# The Simple Electronic RB106 MK2c:

COMPENSATED ELECTRONIC DYNAMO REGULATOR and True LUCAS RB106 Emulator:

Dr. Hugo Holden. Sept. 2012.

(As per previous notices: Do not attempt to work on the electrical systems of your vintage car unless you are qualified to do so, or can get help from someone who is. The use of my freely given designs by any party is entirely at their discretion and at their own risk).

This article describes an all electronic modification or upgrade to the Lucas RB106 Dynamo regulator into a fully electronic unit which emulates the electrical properties of the original Lucas RB106. The purpose of this is to have a reliable unit with no moving parts or contact wear or adjustment issues and yet behaves identically to a correctly adjusted Lucas RB106. Moreover this design has been simplified to the extent that it only contains two transistors and 4 rectifiers and can be made as positive or negative ground versions by using complimentary components. The top cover fits over the unit as usual so the unit looks unchanged when mounted in the car.
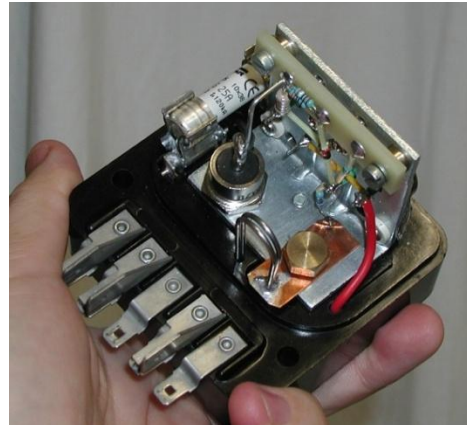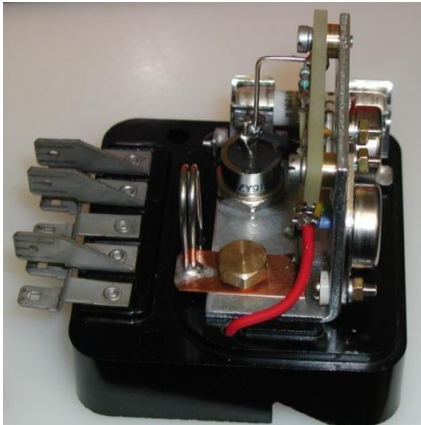
TRUE ELECTRONIC RB106

Background to the evolution of the true RB106 Emulator:

While attempts have been made in a number of areas to replace the Lucas RB106 with an "electronic version" the regulator presented here is currently the only version in existence which replicates the functionality of the original unit where the output voltage depends on current load. All other versions use fixed voltage control.

On starting to build electronic regulators to replace the RB106, over 5 years ago now, I had initially ventured along the road of a fixed output voltage design (14.3V) myself as others had. This produced a control system much like that used for alternator systems. The units would then either have a fuse to protect the dynamo or additional transistors or IC's to act as a 22A automatic current limiter to suit the C40 dynamo. This required more complexity and more parts. This went against the goal of a simple and elegant solution for an "electronic RB106".

On returning to Lucas's original RB106 **compensated** design system and studying it and testing it extensively on a specially built test machine, I have concluded that the system concept of compensation, where the voltage depends on the load, is very elegant, simple and clever.

"Compensation" as a technique to prevent dynamo overload is explained in more detail below, but for now one of its great features is that it effectively synthesizes a similar type of protection from overload conditions which is intrinsic to the alternator system.

In the alternator which is an "AC machine", on its AC side (stator windings) there is inductance (or leakage reactance) which acts as though it is an inductance in series with the stator windings. Inductance has impedance to AC currents, or is a form of resistance to AC currents. Also it is a form of resistance which also does not dissipate heat. This limits and levels off the alternator's output current with increasing RPM (which increases the AC frequency) or increasing load and protects the alternator from overload and burnout. It is what could in effect be described as a form of a "heat lossless AC ballast resistance". This is why alternators require only voltage regulation and generally have no current limiters. This intrinsic property protects the alternator from overload.

No such "ballast" protection exists for the DC machine or dynamo and the load current can increase unchecked with increasing rpm or increasing loads. This requires some system of current detection and limitation to protect the armature from burnout. High current conditions can prevail when battery is in a state of low charge combined with external loads such as headlamps.

The voltage reduction with current loading which is "synthesized" by Lucas's original compensated RB106 regulator, in effect acts as a "heat lossless ballast resistance" in series with the dynamo output, lowering the voltage with increased load current. This ensures the C40 dynamo remains protected with increasing load and rpm without the need for an independent current limiter system.

In addition the design concept of Lucas's compensated regulator was not a problem in itself. The problem is with the reliability of the actual RB106 unit due to the voltage regulator's contact with oxidation, wear and burn. This throws the unit out of adjustment with time and making it unreliable. This problem is typical of electro-mechanical devices such as switches or relay contacts when switching inductive loads where the high back *Emf* (voltage) from the quickly collapsing magnetic field generates high voltages from the windings that the contacts are switching. This causes contact arcing and oxidation. This problem is by no means unique to the RB106 regulator unit and various methods of arc suppression either with damping resistors or rectifiers will reduce but not eliminate this problem.

How compensation works:

It is necessary to explain what a "compensated" regulator is, what it does, how it works and why compensation was invented:

To clarify there are **two** forms of compensation operating in the standard Lucas RB106. One is **temperature compensation** to lower the output voltage with increases in both ambient temperature and increasing temperature of the regulator unit itself. The latter is correlated with dynamo temperature. The temperature compensation is rarely alluded to in the automotive manuals aside from advice on setting the dynamo output voltage with respect to ambient temperature during the calibration process before the regulator assembly heats up.

The other form of compensation is **voltage compensation** to lower the output voltage in response to the current loading.

Temperature compensation will be discussed first:

Temperature Compensation:

There are at least three reasons why temperature compensation is required.

1) The battery's internal resistance increases as the temperature drops requiring a higher charging voltage at lower temperatures, or a lower charging voltage as the battery heats up.

2) The copper wire which composes the shunt coil on the voltage regulator bobbin has an increase in resistance with temperature. Therefore for any fixed voltage applied to it the current and therefore the magnetic field weakens with heating, this would progressively raise the output voltage with heating if not corrected for.

3) It is permissible for the dynamo to run a higher output current while colder and a lower current when hotter. Heat dissipated by the regulator's series coils is correlated with the dynamo

current which is correlated with dynamo armature heating. So there is a relationship between the temperatures inside the control box and the dynamo.

The required negative temperature coefficient of a charging system's output voltage to compensate for the battery's temperature is around -0.01V/degree C. Generally the initial temperature of the battery is ambient temperature. Looking at the service manual data on the RB106, the suggested open circuit voltages at any temperature for the calibration setting, this value holds true. They also recommend setting it quickly before the regulator heats up.

On testing the actual RB106 the temperature coefficient for the metal frame temperature of the unit is around -0.03V/Degrees C. This additional amount of another -0.02V/Degrees C allows for the properties of the copper wire in the voltage regulator bobbin shunt coil and the dynamo heating itself as noted above.

In practice the negative temperature coefficient is achieved with special return springs on the voltage regulator's contact arm which decrease their force with heating.

Voltage compensation in response to current load:

This is the "compensation" that most people talk about and are familiar with in conversation about Lucas's RB106 regulator.

As noted the current in a dynamo system can climb to very large values with overload either from additional added external loads (eg fog lamps or high beam headlamps) or a low state of charge battery in conjunction with the external loads of the car's electrical system.

Before examining this in more detail it is useful to look at the contents of a typical regulator or "dynamo control box" It was once customary to have *three* control systems inside the dynamo's control box:

1) C**ut-out** or cut in: This device ensures the dynamo is only connected to the battery when the dynamo's output voltage is at least equal to the battery voltage so that the battery cannot discharge into the dynamo armature circuit when the dynamo is not rotating or rotating slowly. This is achieved with a relay coil and contact assembly in the original RB106.

2) V**oltage regulator** or voltage limiter: This controls the dynamo output voltage, or levels the voltage off, regardless of increasing dynamo rpm. This is achieved by controlling the average field coil current in response to the dynamo's output voltage by a separate relay coil and contact, interrupting the field coil current at a rapid rate typically 20 to 50 cycles per second.

3) C**urrent regulator** or limiter: This is achieved with another relay operated by the magnitude of the dynamo output current and again with a contact interrupting the field coil current when a certain current is achieved, levelling the current off to a near fixed value.

In each instance the measured or detected variable is either current or voltage and it generates a magnetic field in the relay's magnetic core which opposes a spring force. Eventually the spring force would be overcome. Increasing magnetic force closes a contact in the case of a cut-out and links the dynamo to the battery. It opens a contact in the case of the voltage regulator or current regulator relay reducing the average field coil current.

In a **voltage regulator relay** the parallel or "shunt" coil has a large number of turns and a high resistance which serves to convert the applied voltage to a relatively low current and the current creates the magnetic field opposing the spring force. In contrast in the **current regulator relay** there are a small number of very thick turns (called a series coil) with relatively high currents. In both cases the magnetic field produced is proportional the product of the coil's current and the number of turns and it is called the Ampere-Turns, abbreviated AT.

To execute the three features required to make a dynamo control box work the design traditionally required three "bobbins" or three relay coil assemblies each with a contact assembly.

Lucas realised there was another way to create a control box with only two relay coils. The idea was to **mix the functions of voltage regulation and current regulation onto one bobbin** or one relay coil and not have a separate current regulator bobbin.

This idea changed forever the functionality of the "control box" and made the dynamo's voltage fall in proportion to current loading. In addition the drop in voltage was not associated with the evolution of heat as it was mediated by switching control of the average field coil current. It is this very function that provides overload protection to the C40 dynamo used in conjunction with Lucas's RB106 control box.

The output voltage is then said to be "compensated" *downwards* as the current loading increases over the full range of currents from a few amps to a high current of 20A for the C40/RB106 dynamo system. The thick wire coil added to the voltage regulator bobbin was also called the "compensation coil" as the current in this coil assisted the magnetic field of the voltage shunt coil lowering the regulator's output voltage as the load current increased.

Moreover the settings were chosen by Lucas for the original RB106/C40 22A dynamo system so that at the maximum loading of 20A (2A is directed to the field coil at maximum output) the output voltage had fallen close to 13V which is the "charge neutral voltage" where a well charged battery draws practically zero current from a 13V source. (As a brief aside this is why auto volt meters used with alternator charging systems often show the 13V value on their faces as the zero charging level).

In contrast in the case of a typical three bobbin regulator the voltage would remain fairly stable up until the maximum current level was reached and the current limiter would then suddenly activate to limit the current at that point. However, even in the three bobbin regulator such as the

Lucas RB340, Lucas still had some protective compensation present as usually one turn of main current carrying wire placed around the voltage regulator bobbin. So with an independent current limiter, some compensation was still considered necessary by Lucas to protect the dynamo.

