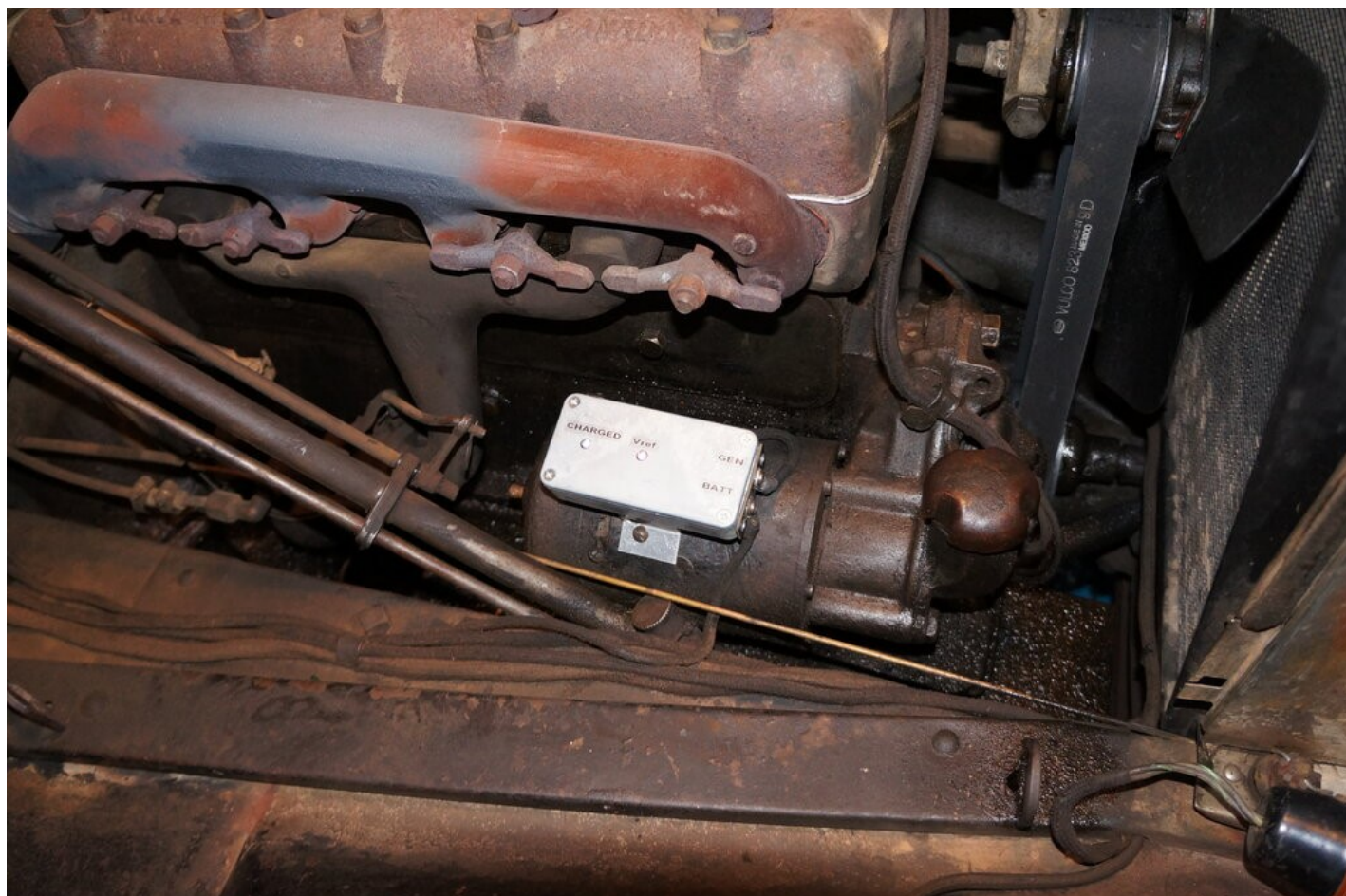
Final bench test before installation in the Model T.

The Big Test!

The regulator was mounted in the car, and connected up. The Vref LED lit up as it should. The engine was started, and it was a total anti-climax; the circuit started regulating within a few seconds as the battery voltage came up. Switching was very clean and not affected by the ignition system. Operating the headlights increased the switching frequency as expected. Similarly, with no load except for the ignition, the frequency was much slower. The trimpot needed a small tweak; the voltage now being 6.6 to 7V.

I found that a Fluke 8000A digital meter was affected by the ignition, so reverted to an AVO 8. This was no surprise - some DMM's work on Model T's; others don't.

