THE 1960 ERA GERMANIUM ELECTRONIC DYNAMO REGULATOR (RB106 SUBSTITUTE)

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Background & History:

Would it have been possible to build an electronic dynamo regulator for the Lucas C40 dynamo in the year 1960? If so what semiconductors would it have contained, what would the circuit have looked like and what would the unit have looked like? The answers are in this article.

It does beg the interesting question why Lucas didn’t build an electronic dynamo regulator. Possibly because as their experiences with electronic controls increased in the mid 1960’s dynamos were already being phased out. Alternators were set to replace them. In the mid 1980’s Bosch built the only commercially successful electronic dynamo regulator, the 30019, as a replacement for one of their older electromechanical regulators. These contain silicon transistors and a Mosfet output stage to drive the field winding.

This article describes an electronic dynamo regulator composed of 1960 vintage germanium transistors and germanium power rectifiers of Philips manufacture. This regulator replicates the electrical properties of the original electro-mechanical RB106 and conforms closely to the equation for this unit. See article on the RB106 Emulator for the RB106’s descriptive equations:


Compensated voltage regulation versus fixed voltage and fixed current control:

The compensated system is a mixture of current and voltage dynamo control where the current loading affects the output voltage. It provides good dynamo protection from overload. At the full A terminal current load of 20A the voltage limits to 13V and the battery charge current (for a well charged battery) is near zero and the power is directed to the headlamps and other loads. The battery does not discharge or charge at maximum dynamo load unless the battery is in a discharged state. The dynamo supplies 20A x 13V = 260 watts which is the C40 dynamo’s maximum rating, plus the 2 x 13V = 26 watts consumed by the dynamo’s field winding which the dynamo itself has to support.

In contrast, in a fixed voltage control and current limited system, say 14.3V, then the A current needs to be threshold limited to 260/14.3 = 18 amps for the same 260 watt dynamo power output. If this is not done then the dynamo will be pushed harder than Lucas intended. In addition a proportion of the 18A current will be directed to the battery because 14.3V is not “charge neutral” even for a well charged battery and less current is available for the external loads. Fixed voltage and current regulation also requires more complex circuitry with a current detector, which needs to be either a current mirror system monitoring the voltage across a resistive load, an OP amp or a Hall current detector system etc. This adds to the circuit complexity increases the fragility and component count. As will be seen the compensated regulator design can be
elegantly executed with only two transistors and faithfully follows Lucas’s design functionality for controlling the C40 dynamo.

Therefore after many years of experimenting with regulator designs I have come to prefer the compensated design for the Lucas C40 dynamo control over any other system. It also preserves the originality of function of the car’s electrical system, including the behaviour of the amp meter. Amp meters are less informative in fixed voltage charging systems (like the alternator system) and that is why "ammeters" were dispensed with and replaced by volt meters in cars running alternators with fixed 14.3V charging systems.

The Germanium regulator described here uses a compensated dynamo control system which I designed to emulate the electrical properties of the original Lucas RB106 control box. In this system the zero load output voltage is set to 16V @ 25 degrees C. With the normal daytime load in the car the dynamo output voltage limits to around 14.4 to 14.8V. With increasing loads such as night driving/headlamps the voltage is lower and at full load of 20A the D terminal the voltage is limited to close to 13V which is charge neutral for the battery. Also 1.5 to 2A is directed to the field winding.

The schematic for the Germanium Electronic RB106 is shown below which operates at a maximum D current of 22A provided by the C40 dynamo:
Some Germanium devices from Electronics history:

Germanium is a very interesting semiconductor. It has 4 electrons in its valence shell, just like silicon or carbon. The electrons of the germanium atom are grouped according to the energy they possess and are arranged in shells. The first group is the k shell with the least energy containing two electrons. The next shell is the L shell containing 8 electrons and the third group is the M shell with 18 electrons and the 4th group, the N shell, or valence shell which has 4 electrons. Germanium atoms combine together and share electrons to create 8 electrons in their N shell to attain a stable state. So they form a lattice like 3 dimensional structure much like silicon or carbon in its diamond form. N germanium is doped with Arsenic which has 5 electrons in its outer shell and supplies free electrons while P germanium is created by doping with Indium which has 3 electrons in the outer shell creating “holes” These are sandwiched together to create a PN diode or in three layers as a PNP or NPN transistor.

Until the early 1960’s Germanium was used extensively in the manufacture of transistors and diodes of many types. The very first transistor radios used germanium transistors. For example the early very successful Regency TR-1 radio and the Sony TR-72 portable transistor radio from 1955 used NPN germanium transistors. This was unusual as most early types of germanium transistor were PNP although Philips did make the OC139/140 NPN types for computer switching applications. One of the early successful Philips/Mullard power transistors was the OC16 released for sale in 1958 and 32V rated and could deliver 2 watts to a speaker in Class a use and up to 9 watts with a pair in push pull and a 14V system.