In the compensated system and operating with low to medium external current loads (car ignition current & battery charge current) with day driving the battery is charged from a higher source voltage, typically in the average range of 14.4 to 14.8v. This is higher than 14.3v (typical of alternator systems) and therefore the battery does pick up more charge during the day. This helps to allow for lower charge rates with night driving and headlamps running and higher current loading when the system voltage could be between 13v to 14v due to the compensation. So Lucas's idea was that the output voltage variations would "average out" between day and night driving. This concept assumed some reasonable balance between day and night driving.

It also meant that because the regulator's output voltage varies over a range of values over the full load, say from around 14.8v at low loads to 12.5 to 13V at full 20A external load, the correct setting on the RB106 unit was more critical to obtain a reasonable charging balance between day and night driving and have the average value nearer the 14.4V arena.

NOTE: The "no load" condition never occurs in practice because there is always a few amps ignition current and there is usually a few amps charge current especially with the higher range voltages so in practice the output varies between about 14.8 and 13 volts. **The no load scenario is only used to calibrate the regulator's output**. So in practice the output is always lower than 16V even though the 16.1V setting @ 10 degrees C was used in the unit's calibration process.

In a nutshell the compensated system designed by Lucas was designed to simplify the control box and make one relay or bobbin do the work of two and reduce the size and cost of the control box and was a very clever idea affording good overload protection to the dynamo.

While there are reliability issues with an aged and used RB106, when it was brand new and properly adjusted it was a perfect companion to the C40 dynamo as one might expect.

 What it means to have a "True Electronic RB106":

If a reliable transistorised version of the RB106 is constructed it would be a very satisfactory device with none of the wear and adjustment issues. It would also make the best use out of the compensated design system that Lucas created. It would also be simpler than any other electronic regulator with a separate transistorised current detector as it would not require additional transistors to implement and the design of it could be kept robust and simple.

In addition the behaviour of the instrumentation such as the car's Amp meter and the way the battery's charge currents vary with the car's different electrical loads remains authentic and identical to a perfect working electro-mechanical unit. In contrast in the constant voltage

charging systems such as the Alternator, the battery amp meter is far less informative of the car's electrical conditions. This is why it became customary to use volt meters instead of amp meters with alternators.

In other words the compensated design concept would confer to a transistorised electronic regulator the same simplicity and elegance it conferred to the original electro-mechanical Lucas RB106.

Re-Cap of Lucas's RB106 design:

It is worth reviewing the design of the RB106 to see how Lucas did it. There are a number of subtle and interesting details in their design.

Figure 1 below shows the basic arrangement of the Electro-mechanical regulator as seen in many vintage manuals.
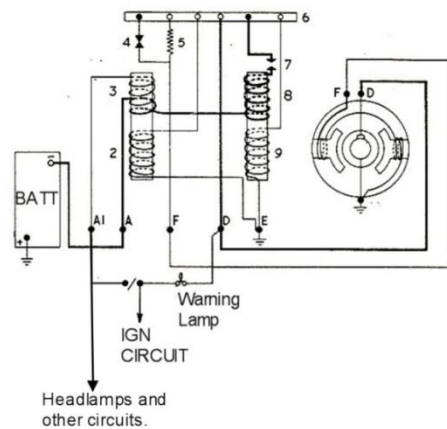
Fig 1

Essentially there are two relays in the RB106 box. Both have a shunt coil 2 and 9 in the diagram (many turns of wire) and a series coil 3 and 8 (fewer turns of thicker wire). The cut-out relay is magnetically energized by the shunt coil 9 which connects to the dynamo's armature output on the D terminal to bus 6 which is the regulator's metal frame. When a sufficient voltage is supplied by the dynamo the current increases in coil 9 and the magnetic field generated by this overcomes the relay return spring and the cut out relay pulls in, closing the contact 7.

The relay "cuts in" connecting the dynamo (D connection) to the series coil 8 on the cut out relay and this is also connected to the series coil 3 on the voltage regulator relay and it passes out to the A and A1 terminals.

Normally the cut in voltage is equal to or higher than the battery voltage, especially after starting. At cut in therefore the dynamo D voltage could be transiently loaded down, causing a cut out, and the contact could chatter and become oscillatory especially if the dynamo rpm hovered around the cut in value. The series coil 8 current enhances the closing forces of contact 7 by increasing the magnetization opposing the return spring and increases the forces keeping the contact 7 closed so it closes well without any chatter.

As the dynamo voltage falls to a lower level than the battery, then the current flow in this series coil 8 is *reversed*, opposing the magnetization from the shunt coil 9, so the relay cuts out cleanly disconnecting the dynamo from the charging system at low rpm.

In general cut outs work very well. The relay opens and closes from time to time with minimal wear and doesn't often require adjustment. The same cannot be said for the voltage regulator relay and its contact. Generally the cut-out contacts are Silver and the voltage regulator contacts are much harder, usually Tungsten.

The **voltage regulator relay shunt coil 2** receives the dynamo's output from the frame or D connection. The normally closed contact 4 connects the dynamo's field winding to the dynamo's D output when the shunt coil is not energized. As the dynamo voltage increases the magnetic force builds up opposing the return spring keeping the contact 4 closed. Ultimately the contact opens and the dynamo's field winding then loses most of its magnetization current thereby lowering dynamo output voltage. The contact then rapidly closes and this cycle repeats over and over with time at roughly 20 to 30 cycles per second thereby regulating the output voltage to a near fixed value.

The dynamo's field winding is not completely disconnected when contact 4 opens, but a loading resistor 5 is left in the circuit to damp the back *Emf* generated from the collapsing field coil's magnetic field. If that were not done the arcing at the regulator contact would be massive and quickly destroy the quality of the contact's electrical connection. So this resistor is as small in value as it can be to damp the voltage oscillations from the collapsing magnetic field of the field coil, but not so small that the field coil drive isn't significantly weakened with just the resistor alone.

The constant opening and closing and contact arcing (despite the resistor) wears away the contact 4, throwing the regulator out of adjustment with time.

The series coil 3 on the voltage regulator relay is known as the "compensation coil". Dynamo current flowing through this coil from the D to the A terminals assists the shunt coil 2 and opposes the relay return spring. This lowers the dynamo's voltage output and limits the dynamo output current under high loads. The concern for the manufacturers was night driving with a battery in a low stage of charge and a high charge current, combined with the external loads such as headlamps/fog-lamps which could exceed the dynamos output current rating and cause armature wire burn out or commutator and brush overheating.

Current via the series coil 3, like the shunt coil 2, weakens the dynamo's *average* field coil's current drive by altering its on-off duty cycle, lowering the dynamo output voltage and reducing the charge current.

There are more series turns added for the external load currents via the A1 terminal and less for the battery charging current via the A terminal. The idea being that during day driving a higher charging system voltage & current can be available to the battery to compensate for the lower night charge rates.

The manual suggests settings (regulator off load) of an output voltage of 16.1V @ 10 degrees C or 15.8V @ 40 degrees C, in other words a negative *temperature coefficient* (tempco) for the voltage regulator of - 0.01 volts per degree C with respect to **ambient** temperature for the calibration *before the regulator heats up.* The recommended zero load setting on the D terminal therefore is 16.0V @ 20 degrees C.

As the voltage regulator shunt coil 2 heats up its electrical resistance increases (because it is made of copper wire) and all other things being equal the magnetic field would weaken and the output voltage would therefore increase with temperature. To compensate for this and acquire a negative temperature coefficient, the return spring closing the contact 4 is a special temperature sensitive spring. This spring decreases its force with heat causing the output voltage to drop with heating rather than increasing.

As noted above the overall temperature coefficient is in the order of -0.03V/Degree C. The net result is a charging system where the output voltage decreases with increasing temperature or increases with decreasing temperature. This effect also provides a form of "thermal negative feedback" so the currents and heat generated would tend to decrease with heat so as to prevent a form of thermal runaway from positive thermal feedback.

Testing the Lucas RB106 and finding its equation:

On the dynamo test machine it was possible to determine the equation for the original RB106 & C40 dynamo output voltage Vd (dynamo voltage on the D terminal) in terms of current loading and temperature and it is close to:

$$Vd = 16.6 - 0.03Tf - 0.143A1 - 0.095A$$

Where A1 and A are the output current loads via those terminals (A1 is the main load current and A is the battery charge current) Tf is the *metal frame temperature* in degrees C and 16.0 volts is the "no load" setting @ 20 degrees C.

The equation above explains how the output voltage of the RB106 drops with both current loading and temperature. The equation can also be modified to include the voltage drop from the D to the A1 & A terminals due to the resistance of the thick wire in the unit and the contact resistance and other conductors between the D and A terminals and in a new unit with perfect contacts the resistance is about 0.013 Ohms.

Therefore for the A voltage Va (on either A or A1):

$$Va = 16.6 - 0.03Tf - 0.143A1 - 0.095A - 0.013(A + A1)$$

At a 20A full load on A1(the A current is generally near zero at this voltage with a charged battery) at full load and at 20 degrees C the **A terminal voltages** (Va) would be 12.88 Volts for example.

Open circuit (calibration equations):

Setting the regulator to 16 volts on the D terminal (Vd) quickly for calibration purposes, with the cut-out contacts insulated (zero A and A1 current) and before it heats up, the equation is simply:

$$Vd = 16.20 - 0.01Ta$$

Where Ta is the **ambient** temperature. Measuring the regulator's metal **frame** temperature Tf instead:

$$Vd = 16.6 - 0.03Tf$$

Tf = Ta before the unit heats up and the Lucas recommended setting for Vd is 16.1V @ 10 degrees C.

Full load equations:

As noted at full load or 20A, the A current is close to zero with a fully charged battery. So at the maximum load current of 20A the equation for the D or A voltage reduces to:

$$Vd = 16.6 - 0.03Tf - 0.143 \text{ x } 20$$

OR $\qquad\qquad$ $Va = 16.6 - 0.01Tf - 0.143 \text{ x } 20 - 0.013 \text{ x } 20$

And the full load "compensation" voltage drop on the D terminal is − 0.143 volts/amp x 20 amps = − 2.86 volts.

Obviously any true RB106 regulator emulator would have to conform to the above equations.

Note especially that by the time the load current on the A1 terminal is 20 amps, the output or D voltage has dropped to close to 16 - 2.86V = 13.14V and the A1 voltage is a little lower at around 12.88V due to the resistance from D to A. At this point the battery charge current (for a well charged battery) on the A terminal is near zero amps. *The battery is not discharging or charging either under this full load condition.*

Another observation is that the "compensation voltage" is -0.143 x 20 or -2.86 volts at maximum load. Lucas designed the system so that there was a little less compensation on the battery (A terminal) than the main load (A1 terminal) in fact 2/3 as much. Of the three thick turns that make up the compensation coil, two are for the A terminal and three for the A1 terminal. This means that in the range from some few amps load to 20A the battery charge current via the A terminal has less effect in reducing the output voltage than the main load on the A1 terminal.