The rest of the story is best told by watching the demonstration video.



- See the regulator working on the car here <https://www.youtube.com/watch?v=gg1xN2KBOtg&t=1s>
- See the ammeter in operation whilst driving here <https://www.youtube.com/watch?v=leY3cy69zpQ>
- Temperature test here <https://www.youtube.com/watch?v=J3RJO5nUA&t=2s>

As to future developments, provided I can get an empty cutout housing, I may make a PCB for the circuit. As far as the project with the MTFCA guys is concerned, that will continue working towards a design that suits the average Model T owner, and will allow for other voltages. Importantly, the design will need to fit into a cutout housing. I will continue to use my prototype and see if any limitations become evident.

Battery Charging Fallacies.

Once a battery has reached full charge, it is undesirable to keep pumping current into it. Many non-electrically minded Model T owners are uncomfortable unless their ammeter is always showing a charge.

Many also operate with an unnecessarily high charging rate; 10A or more - worried that they might get caught with a flat battery if it's any less. Indeed, the Ford manual does suggest 10-12A for the charge current, so it's easy to see where this apprehension might come from. When Model T's were used as every day cars, there might be some justification for this, with frequent starter motor and headlight use.

So what happens after continuing to drive once the battery has reached full charge? The battery temperature increases, the terminal voltage rises, and electrolyte begins to be lost as hydrogen gas is produced. And, the generator continues to run at its full charge current, unnecessarily wearing the commutator, brushes, and bearings. In summary, the battery and generator life is reduced. At particular risk are modern sealed batteries - these can only absorb so much hydrogen gas before damage occurs. It is well to note that the Ford Instruction Book says to add water to the battery every two weeks!

Of course, a voltage regulator is an improvement, because charging rate is reduced as the battery comes up to charge, stopping altogether once full. Using a voltage regulator also allows a 10A charge current to be used without harm, if this is desired. It is quite safe to charge a battery at this, or higher currents, **provided** the charge is terminated when the battery is full.

In actual fact, the charge current does not have to be so high. Let's put this into perspective: The battery has a capacity of around 100Ah for a typical wet lead acid 6 volt 13 plate battery, or in the case of a Red Top Optima AGM battery, 50Ah. Considering that the Ford ignition system would draw probably no more than 1A (while the average current per coil is around 1.3A, the coils are not continuously operating because of the dead space between the timer contacts), it can be seen that the ignition can be run for a considerable amount of time on one charge. Those with a working magneto don't even need to worry about this scenario!

If the original, non regulated cutout-only, charging system is to be retained, the charge current can be reduced to the point where it won't be too harmful, once the battery is fully charged. Around 5A is a practical compromise. In driving my Model T for 19 years with a 5A charge rate, I have **never** had a flat battery, despite occasionally using a car fridge (8A), sometimes driving for two hours at night with incandescent headlights (10A), and using a valve radio (5A) for the entire trip. For some of that time, the charge current is much less than the load current, but that's the whole point of having a battery - it contains a lot of reserve power to be used in such situations. For example, if the charge rate is 5A, and the headlights draw 10A, then in fact only 5A is being taken from the battery. Most Model T owners don't even drive their cars at night anyway. While the starter motor might draw 150A, remember this is only for a few seconds, so in actual fact the overall power consumption is very low. A rough calculation reveals that for a five second use of the starter, a little over 200mAh is consumed.

A charge rate of 5A also has the advantage that if the generator becomes unloaded due to a wiring fault, it is very much less likely to cause

damage to the windings - I know this from driving quite some distance with a faulty mechanical cutout several times.

With the comparator type regulator, the battery charge is terminated once the battery voltage reaches 7V (or whatever the full charge voltage is set to). That's it; no need to put more current into it. Only when the battery voltage falls to a certain point, either by self discharge, or by a load connected to it, will charging recommence. By that notion, it can be seen that switching frequency depends on the current being drawn. With no load on the battery, the charging might occur for 10 seconds, and then switch off for 40 seconds. With a load being drawn which is higher than the charge current, the charging will be continuous, and not switch off unless the battery comes up to full charge, by reducing the load. The whole point of this digression is to illustrate that once a voltage regulator is fitted, the ammeter will at times show zero charge current. This is nothing to worry about, and merely indicates that the battery is fully charged and the regulator is working.

Constructional Points.

For anyone wishing to duplicate the regulator circuit, there is some choice regarding components.