(Note there are variants of the Lucas RB106 that have one additional turn on the compensation winding and they are still labelled RB106/2 and possibly they were a variant for a 19A rated dynamo)

Emulating the LUCAS RB106 Electronically:

It should be remembered that the "mixing" of the currents relating to those in the shunt voltage coil 2 and the series current coil 3 on the RB106's voltage regulator bobbin is achieved from the addition of the magnetic fields generated by the AT's of the two coils. Both of which contribute to the field coil contacts opening at some threshold. In achieving this effect electronically, with no moving parts, it is a matter of mixing either voltages or currents.

Closed loop conditions:

It should not be forgotten that the regulator operates in a closed negative feedback loop with the dynamo. So any increase in current in the series coil 3 will cause a drop in D voltage which in turn drops the current in the shunt coil 2 which opposes the overall change in magnetic field in the voltage regulator's relay's magnetic core caused by the imposed change on coil 3. **This is typical of a system enclosed within a negative feedback loop where an imposed change on a component within the loop is partially counteracted by the loop behaviour.**

Before presenting the circuit of the "Electronic RB106 Emulator" it is necessary to explain how the electronic version of "compensation" actually works with a circuit model to simplify the mathematics.

Due to the fact that in use the regulator finds itself within a negative feedback loop cited above with the dynamo, then understanding and calculating how it works is quite complicated despite the simplicity of the circuitry itself. It is therefore necessary before working out the correct circuit values to draw a **"model"** which includes a representation of the negative feedback loop in which the regulator circuitry finds itself in use. Also the average base-emitter voltage and average base current of the regulator's input transistor needs to be known. This is easily measured:

With the regulator operating under normal conditions from low to high loads testing shows that the *average* base emitter voltage on the MJ2955 input transistor in a test regulator setup is in the range of 0.54 to 0.56 volts, or about 0.55 volts.

 Therefore the following **voltage mixing model** is created with the 0.55V value as the reference voltage and drawn initially as a negative earth system to aid in the analysis. Figure 2 below shows the **model.** The model is not a real regulator but a model of how to calculate factors that will relate to the real unit.

FIGURE 2.
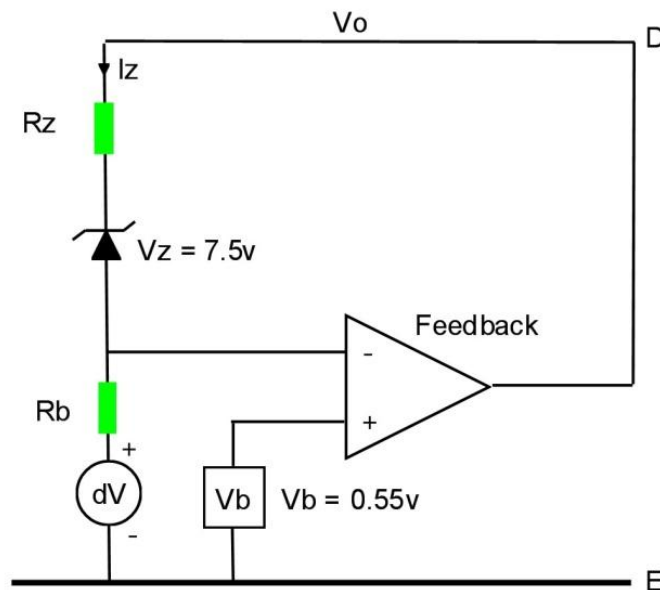
dV is a variable voltage generated across a theoretical current sensing resistor in the main current pathway of the RB106 and has a magnitude that is directly proportional to the current load. The model creates a feedback system where any change in dV results in a change in Vo because the **imaginary feedback amplifier** alters its output in a way to make the difference in its input voltages zero. Vo itself is representative of the D voltage or dynamo armature output.

The question which needs to be answered is:

How does the magnitude of the voltage dV alter Vo?

Iz is the current via Rz and the 7.5v zener diode and Rb. From the diagram:

$$Iz = (Vb - dV)/ Rb$$

Also: $$IzRz = Vo - Vz - Vb$$

Therefore: $$(Vo - Vz - Vb)/Rz = (Vb - dV)/Rb$$

Solving for Vo: **Vo = Vz + Vb + Vb.Rz/Rb − dV.Rz/Rb.**

As can be seen the output voltage Vo is reduced by an amount equal to dV.Rz/Rb and this is the "compensation voltage"

If we take initially at least dV to be zero in the "no load" state then the output voltage of the regulator is equal to Vz + Vb + Vb.Rz/Rb. Using the 7v5 zener and with a fixed Vb of 0.55V then the ratio of Rz/Rb for a 16 volt Vo is

$$16 = 7.5 + 0.55 + 0.55Rz/Rb$$

Making the ratio: Rz/Rb = 14.45

Obviously if the zener voltage Vz was lower, the Rz/Rb ratio could be higher allowing a higher compensation voltage with a 16V output voltage. Looking now at the compensation voltage and making it the same as the original RB106; making it -2.86V then solving for dV:

$$-2.86 = -dV.Rz/Rb$$

Rz/Rb is 14.45, therefore dV = 0.197 or very close to 0.2 volts.

Given that this is to occur over a 20A current range then the current sensing resistor to achieve this dV is 0.197V/20A or about 9 to 10 milli-Ohms which can easily be constructed as will be shown below from two lengths of Constantan wire.

So far although the ratio of Rz to Rb is known and the correct value for the current sensing resistor which generates dV is now known also, we don't yet know the absolute values of Rz and Rb, just the ratios. The absolute values determine the current Iz in the divider chain and the source resistance presented to the imaginary feedback amplifier.

The "voltage mixing" model above assumes zero current into the negative input of the imaginary feedback amplifier. This would correspond to the input at the base junction of the actual regulator's input transistor. Real transistor base-emitter junctions draw current. Measuring the average base current with a working regulator at the input transistor is in the order of only 0.06mA. Therefore if the Thevenin resistance of the combined values of Rz and Rb (which is dominated by Rb which is about 14 times smaller than Rz) is in the order of a couple of hundred ohms, say 220 ohms then the voltage offset at the input induced by base current would only be about 13mV, corresponding to only a 0.2V offset of Vo and ensure the voltage mixing model and calculations were sensibly accurate.

So if Rb is set at 220R and therefore Rz at 14.45 x = 3179 or around 3.18K the conditions would be satisfied. Moreover the exact resistance can be created in practice with a 3k3 and a higher value calibration resistor. Drawing the **idea** now as a **real circuit** of a regulator rather than a model and again as a negative ground convention Figure 3:
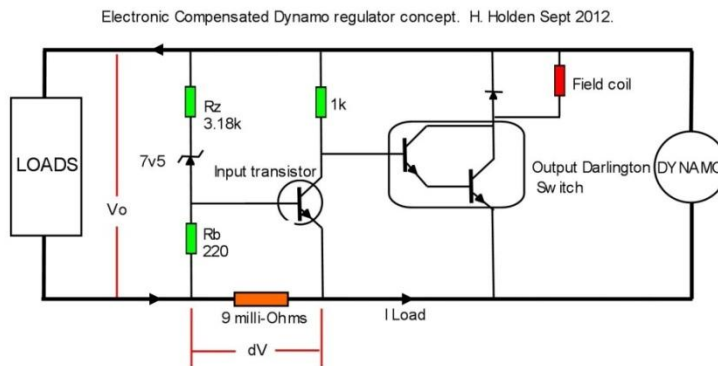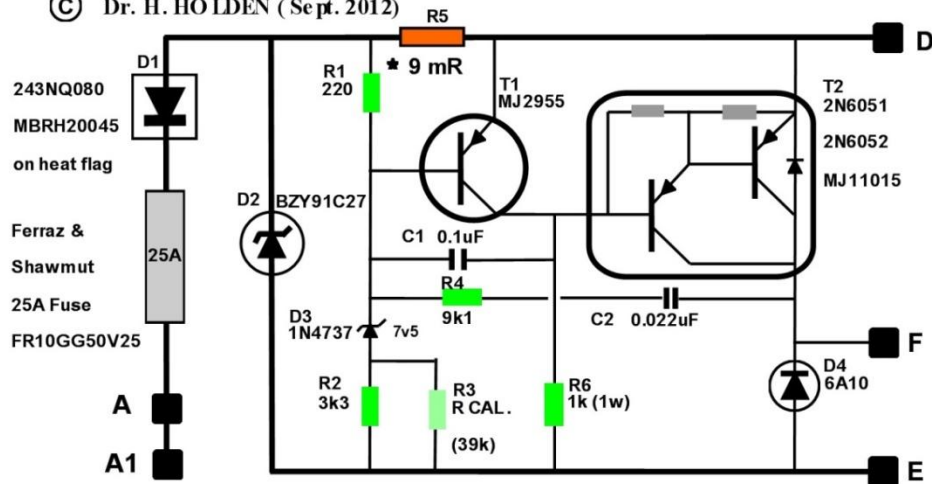

FIGURE 3.

The model of figure 3 above needs to be flipped around to allow for the fact that Lucas's dynamo field coil is earthed. Also a filter and feedback capacitor added. Figure 4 below shows the circuit of the Compensated Electronic RB106 (Mk2c)

ELECTRONIC DYNAMO REGULATOR:
THE LUCAS RB106 "EMULATOR" (COMPENSATED VOLTAGE REGULATOR) TO REPLACE ORIGINAL ELECTRO-MECHANICAL REGULATORS AND RUN WITH THE LUCAS C40 DYNAMO SYSTEM.

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★ 9 mR resistor is composed from two lengths of Constantan wire, 18 mR each, see text.

FIGURE 4.

Voltage transient protection:

The power zener clamps off the high voltage spikes that appear on the D terminal if the battery is disconnected in use. These result from field coil switching and the leakage reactance between the dynamo field coil and armature. These can be as high as + 60 to + 80 volts but they are clamped to 27V by the zener. This protects the regulator transistors.

Also in the event of reverse battery polarity the forward voltage drop across the power zener is low and along with the fuse provides some protection for the series combination of the field coil snubber diode and the internal darlington collector emitter diode.

Operating principle of voltage regulation:

The basic principle of operation is the same as any variable frequency regulator. Basically the output Darlington transistor T2 is biased into conduction by the current via the 1k resistor R6 which turns on the field coil. When the voltage rises to the set voltage the driver transistor T1 conducts removing the base current from the Darlington and therefore the field coil switches off sharply. The sharp switching is aided by the positive feedback of the 9k1 and 0.022uF feedback network of C2 and R4. This ensures clean noise free switching as there are ripples of the commutation process on the D voltage. With the dynamo on load these ripples consist of a triangular like waves at 14 times the rotational frequency of the "28 segment" commutator and some high frequency spikes are also present due to imperfections of the commutation process. (See article on the C40 dynamo and its armature). The 0.1uF capacitor C1 acts on the MJ2955's base to collector to form an integrator and filter, lowering the overall high frequency response and improving the immunity to noise.

After the field is switched off the dynamo's voltage output falls and the field coil switches back on again and so the *cycle* repeats. The switching duty cycle self adjusts so as to maintain a constant voltage on the D terminal. The 6A10 rectifier maintains and controls the field current when T2 is off and also prevents the collector voltage of T2 falling more than about -0.7V below the negative E terminal (earth).