- The MOSFET can be one of many types. In particular, the gate turn on voltage must be no more than 5V. Many MOSFET's are designed for logic level control, and are well suited. The "on" resistance should be as low as possible; less than .02 ohms is a starting point. Drain current ratings are by default quite high; the one I used has a 60A rating. Type IRF3205 has been bench tested and appears suitable. Type STP60NE06-16 is being used in the prototype.
- The cutout diode also has many choices; something with at least 30A current rating. It should be a Schottky type. (You can use an ordinary silicon diode, e.g. from an alternator, but it will need extra heatsinking because of its higher voltage drop). The kind of thing that is used in computer power supplies for the low voltage rectifiers is ideal. These usually consist of two diodes in the one package, which can be paralleled. For a 6 volt electrical system, the voltage rating of any such diode will be adequate.
- The two transistors are common types in the UK/Europe, and Australasia. In the U.S., these Philips types are not well known, but any similar small signal transistors can be used here.
- The LED's must be high brightness types, if you want the diagnostic features. An ordinary red LED will work for the voltage reference. If you can clearly see the LED operate with reasonable brightness, when powered from a 9V battery via a 100k resistor, it's the right kind. Normal LED's will give a barely visible glow. High brightness LED's are typically identified by a clear body and a narrow viewing angle (e.g. 15 degrees). They also output 1000mcd or more.
- The 'Charged' LED is optional. It is purely for diagnostics and makes setting the voltage easier. I do not recommend using a normal LED here, by means of reducing the 22k, since the extra loading will cause more of a drop in the 100R filter resistor, which may affect the switching voltage.
- Undoubtedly, the LM393 could be replaced by other comparators, but no work has been done on testing substitutes. Be prepared to experiment otherwise.
- It is possible, given the spread in LED characteristics, that the 22k in series with the trimpot might need to be altered, if the voltage cannot be set. If this happens, measure and record the voltage reference LED voltage with the circuit powered up. With the trimpot at its centre setting, measure the voltage at its wiper. Increase or reduce the value of the 22k resistor, such that the trimpot wiper voltage is as close to the reference voltage as possible. Alternatively, use a multiturn 10k pot for a wider adjustment.
- All resistors can be 1/4W. Capacitors need not be any more than 16V, although in view of unregulated battery chargers that might be connected, a 25V rating for the 2200uF would be more appropriate.
- The 15V zener can be 400mW or 1W. Since it is for protection only and not regulation, its voltage is not critical. As long as it is a few volts above the fully charged battery voltage, and less than about 25V, it will do.
- The astute reader may notice that the BC557 transistor could actually be replaced by a diode, since the LM393 has an open collector output. I have not actually tried it in this particular circuit, but if you wish to experiment, connect a 1N914 as per the base and emitter connections, ignoring the collector. I bring this up merely as an observation. It's not as if a small signal transistor is much more expensive than a diode, and one extra connection isn't really a big deal.

Setting the Voltage.

An approximate setting of the voltage can be done on the bench, but a more accurate result will be obtained in car. This is because of the wiring resistance between the regulator and battery, and the resultant voltage drop across it due to the charge current. The setting should be done with an accurate analog meter connected directly to the battery terminals (I used an AVO 8), or with a DMM that is not affected by the Model T's electrical system. For the pedantic constructor, remote sensing can be used. That is, to run a separate wire from the 2200uF right to the battery terminal. The regulator will then be unaffected by wiring resistance. However, doing this will remove the over voltage protection if there should be an open circuit in the wiring between the cutout diode and the battery (e.g. at the terminal block or ammeter).

Voltage Drop.

It may be seen that the switching voltages are slightly different when the engine is running at idle, compared to at high revs. The reason for this is the wiring resistance between the regulator and battery. At low revs, charging current is low. Voltage drop across the wiring to the battery will therefore be low. When charge current increases with engine revs, the wiring resistance has more effect. Let's assume a wiring resistance of .04 ohms. If the charge current is 5A, then 200mV will be dropped across the wiring. Now, because the voltage is sensed at the regulator and not actually at the battery, we can see how this affects the switching voltage. If we've set the regulator at idle speed for 7.2V, at high revs the regulator will see 7.2V when the battery is actually at 7V. Luckily for a lead acid battery, the charge voltage is not *that* critical. My recommendation is to set the charging voltage at high revs, since this is when most of the charging time occurs. It goes without saying that the wiring should be in good order with clean connections, etc. In my instance, I have set the regulator for 7V at the battery, at high revs. Finally, it should be pointed out that the Fun Projects regulator suffers from the same limitation. This is difficult to avoid unless remote sensing is used.