This acts identically to the original RB106, where the field coil contact is normally closed and opens at a specific voltage threshold.

All the resistors are 1/4w metal film 1% except R6 and R5. The capacitors are axial monolithic ceramic which are rated to 125 degrees C.

The 7.5V Zener diode (1N4737A) has the correct temperature coefficient to ensure that the output voltage is basically stable with temperature and overall the unit has a small negative temperature coefficient similar to the original Lucas RB106. This is because the positive tempco of this zener incompletely cancels the MJ2955 base emitter voltage negative tempco.

This type of regulator acts as a ***variable frequency regulator***. To understand exactly how these work and what determines the switching frequency & duty cycle please see the article on the Dynamo & Alternator Emulator on www.worldphaco.net It is a little more complicated than one might imagine. Essentially the regulator electronics reside in a feedback loop in this system and the electronics form a servo system to control the dynamo output where the measured variable (voltage) is used to adjust the duty cycle (on-off percentage voltage drive) to the dynamo's field coil to ensure that the dynamo output voltage matches reference value. In addition in the compensated regulator scheme here the current is a simultaneous variable controlling the field coil duty cycle because the current effectively alters the reference value. The compensation voltage of -2.86V at 20A is generated by the 0.18V drop across the 9 milli ohm resistor at the load current of 20A which alters the regulators voltage set point downwards by 2.86v.

Physical construction of the MK2c, the RB106 EMULATOR:

IMPORTANT NOTICE: READ THIS FIRST.

There is little point in having a *theoretical* circuit to suit a task if the *physical* implementation of it is inadequate for the said task.

An electronic RB106 for example has specific requirements which go well beyond the types of components and circuits seen in typical household domestic appliances containing devices such as IC's and electrolytic capacitors. The regulator has to tolerate harsh environmental conditions in the car's engine compartment due to large temperature changes there and has to be immune to voltage transients (spikes) which are presented to it both from the car's external circuits but also the dynamo's commutator.

The use of high impedance circuits are undesirable as the unit must also be "humidity immune" Some designers resin pot the circuitry, but this reduces the opportunity for testing & repairs. Low impedance circuits are superior for this application in this respect. It is also important that the unit does not draw standby current and discharge the car's battery in storage.

The RB106 is a "high current capable device" so there are important physical considerations between the D and A terminals. The conductor material type and the conductor's cross sectional area and the rectifier's physical properties need to be adequate with a very wide operating safety margin, of close to a factor of 10. The conductors in the main current pathway need to be brass or copper and the spring washers are copper or phosphor bronze, or beryllium copper. Lucas's original conductors were zinc & silver plated brass, beryllium copper & silver cut out contacts with a section of steel on the cut out armatures (moving arm).

So consider carefully the implications of deviating from the components shown here and be aware that a good "electronic RB106" is just as much a challenge in mechanical engineering as it is in electronics engineering.

The original coils and contacts of the RB106 are removed, leaving the bare metal frame which is attached to the regulator body by a central fixing screw. The frame is removed for drilling. Firstly the holes are marked and drilled. Figure 5 shows the arrangement:

FIGURE 5.
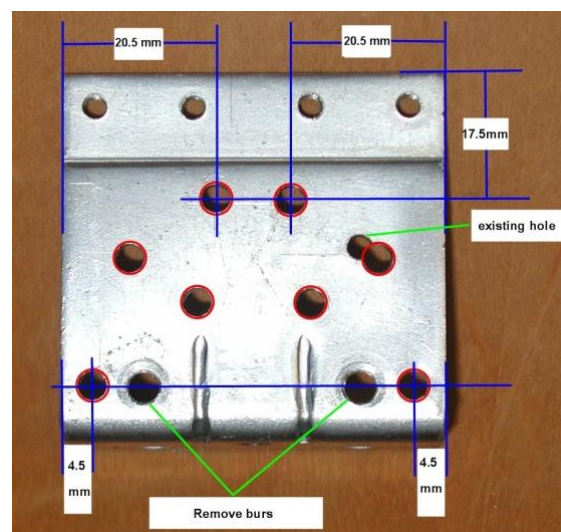
The holes which previously accommodated the adjuster screws often have a sharp edge or bur, so recess these a little with a 10mm diameter drill by hand. Due to the fact that one hole enters the region of a pre-existing hole, the metal frame needs to be firmly clamped for drilling, or the drill will ride into the existing hole.

The fuse is fitted by drilling holes into the black regulator body to fit the fuse clips and cutting down the A and A1 terminals to 5mm above the regulator's phenolic body. Figure 6 shows where the holes go. The 3.5mm hole on the right is placed exactly midway between the A and A1 connections.
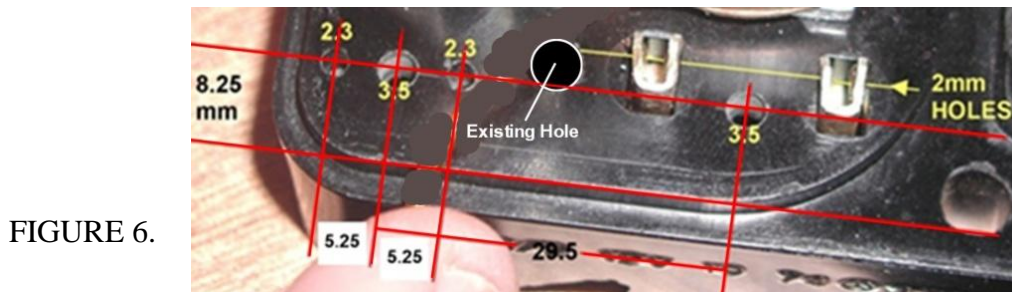
FIGURE 6.

The front Buss fuse clip is fitted by cutting off its small mounting tags and then slipping in a 24mm length of copper wire devoid of insulation (scavenged from the RB106 coils). A small flat is filed on the side of the 4BA mounting screw C to facilitate fitting of this wire, figure 7.

 The cleaned wire A is slipped though the holes drilled in the A and A1 terminals B. The wire passes by the flat on the screw head C. Then the area is soldered together as shown in figure 8 below:
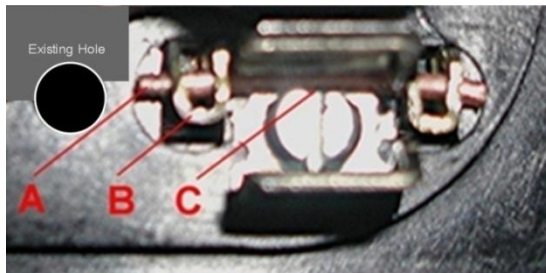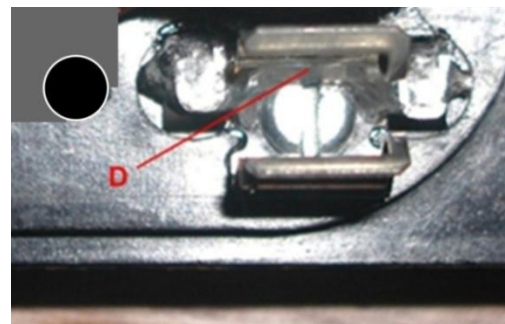
FIGURE 7.   FIGURE 8.

As can be seen the wire is soldered to the fuse clip D in figure 8 and thoroughly soldered to the A and A1 terminals. It is important that before this soldering is done that the inside and outside areas of the cut down A and A1 terminals are polished and free from oxidation. They are silver plated brass.

Drill the *rear* fuse clip centre hole in the regulator body out from 3.5 mm to 4.75 mm or 3/16 of an inch. The idea is to place a small brass spacer in there which is just a little longer than the thickness of the regulators black phenolic body (5mm). So a 3.6mm ID x 4.75mm OD x 5.3mm long spacer is used. These spacers are available from Jaycar (part HP-0862) at 9mm long and need to be trimmed down to 5.3mm.

The purpose of this 5.3 mm long spacer is that when the rear fuse clip screw is tightened up there is a metal versus metal tightening between the fuse clip body, the 5.3mm spacer, the 14.5 mm brass spacer (see below) and the heat flag assembly. Then the black regulator phenolic material is not required to be compressed to tighten the screw. Figure 9

4.75 mm OD & 3.6 ID x 5.3 mm long spacer placed inside rear fuse clip hole: See Text.

FIGURE 9.

Nickel plated 4 BA brass full nut soldered into base of rear BUSS fuse clip
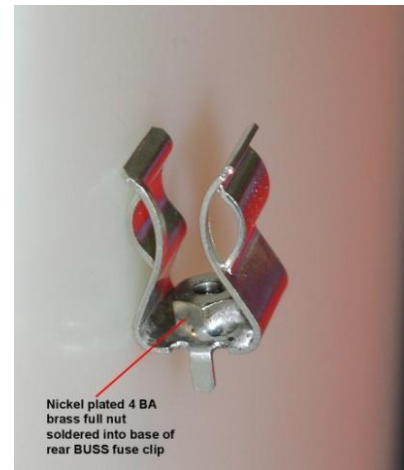
FIGURE 10.

The Jaycar description says these spacers are 3.4mm ID but they fit a 4BA screw (3.5mm) and most I have measured are actually 3.6mm ID.

The rear fuse clip and brass nut can be soldered together. This reduces the electrical resistance and makes for easier assembly too as nut rotation is prevented. The fuse clip has its nut soldered in to it as shown in figure 10. This is done by holding it there with a screw and temporary spacer.

Rectifier assembly:

The main power rectifier assembly fits into the base area of the RB106 body and replaces the function of the cut out in the original unit, only allowing current flow from the dynamo armature's output to the battery and no reverse current. Rectifiers do have reverse leakage current but it is very low for this rectifier in the order of 10 micro amps.

The rectifier assembly is prepared as shown in figure 11:
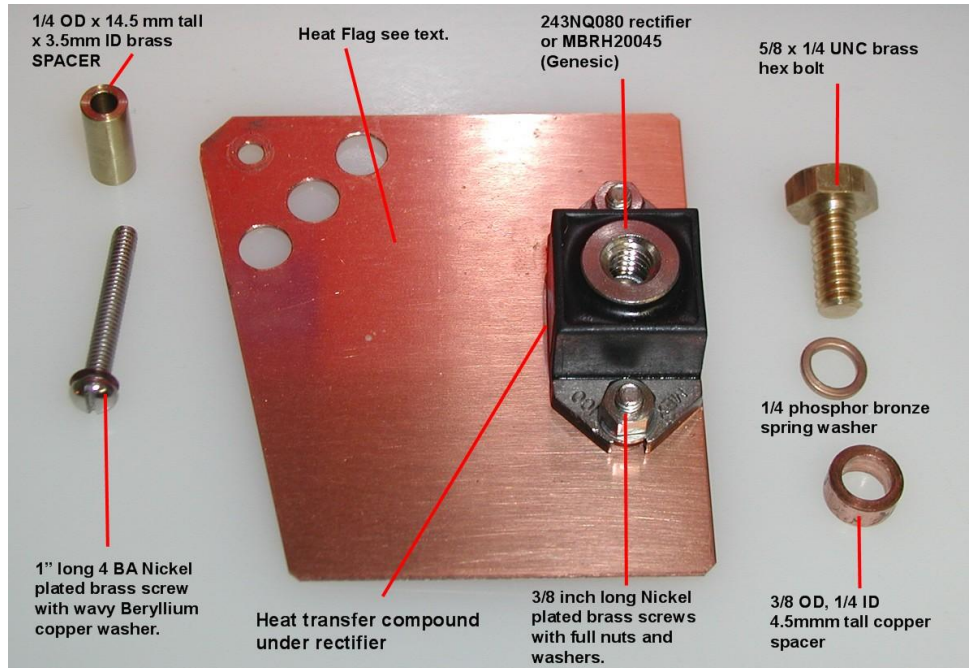
MAIN RECTIFIER ASSEMBLY

FIGURE 11.