Note that the regulator described is a voltage regulator only. The current regulation is still dependent on the 3rd brush setting. This should have

already been set to an appropriate current with the previous cutout, before connecting the regulator. Nevertheless, there is no reason the current cannot be adjusted with the regulator in circuit. It will be necessary to wait for the MOSFET "off" times (i.e. 'Charged' LED off) before adjusting the 3rd brush. To extend the off times while making this adjustment, turn on the headlights and other loads.

Other Voltages.

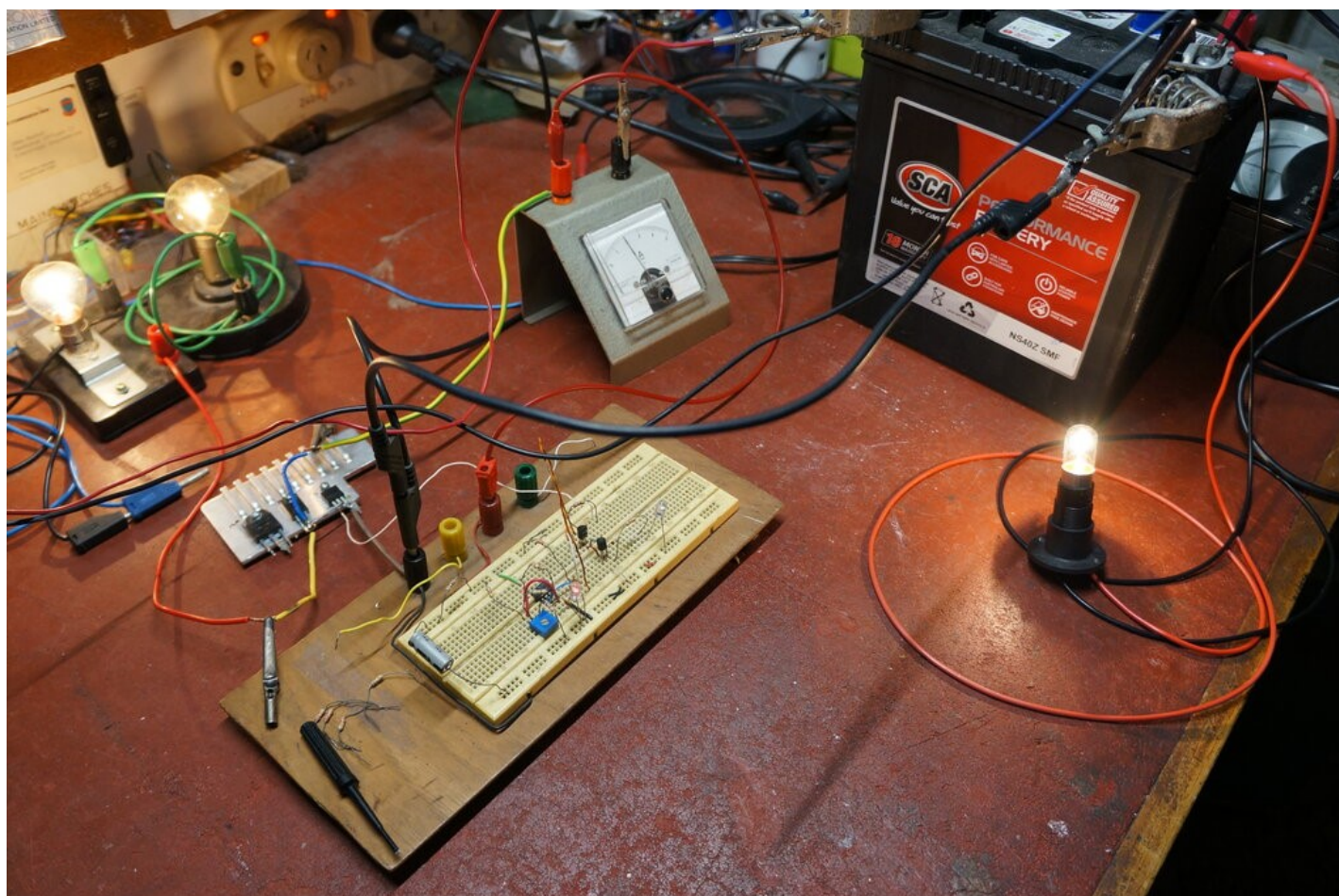
The Model T was designed for 6V, negative earth. For various reasons, some have ended up with 8 or 12V batteries instead. To answer the inevitable question of how to use the regulator with these voltages, work has been done to bench test the modifications required.