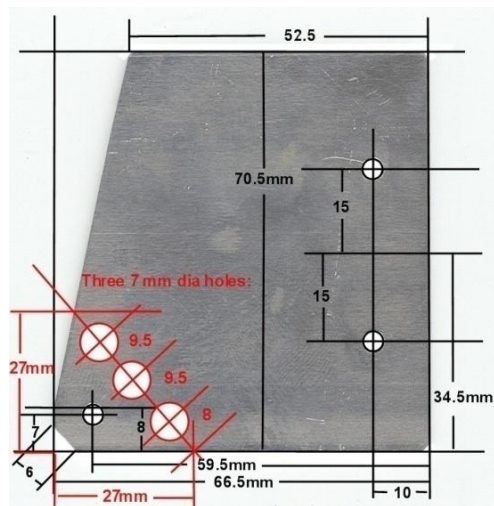The geometry of the heat flag is shown in figure 12:

FIGURE 12.

The heat flag is made from approx 0.63 to 0.7 mm thick copper sheet (0.025"). Suitable material is K & S engineering (Chicago IL) 0.025 x 4 x 10" sheet.

A small tag or "eyelet" board is fabricated as shown in figure 13 & 14 below. This is made of 1/8" thick fibreglass. This board material comes with the eyelets and a small tool to fit them from Ken Watts Audio, Saint Petersburg, Florida USA.
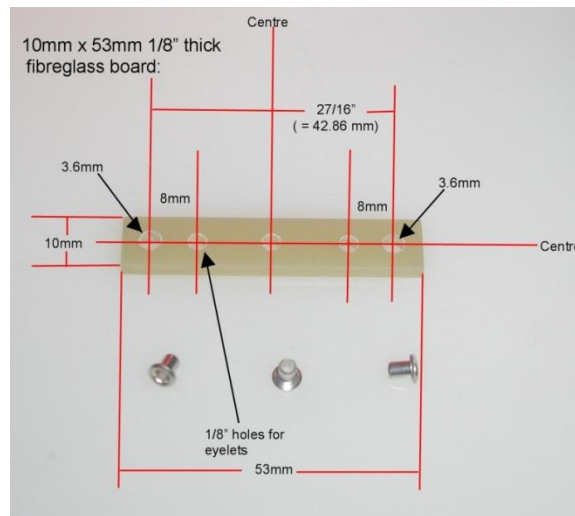

FIGURE 13.

The eyelets are fitted to the board and two brass spacers are used to mount the board, figure 14:
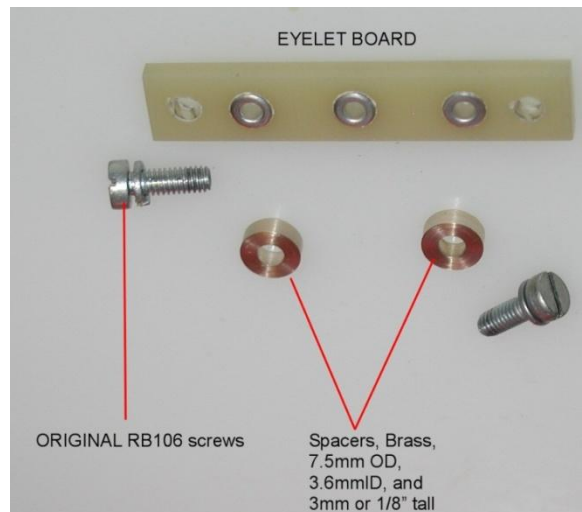
FIGURE 14.

The eyelet board comes in different colours as well as the natural fibreglass colour shown above. It would be sensible for regulator identification, for positive and negative ground versions to use **blue material for the negative ground versions** and **red material for positive ground versions so as** to aid in quick recognition of the regulator as otherwise at a glance they look the

same except for the numbers on the transistors and the reversed diode polarities. Figure 15 below shows an eyelet board made from the blue material:
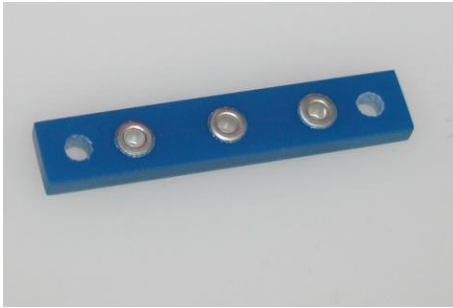
FIGURE 15

The next step is to fabricate is a special copper solder lug made from the same copper sheet material as the heat flag, shown in figure 16 below:
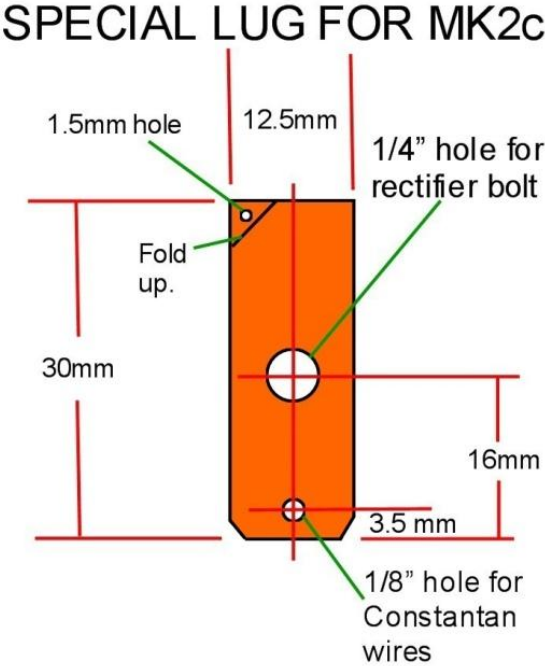
FIGURE 16.

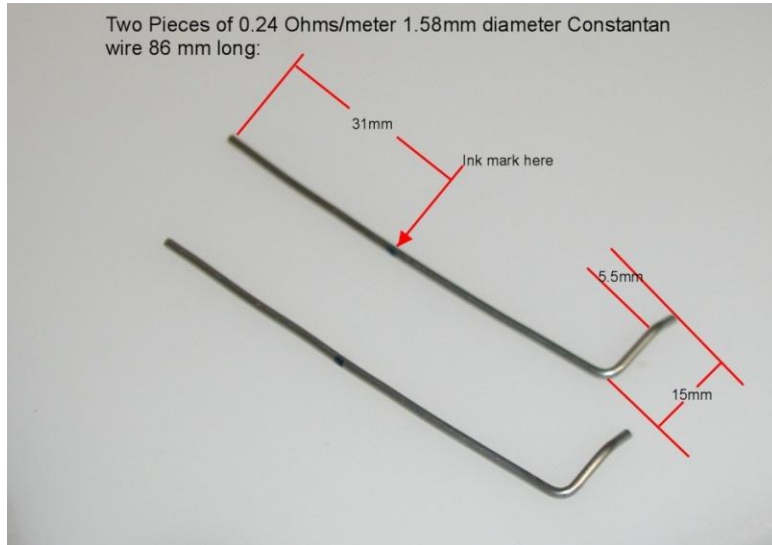Two lengths of constantan wire are prepared as shown in figure 17:

FIGURE 17.

The two pieces of Constantan resistance wire are longer than the actual resistance value required because their soldered ends use up some of their length from the point of view of their electrical resistance. An ink mark is also placed along the length of the wire that will project above the regulator's body (though still under the top cover). This assists in making a round bend in the wire later, which is done by bending it around the shank of a 12mm diameter drill. The free ends then project into the rectangular copper special lug on the top of the unit. This wire is available on ebay UK.

Figure 18A below shows the base of the unit during various stages. The frame holes where the coils once mounted have been drilled out to ¼".The bush for the rear fuse clip is visible. The nut and screw securing the front fuse clip is visible. The 6A10 diode had been added between the field connection and ground connection. The D terminal strap has been cut down along its pre existing sharp fold. Two 1/8" holes have been added to the regulator's phenolic body.
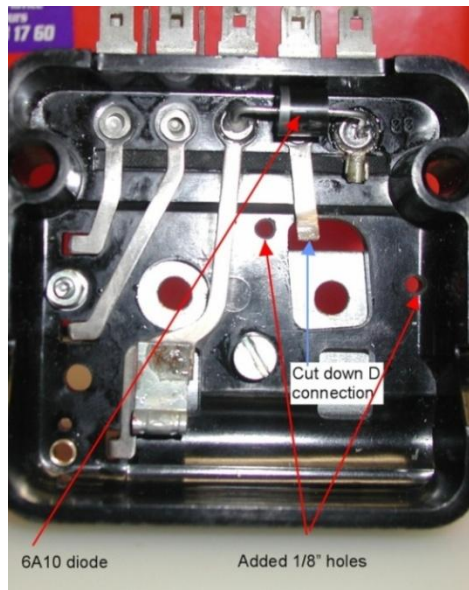
FIGURE 18A.

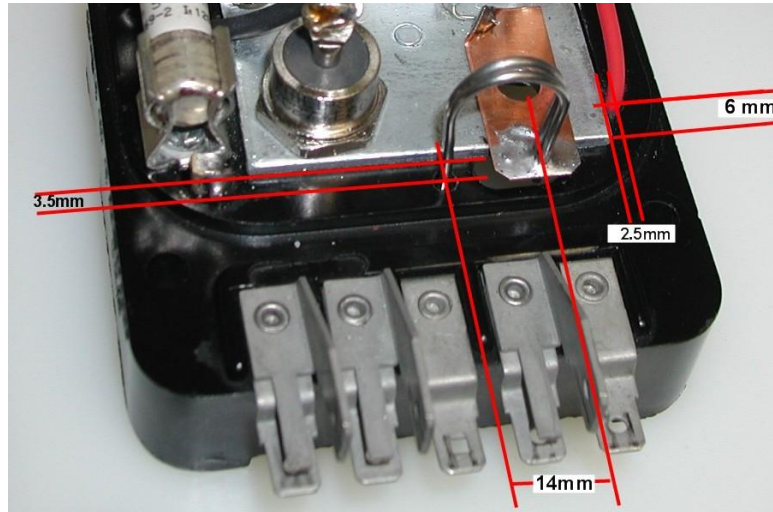Figure 18B shows the locations of the two 1/8 inch holes added to the body:

FIGURE 18B.