For 8V.

- 6.8k between 1k voltage set pot and earth is changed to 4.7k.
- 180k hysteresis resistor is changed to 220k.
- The bench tested unit switched on at 8.8V and off at 9.6V.

For 12V.

- 15V zener diode changed to 18V 400mW or 1W. Note that 18V is also suitable for the 6 and 8V versions.
- 22k in series with positive end of 1k voltage set pot is changed to 47k.
- 180k hysteresis resistor is changed to 470k.
- 22k in series with voltage reference LED (pin 2 of the LM393), is changed to 39k.
- 22k pull up resistor at pin 1 of the LM393 is changed to 33k.
- The bench tested unit switched on at 13.25V and off at 14.18V.



Bench testing circuit modified for 12V.

The Model T generator can charge 8 or 12V batteries, since it functions as a constant current source. It is important to derate the charge current under these conditions, in view of the 100W maximum power rating.

So, for 15V output (cutout diode drop + 14.4V charge), the maximum current that the generator should ever be set to is 6.6A.

Update 23/12/21 - the 2200uF capacitor.

After some investigation, it appears the 2200uF is not actually required. The generator waveform is very spiky when the cutout diode is not conducting, but from all tests the 100R and 100uF decoupling circuit is sufficient to keep any spikes out of the LM393 circuit. No change in switching voltages was detected, and the LM393 supply rail was smooth at all times. For now, the 2200uF has been removed from the test unit. Since it is a bulky component there is some advantage in deleting it. However, the 2200uF does do a good job of cleaning up the unloaded generator waveform. In that regard, it's more of a technical nicety than a practical necessity. Please yourself whether or not you want to include

it.

Using a Cutout Housing (23/4/22).

The prototype construction in the diecast alloy box is perfectly valid, and I used this unit for several months. Only because one became available, and for the look of authenticity, did I build a final version in a cutout housing.

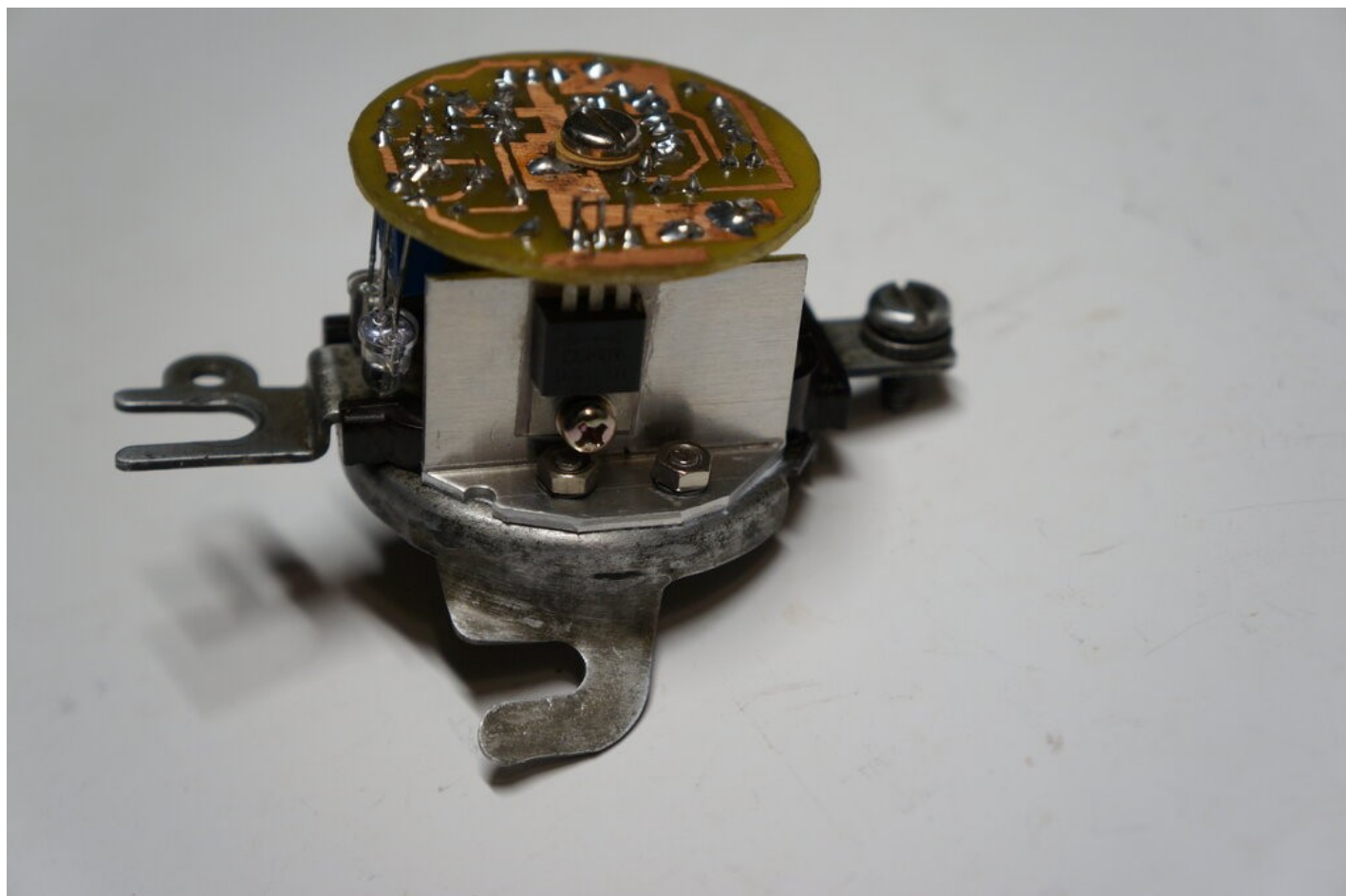
The cutout housing I used is a repro of unknown origin. The terminal construction is different to the original Ford unit, and in my opinion far better, using solid bakelite rather than the original crumbly fibre insulators. This particular cutout had an open voltage coil, and the construction of the points was not of quality construction. So, I felt no loss re-using the housing for my new regulator. The 2200uF capacitor was not included, since continued testing over the past four months has confirmed it is superfluous. Otherwise, the circuit is identical to the prototype. This time, the diode used was an SB2045CT, and the MOSFET was a P40NF03L. Also, a KA393 was used for the comparator.



Heatsink brackets with diode and MOSFET attached. Central pillar supports PCB.

Because of the large bakelite insulator, it was not possible to mount the diode and MOSFET as per the Fun Projects regulator. Instead, two aluminium heatsink brackets were made up to support these components vertically. It was hoped there would be sufficient thermal conduction to the base of the cutout housing. Thermal paste was applied between the surfaces to help this.

With the small space available, a PCB was essential. Veroboard, as used in the prototype, will not allow sufficient component density. And, so a board was designed using Protel, then etched, and drilled. The details of this process are [described here](#).



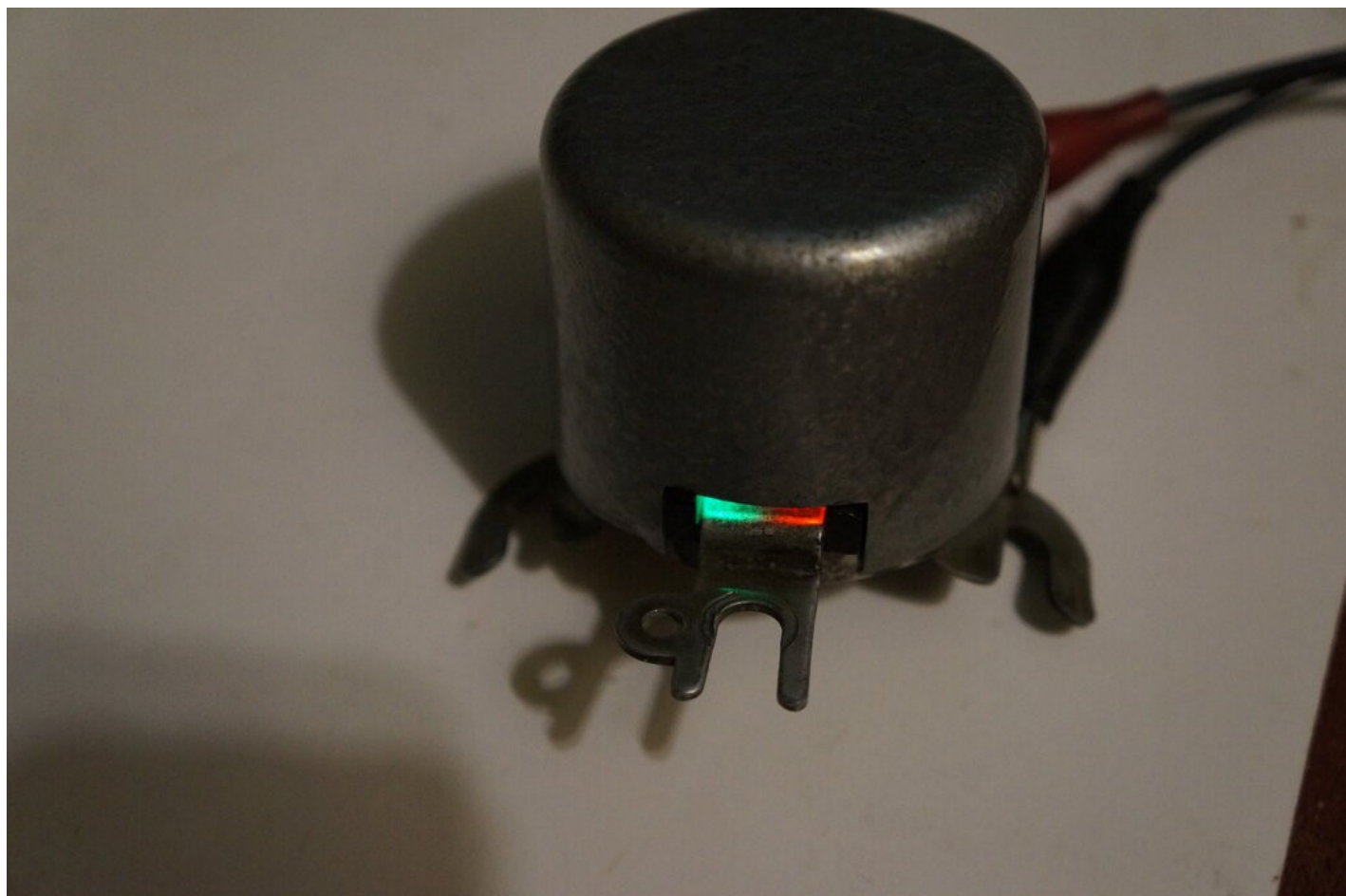
Board is supported by the diode and MOSFET, and the central pillar.

The board was quite reasonable, given the home made method of applying the 'resist'. There were no shorted or open tracks. The main thing is a 'bluriness' with some tracks; I suspect caused by the paper moving before it had heated up sufficiently under the iron. Importantly, the electrons would never know the difference! I should have allowed for one more size up for the resistor lengths, but despite that, they could be made to fit. I was very pleased that the board lined up centrally with the diode and MOSFET pins.



Vref and Charged LED's reflect off generator terminal strip.