 It is very important that before the 6A10 field snubber diode is soldered into position that the internal surface of the rivet on the field connection is cleaned down to the bare brass, as that area is often quite oxidised and could be difficult to solder to if not properly prepared. Some 400 grade silicon carbide paper is used to clean it by rolling it up into a bullet and rotating it in the hole. Do not attempt to solder the 6A10- diode in until its properly cleaned, figure 19. The 6A10 diode was prepared as shown in figure 20.
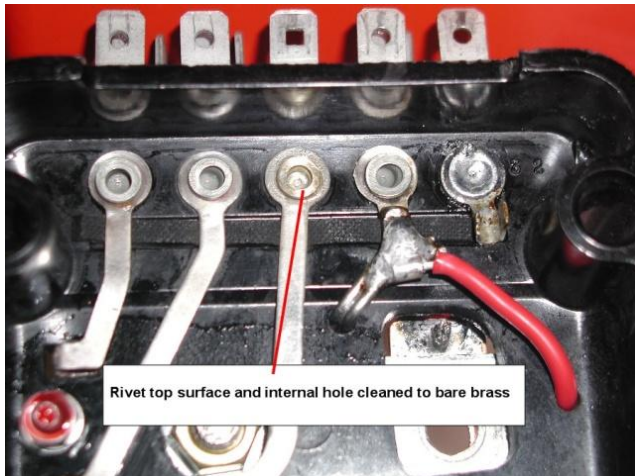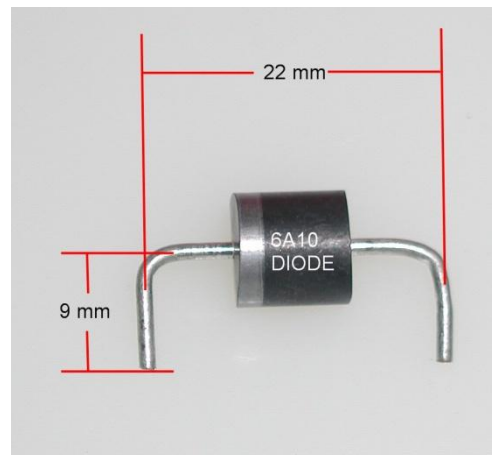

FIGURE 19.

FIGURE 20.

Figure 21 below shows how the D connection folds around the constantan wires for soldering. Also the photo shows the Brass nut securing the power zener diode.
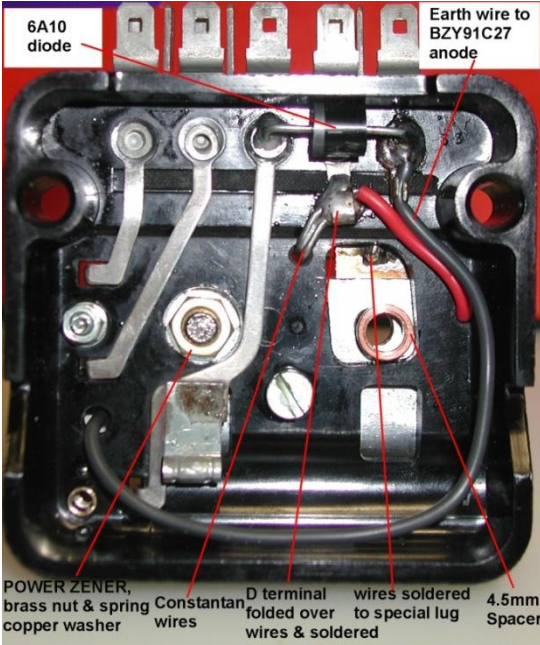

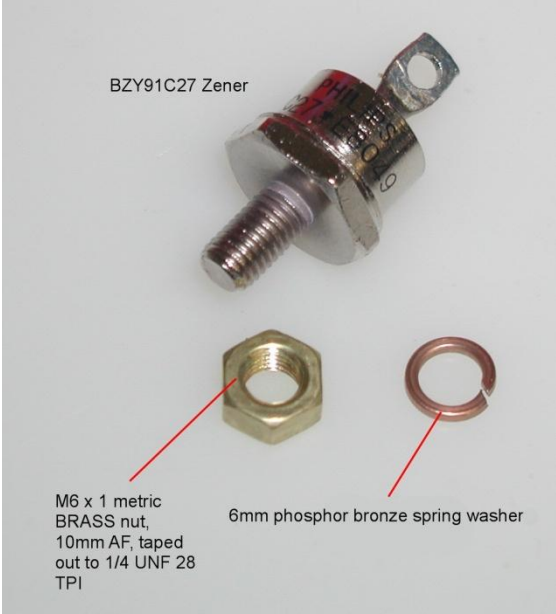FIGURE 21.

The power Zener diode is shown in figure 22:

FIGURE 22.

The usual ¼ UNF steel nut for the zener is not suitable as it is steel which is not ideal and it is too wide across the flats. A new nut is made from an M6 brass nut, by running a ¼ 28 tap through it. The phosphor bronze spring washer is the same type used under the head of the 243NQ080 fixing bolt (alternative includes a 6mm Beryllium wavy washer see parts list)

The hole in the phenolic body, around where the power zener's nut resides is variable in size from early units to later units and is usually 13mm to 14 mm diameter. The area is a little crowded around the zener's nut especially in the later post 1966 RB106 units. Therefore a special tool is made which is merely a reduced outer diameter 10 mm socket so as to be able to tighten the nut properly, figure 23. The rectifier's brass bolt is simply tightened with a ring spanner figure 24.
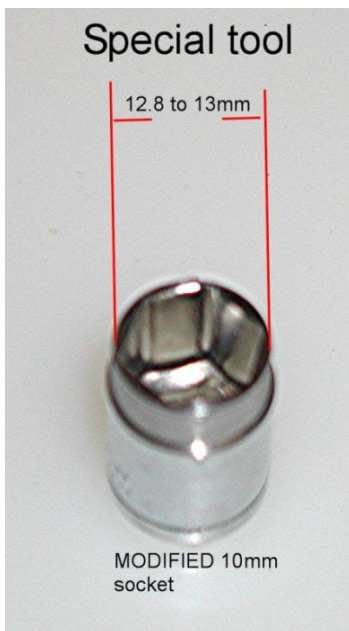

Special tool
12.8 to 13mm
MODIFIED 10mm socket

FIGURE 23.

Ring spanner tightens rectifier bolt

Slim socket tightens zener nut from underneath before rectifier & heat flag assembly fitted.
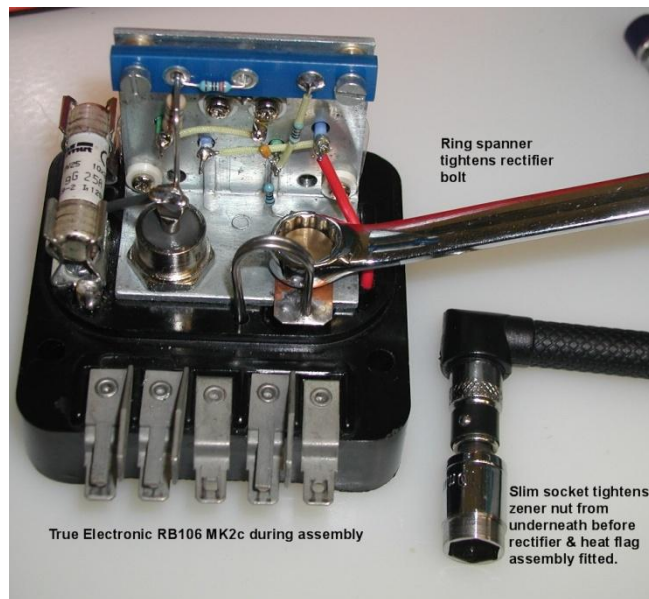
True Electronic RB106 MK2c during assembly

FIGURE 24.

Figure 25 shows a top view after the constantan wire has been folded around. It is best to temporarily thermally insulate the special lug with paper temporarily to assist soldering. To solder these I use a very hot iron, 420 degrees C and high MP solder RS stock part No: 556-503 however standard solder is satisfactory.
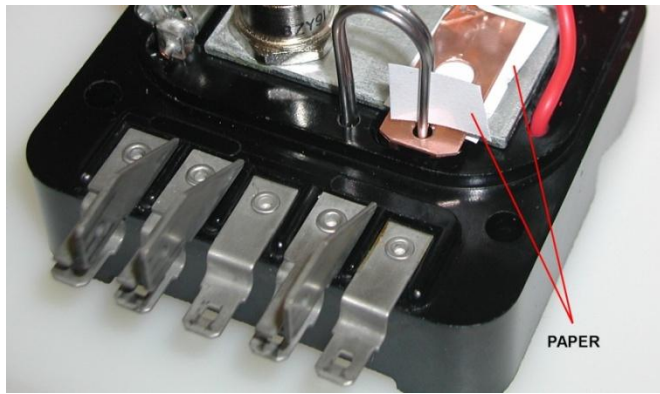
PAPER

FIGURE 25.

Figure 26 shows the result after soldering. The small bent up area in the rear part of the special lug is soldered to the 220 ohm resistor:

FIGURE 26.

The unit depicted in figure 26 is nearly complete except for the rectifier assembly is not bolted in and the calibration resistor not fitted. Figure 27 shows the rectifier assembly fitted to the base.

Note: There are no washers under the heads of the two rectifier mounting screws (their washers are under their nuts between the nut and flat washer). There is one beryllium copper wavy washer under the screw head on the lower left. This screw passes to the rear fuse clip via two spacers. It is important to keep the profile of the screw head as low as possible above the plane of the heat flag to allow clearance with the surface the regulator mounts on, so a thicker spring washer is not suitable here. Also it is better to have the 4BA nut on the fuse clip soldered to it there to keep he electrical resistance low rather than have a spring washer in that location.

FIGURE 27.

To avoid any confusion on how the components are placed the sketch below figure 28 shows the arrangements:
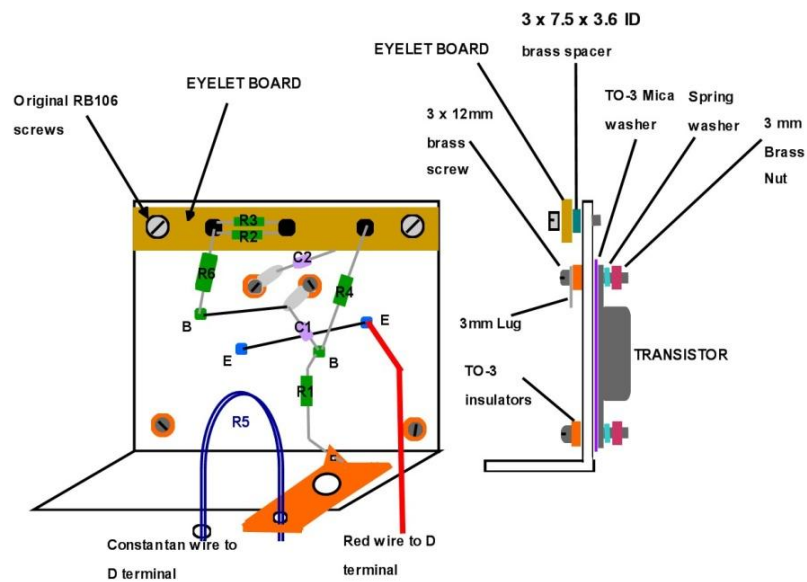

FIGURE 28.