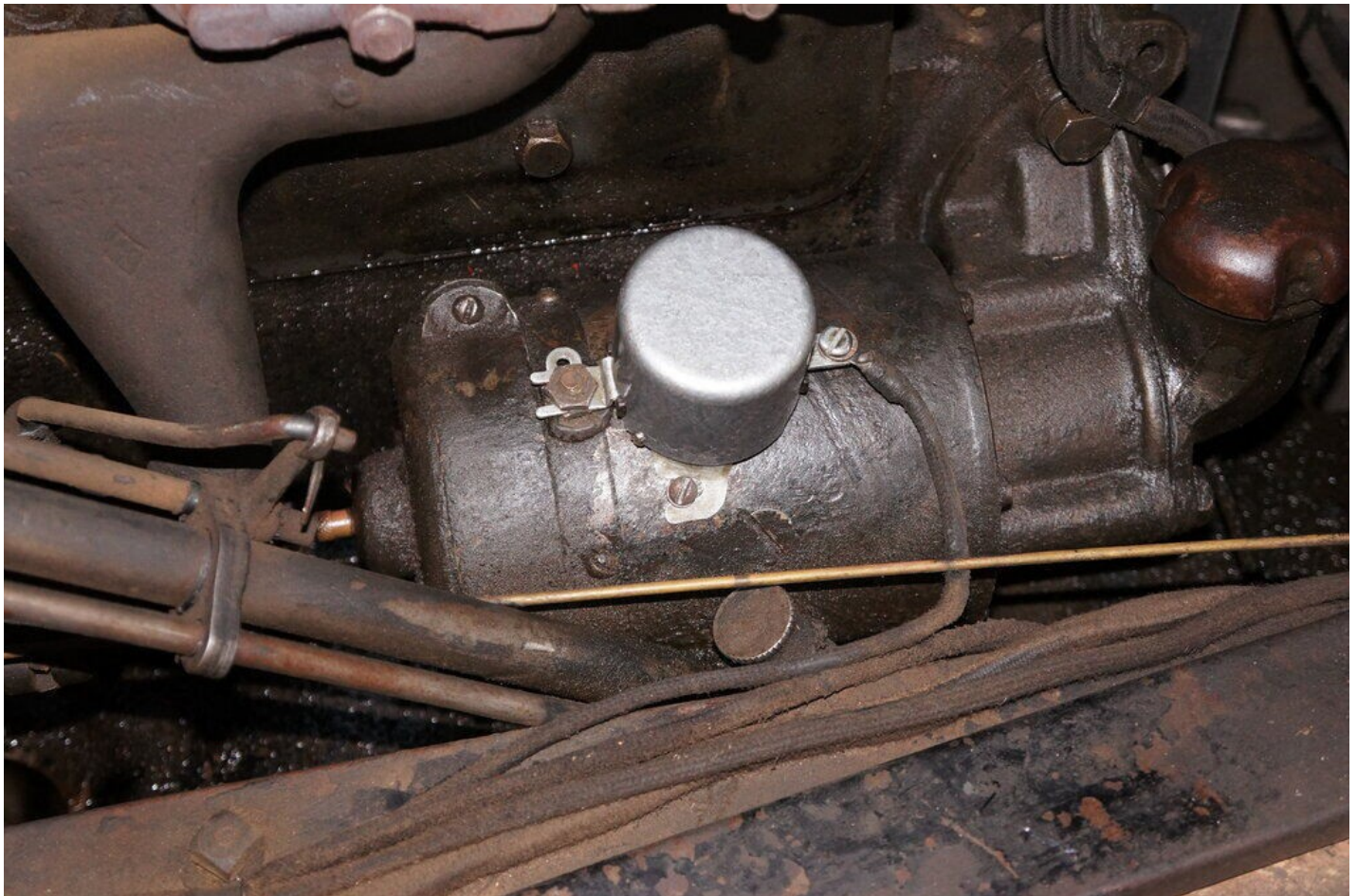
A central brass pillar provided additional support, as well as providing connection to the generator input terminal. I tapped it for a 5mm screw on the base side, and for a 4mm screw on the PCB end. Initial design was the 4mm screw would provide connection to the relevant PCB track, but as this was slightly off centre, and was going to short an adjacent connection, a fibre washer was put under the screw. To keep the lid secured, I drilled and tapped a pair of holes in the base to take 2.5mm screws. The lid needs to be removable to set the voltage in the car.



LED's visible through gap. Red shows V_{ref} , and green shows the battery is charged.

Some thought had to be given to making the LED's visible. I had decided to retain the LED's because of the convenience and reassurance offered in the prototype. Drilling holes in the cover was something I'd prefer not to do, but as it happened, there was a sufficient gap between the generator terminal strip and cover, for their light to shine out of. The LED's point down at the terminal strip and the reflected light is visible through the gap. This worked perfectly, and does not detract from the authentic appearance. Since there are two LED's which are not directly visible, the obvious way to differentiate between them was to make the 'Charged' LED green. (Changing the 'Vref' LED to green would have altered the reference voltage, requiring a redesign).

Initial bench testing showed all was well, and the unit was then mounted in the car:



Looks just like an original mechanical cutout, but prevents battery overcharge.

Testing showed identical performance as compared to the prototype.

Final Thoughts.

The project is now complete and working with the results I had hoped for. However, it should be pointed out that the design of the cutout housing I used was not ideal from a heatsinking perspective. The amount of thermal transfer is limited. Also, the mild steel base is a less efficient heat conductor compared to aluminium. In short, the alloy diecast box is technically a better construction. With the cutout housing version, I would be reluctant to increase the charge current beyond the existing 5A. Unless a diode with a lower voltage drop can be found, I don't recommend this method of construction for higher charge currents. At 5A, there is 450mV dropped across the diode, which results in 2.25W dissipation. It runs warm, but not uncomfortably so. It must be remembered that in the car, the body of the generator will also actually add heat to the whole thing. A further comment needs to be made with regards to the mounting of the cutout housings, whether repro or original. The shape of their feet does not provide full contact under the screw heads. In fact the more I look at it, the aluminium mounting brackets I made up for my prototypes are far superior, and provide a much better mechanical (and electrical) connection to the generator case. Furthermore, my brackets allow the regulators to be stood off the generator with a flow of air underneath - as well as keeping the regulator further from the hot generator body. I'd only use a cutout housing again if I was building another unit for someone who was concerned about original appearance.

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