Figure 29 above shows the hardware to mount the heat flag and rectifier. It is important that heat conducting compound is placed between the rectifier & plate.

3.5 mm diameter wavy washers are a less common size than 3mm, however ones intended for "3mm use" have an ID of around 3.3 mm and if enlarged just a little will fit over a 4BA (about 3.5mm diameter screw).True 4BA beryllium copper wavy washers are available too, see parts list.

Mounting hardware for rectifier and heat flag:

4BA x 25 mm(1")
nickel plated brass

4BA x 9.5mm (3/8)
Nickel plated brass

Plain 4BA
washer

Beryllium Copper
wavy washer
goes under screw
head.

4BA nickel
plated brass
nut.

243NQ080
or
MBRH20045

Beryllium
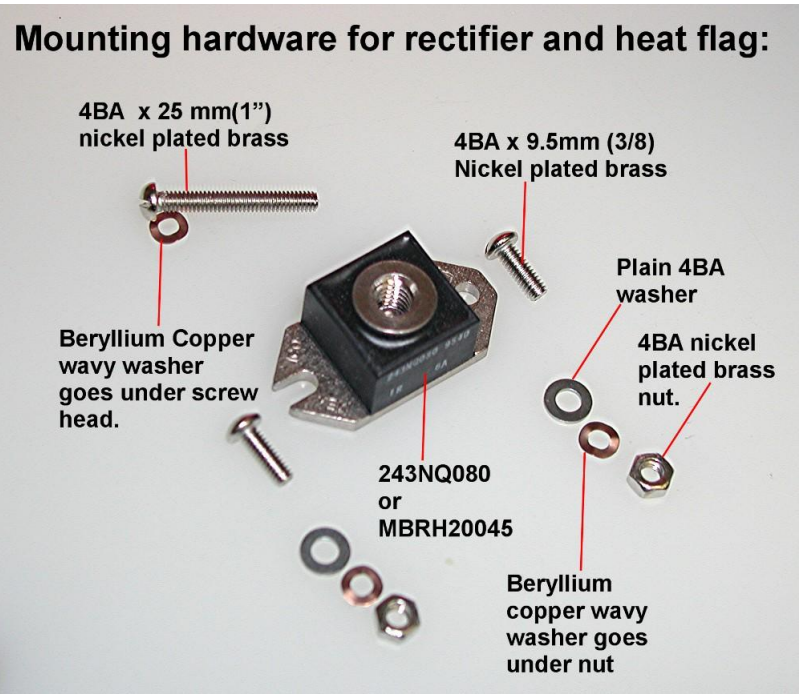copper wavy
washer goes
under nut

FIGURE 29.

Figure 30 shows how a standard ¼ inch Jaycar lug is bent at right angles and used to couple the collector of the darlington transistor to the silver plated brass strap of the field connection. The original section of brass strap is wrapped around the lug and soldered to it:
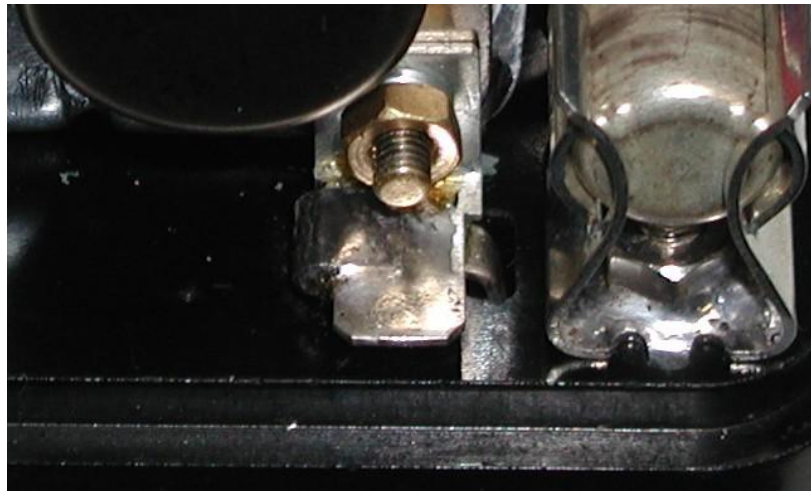

FIGURE 30.

The following series of photos figures 31 to 34 on one page show the views from the top. One very important thing to note is that the darlington transistor 2N6051 or 2N6052 or MJ11015 has

heat transfer compound on both sides of its mica washer. The MJ2955 has no heat transfer compound, just the washer.
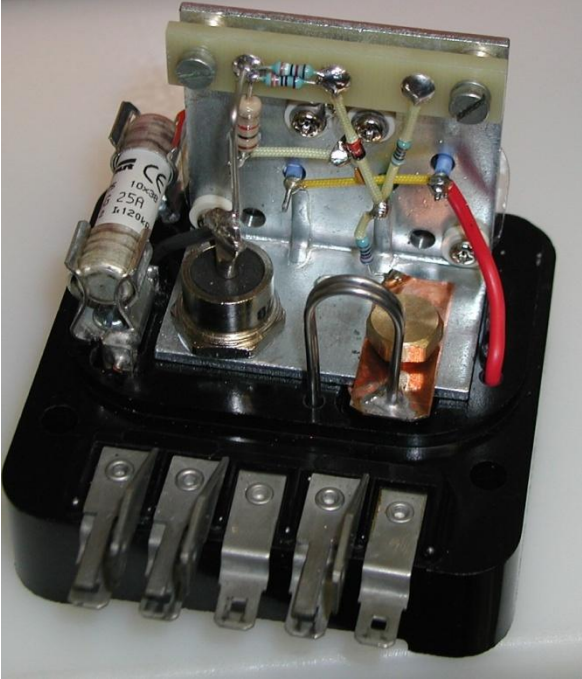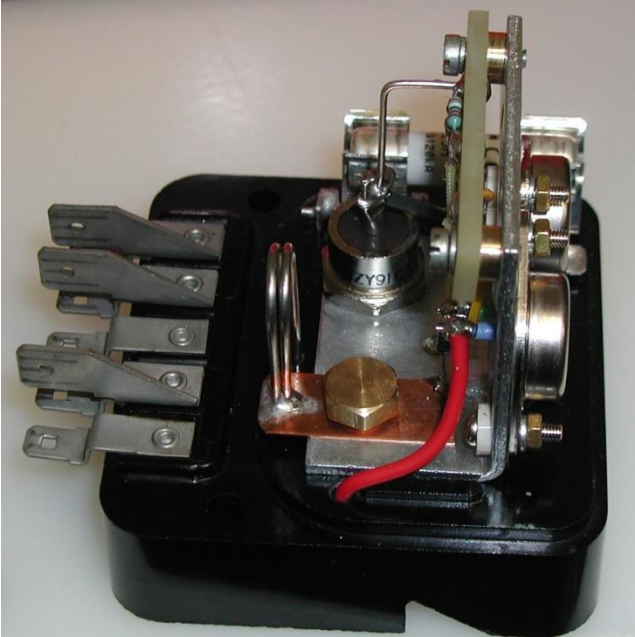

FIGURE 31.

FIGURE 32.

FIGURE 33.

FIGURE 34.

Benefit of the Power Zener diode:

The recording below figure 35 shows how the power zener clamps high voltage spikes emanating from the dynamo armature which appear under certain circumstances. With the battery connected and any significant load of an amp or more these spikes vanish. However, if the battery gets disconnected and with very low load the spikes are very large. I was able to measure them despite their narrow nature at their apex by using the calibrated trigger level threshold on a 2465B oscilloscope. The highest recorded value was 80 volts. The power zener clamps them off beautifully at 27v.
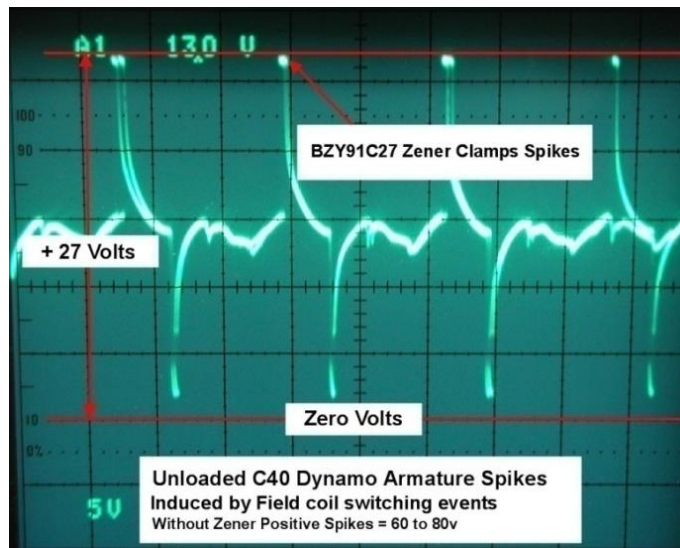

FIGURE 35.

With a dynamo & regulator in use, the mechanical cut out or the rectifier has conducted the D connection to the A & A1 connections (battery and load) at around 12.6 to 13V before field coil switching begins which is normally at the regulation voltage of 14V or above. So the spikes are not generally seen in use. However if the battery A and load A1 terminal get disconnected with the dynamo running, then the spikes appear and the zener limits them. In the calibration process the A and A1 terminals are disconnected and the regulator is in the completely unloaded condition. (The spikes are caused by the leakage reactance of the field and armature windings and coincide with the filed coil switching transitions).

The zener conducting in its forward direction with applied reverse battery polarity helps to protect the field snubber diode (6A10) and the collector-emitter diode inside the darlington transistor also.

POSITIVE GROUND VERSION:

Some enthusiasts may require a + ground version for cars that are still running that original system. This is easily achieved by merely using the complimentary components. Also the 6A10 diode and the 7v5 zener diode need to simply be physically reversed. Every thing else stays the same. The table below shows the complimentary polarity parts:

Negative ground	Positive ground
MBRH20045 or 243NQ080	MBRH20045R (Genesic)
MJ2955	2N3055
2N6051 or 2N6052 or MJ11015	2N6058 or 2N6059 or MJ11016
BZY91C27	BZY91C27R

The BZY91C27R for the positive ground version can be a little difficult to obtain, but the BZY91C22R and BZY91C30R, which are just as satisfactory are available from Langrex Supplies in the UK. Any DO-5 cased power zener in the range of 22 to 33V with anode to stud for the positive ground version is satisfactory. For example the 1N3321B is available from Newark or Element 14, part 1862957 or 10P4863.

Spring washers:

Ideally the spring washers are copper, phosphor bronze or Beryllium copper. Various UK ebay suppliers have these. (6mm versions clear a ¼ inch diameter bolt).

The 3 mm spring washers are used under the transistor mounting nuts. The 6mm spring washers; one is used under the rectifier bolt, the other under the power zener's nut.

3mm Copper Spring Washers EMS Electronics UK

FIGURE 36.

6mm phosphor bronze spring washers
Balls fasteners UK.

FIGURE 37.

Parts List to build the True Electronic RB106 MK2c:

Part numbers in red are Element 14, green RS components and blue Jaycar Electronics.

Resistors Generic 1/4W metal film

220R, 3k3, 9k1 & the Calibration resistor to be determined during calibration (approx 39k).

1 watt resistor :1k0

Transistors: (generally available on ebay or many suppliers- though see notes below)

T1   MJ2955 (Or 2N3055 + ground version)

T2   2N6051/2N6052/MJ11015 (Or 2N6058 /2N6059/MJ11016 + ground version)

Axial Ceramic Capacitors:

1 x 0.022uF / 100v   538-1685

1 x 0.1uF / 50v   538-1663

Diodes:

D4 6A10 rectifier.

D3   1N4737A, 7.5V 1 watt Zener: 146-7575 or Jaycar part ZR-1408.

D1 MBRH20045, 200A 45V Schottky power rectifier for neg earth version. Newark part 19T9484.

(Or D1 plus ground version MBRH20045R. Newark part 19T9485)

Or 243NQ080 Rectifier for neg ground version, GoldenO on ebay.

D2 BZY91C27 ebay for **– ground version.** Or for **+ ground version**: BZY91C27R; Donberg Electronics Ireland. Or 1N3321B, Newark 10P4863, or BZYC91C30; Langrex Supplies UK).

Screws/nuts:

1 x 4BA BRASS 1 inch long screw, to secure rear fuse clip via the 14.5mm spacer/heat flag and via the small 5.3mm spacer: RS 482-8981

4BA full nuts x 3 483-0580. (One to be soldered into fuse clip, the other two for the rectifier)

Two 3/8 (9.5mm) long 4BA nickel plated screws for the rectifier RS 482-8953.

3 x M3 beryllium copper crinkle washers (enlarged a little to fit 3.5mm or 4BA) 289-657 for heat flag assembly

(True 4BA beryllium copper wavy washers are available from RS 289-736 and these probably have an internal diameter around 3.7mm).

Four generic 3mm x 12mm or 3 x 15mm long *brass* metric screws & *brass* metric nuts to mount transistors.

Four M3 Copper spring washers for the two transistors (EMS Electronics UK on ebay).

Two M6 phosphor bronze spring washers for zener nut & rectifier bolt (Balls fasteners UK- on ebay).

5/8 Brass ¼ UNC hex head bolt (ebay and many engineering suppliers).

M6 x1 Metric brass nut, tapped out to ¼ 28 UNF for the power zener. These nuts are 10mm across the flat.

Two 4BA steel screws & spring washers retrieved from the disassembled RB106 contact assemblies.

Insulators & lugs:

Mica washers & insulators for TO-3 Jaycar HP-1122.

One ¼ inch lug, Jaycar PT4910. Used for darlington collector to field strap connection.

M3/6BA plain wiring lugs, RS part 186-7860.

Sundry items:

One RB106 regulator donor (post 1966 units are best), screw or spade terminal version for converting (avoid very early thick base B90 units)

Spacers HP-0862 to make the 5.3mm spacer, for the regulator body under the rear fuse clip.

Approx 0.7 to 0.9mm diameter tinned copper wire small amount needed for hook-up wire.

25A ceramic fuse 499-481 Ferraz & Shawmut.   2 x BUSS fuse clips: 120-5149.

One 14.5mm long, 3.5 mm ID, 6.35mm OD brass spacer.

One 4.5mm high copper spacer with ¼" hole, OD approx 9.5mm.

Copper plate: K&S Engineering, Chicago IL, Copper Sheet 0.025 x 4 x 10. www.ksmetals.com

Heat transfer compound for power rectifier and darlington transistor.

1/8 thick fibreglass material & eyelets & tool from Ken Watts Audio. Suggest blue colour for negative earth versions and red colour for positive earth versions to aid in quick identification.

Silicone rubber sleeving for transistor wires, taken from silicone rubber hook up wire.

ADVICE ON SELECTING ELECTRONIC COMPONENTS:

The 7.5V zener diode:

Ideally for this project the 1N4737 zener diode is a 7.5V diode. These diodes have quite a spread in fact from near 7.2 to 7.8V in actual practice. It is best to buy a few of them and select one with a voltage in the 7.35 to 7.65 volt range. This is done by placing a 2k2 resistor in series with the diode across a 12V battery, the zener voltage is measured with the digital meter.

Selecting transistors:

Unfortunately these days there are a number of cloned/faked/counterfeit transistors about with poor sized transistor dies inside them and shoddy construction. The MJ2955 and the 2N3055 have fallen victim to this and possibly the MJ11015 and MJ11016 too. The 2N6051/8 and 2N6052/9 were not likely targets for cloning. "Cloning" in itself would not be a problem if the manufacturing quality and the actual semiconductor crystal matched the original design, but it is cheaper to make inferior ones and there in lies the incentive for fake devices. Due to the fact that in this design the transistors are significantly over rated for their tasks, even a fake device would work, but it is still better to have genuine quality transistors.

 One way is to avoid this problem is to go for transistors with genuine looking manufacturer markings/logos and early date codes eg 1970's 1980' and early 90's that look like new old stock. Also military spec versions with JX or JANTX in the number are likely to be excellent and not cloned. RCA, Motorola & Fairchild are recommended types.

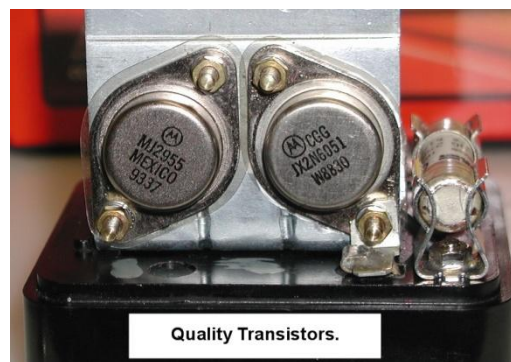Figure 39 shows some quality transistors, a 1993 Motorola MJ2955 and a 1988 Motorola JX2N6051:

FIGURE 39.

Construction Hints:

The "point to point" wiring used in this unit is not a common technique nowadays because circuit boards have taken over. However the technique is highly suitable for a circuit system where there are very few components. It saves on the cost of a PCB. It requires lugs or terminals of some kind to attach the components to. In most case the components are firmly attached before the solder is applied. The TO-3 transistor pin is robust enough to connect components to. The diagram of figure 40 shows how a component lead is wrapt around the pin before soldering.
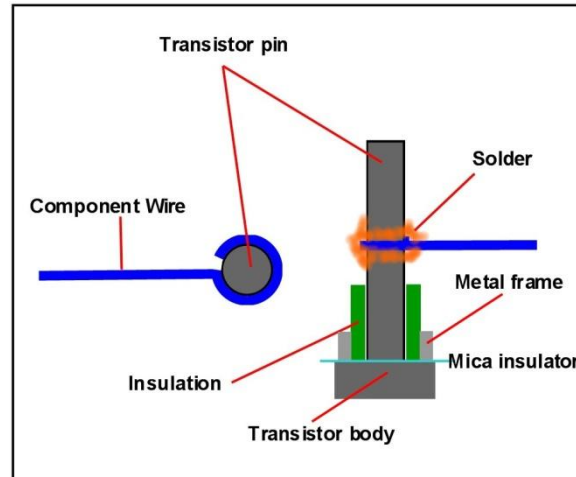

FIGURE 40.

It is also advisable to place some thick sleeving around the transistor pins in the hole areas where they pass through the metal frame. This was once all standard practice however possibly now unfamiliar to those using PCB's. The insulation stops solder or other debris shorting the transistor pin to the metal frame that the transistor mounts on. I prefer silicone rubber insulation taken from silicone rubber hook up wire for this application. Thin spaghetti like sleeve can also be placed on the component leads.

Calibrating the electronic unit:

Since the cut-out function is performed by the 243NQ080 rectifier no adjustment is needed as the rectifier automatically makes sure the dynamo's D voltage is coupled to the battery when the D voltage is higher than the battery voltage and it uncouples the armature (D voltage) when the D voltage falls lower than the battery voltage.

 Also since this unit is the "electronic replica of an RB106" the calibration can be performed just as for the original RB106, as specified in the manual, by setting the open circuit voltage to 16V at 20 degrees C ambient temperature (or 16.1V @ 10 degrees C). This is done by adjusting the

resistor value in parallel with the 3k3. A standard resistance wheel or potentiometer (with a 1k current limiter resistor in series) is placed across the 3k3 and the nearest standard value chosen. To do the calibration the A and A1 terminals are simply unplugged from the regulator and the D terminal voltage monitored with a meter and the engine rpm run at 2000. A high quality Analog meter is very suitable for this test as voltage spikes are integrated.

For calibration at any other **ambient temperature Ta (Deg. C)**, then the D voltage should be set to:

$$\text{CALIBRATION VOLTAGE} = 16.20 - 0.1Ta \quad \text{Volts}$$

Of the two units I have built, both needed a 39K calibration resistor.

SUMMARY:

The MK2c unit is a unique and simple unit. Its equation and functionality matches that of the original RB106 and its behaviour almost indistinguishable from it:

 It behaves exactly as the RB106 would if both the battery and external loads were connected to the regulator's A1 terminal. At maximum load the behaviour is identical regardless of this small difference for D terminal voltage as the A current is near zero and all the load is A1 current anyway. This arrangement gives just a little more compensation having the battery effectively connected to A1 rather than A as this helps to limit very high battery charging currents.

The thermal behaviour of the unit has a practically identical temperature coefficient. On testing the drop in voltage with frame heating is about 0.027 to 0.033 volts per degree C of the frame temperature which matches the original Lucas unit too.

The advantage of this all electronic unit is that it is very simple & robust and conforms to Lucas's original design intentions for a **compensated voltage regulator and conforms to Lucas's RB106 equation** and it has none of the wear or reliability or adjustment issues of the electromechanical unit. Comparing the electronic to the electromechanical unit and at 20 amps A1 load the D voltage output has dropped to 13.1V for both units which is the battery "charge neutral" voltage (very low charge current) for a well charged battery. Looking at the voltage drop from the D to A terminal at full load (20A total on A1 and A) is close to 0.26V in the original RB106 and 0.65V (hot) in the Electronic RB106. The 25A fuse & connections drop approximately 0.1V @ 20A and the Constantan wire 0.18V @ 20A and the rectifier 0.37V @ 20A, making the 0.65V total from A to D in the electronic RB106.

Note, that that full load of 20A on A and A1, the total dynamo D current output is 22A as 2A is directed to the field coil. Also, with a well charged battery, the current via the A terminal is very low as the voltage at that point is 13V (charge neutral) and the full 20A passes via the A1 terminal.
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