Germanium diodes and transistors have high reverse leakage currents compared to silicon devices and have a lower safe operating temperature range however they have other useful properties. The forward voltage drop of a germanium diode (around 0.2 to 0.3V) is lower than silicon (0.7V). Also the collector- emitter saturation voltage drop is very low for germanium power transistors in the order of only 0.1 to 0.15V versus 0.4 to 0.5V for a saturated silicon transistor. This makes germanium power transistors very attractive for low voltage high current switching applications. In fact two germanium power transistors were used virtually universally in the 1960’s for DC/DC converter applications such as 12V DC to 400V DC in a push-pull self oscillating circuit called a Royer Oscillator. The operating frequency of this sort of converter depends on the time it takes for the primary winding of the transformer to begin to saturate. This is the type of oscillator used in many early CDI units to charge the CDI’s discharge capacitor. See article on CDI vs MDI:

www.worldphaco.net/uploads/CAPACITIVE_DISCHARGE_IGNITION_vs_MAGNETIC_DISCHARGE_IGNITION..pdf

The early Philips/Mullard AF114 to AF117 signal transistor range worked well to 30MHz and far exceeded the performance of the original black painted glass body OC44 and OC45’s of early transistor radio fame as they had a much lower collector to base feedback capacitance and did
not require neutralisation when used in transistor radio 455KHz intermediate frequency amplifier stages. The AF118 was an early 70V rated video output transistor used to drive the cathode or grid of a television picture tube in battery operated portable TV sets of the mid to late 1960’s.

(Sad Note: Unfortunately the entire range of AF114-118 and OC169/170 RF transistors have now failed or are about to fail due to the combination of metal encapsulation with a silicone grease fill, because metallic whiskers grow and short the transistor electrodes out. This was cured in the replacement series AF124-127 which, like most modern transistors are resin filled. A highly suitable replacement for the original AF114/OC169 series with a similar look is the AF178. Silicone grease filled glass case transistors do not have this problem. There was no Philips replacement for the AF118 and the best option is the Hitachi 2SA358).

Some germanium signal transistors had very impressive specifications and worked very well right up into the VHF and UHF region. Transistors such as the AF178 were used in Television work and have excellent RF performance and low noise with high gain up to 260MHz. To see a radio constructed from AF178 devices and two OC16 audio output transistors in class AB see:


The AF239 and AF240 for example were good for mixer oscillators right up to 890MHz and were used in television tuners in the late 1960’s.

Germanium power diodes were a little rarer. The one which set the benchmark for high current capacity (max 12A) was the Philips OA31 released in 1959. These power diodes have electrical properties which are not dissimilar to a modern Schottky power rectifier, with low forward voltage drop but more reverse leakage than a standard silicon rectifier but usually not more than 40uA at 15V reverse and 25 degrees C.

One of the most impressive germanium power transistors of the 1960’s was the Philips ADZ12 rated at 80V VcBo and 20A collector current and 45 watts dissipation. This type was electrically similar to the RCA 2N174. By the early 1960’s other large TO-36 cased germanium power transistors such as the RCA 2N441 had found their way into the class A audio output stages of “Hybrid” car radios which used low (12V) anode voltage tubes, such as the EF98. To see a radio crafted with low voltage anode tubes and a single germanium output transistor see:


Germanium power transistor technology, prior to its demise, had evolved far enough to develop impressive TO-3 devices such as the RCA 2N3731 which would work as a line output deflection transistor in a 12V DC operated 12 to 14 inch TV sets, which is quite a demanding task, in both the frequency of operation and the currents involved and the very high peak voltages on the transistor’s collector circuit. Similar European germanium types were the AU104 with lower collector voltage ratings.
Another area where germanium transistors dominated was in very low voltage work, such as transistor radios running of 3V (two AA cells) or 3V Dictaphones where the lower voltage drops of the germanium was useful especially as the batteries discharged. Germanium signal diodes “crystal diodes” were useful in crystal set applications due to the very low forward voltage drops at low RF currents and were used in detector circuits of many radios or in ring modulator/demodulator circuits and have only been rivalled over the last few decades by the more modern HP 5082 series Schottky signal diodes.

Germanium devices, as it turned out, were not suitable for fabrication into integrated circuits and due to the higher leakage properties and poorer temperature tolerance were largely abandoned in favour of silicon devices by the late 1970’s. The invention of the Mosfet also ensured that low on state voltage drops could be achieved without needing a germanium device.

Selecting 1960’s semiconductors for the Germanium RB106 and building the unit:

The power rectifier of choice is the OA31, released by Philips in June 1958. These diodes are beautifully made and have a clear glass-metal seal which is very interesting. The partial data sheet is shown below:
Given these are 12A max rated, the RB106 requires 3 or 4 of these run in parallel to share the load. This is permissible if the diodes are fairly closely matched. A lower current (3.5A) vintage germanium rectifier is an AAY10, rated at 3.5A also is a useful diode for a field snubber.

The germanium switching power transistors of choice are the ASZ15 to ASZ18 range, these were released in 1960. A partial data sheet is shown below. These transistors in this application have very low collector-emitter saturation voltages of around 120mV. The body is bright nickel plated very smooth copper and the original Philips parts were as reflective as a mirror to look at.
Constructing the Germanium RB106:

To gain adequate heat sinking the OA31 rectifiers are bolted into a finned aluminium case. A copper cathode lug was placed under the diodes with heat transfer compound.

The Aluminium body of the regulator was constructed from an unused case from a Delta MARK 10B CDI kitset. This case was cut down in length. These aluminium cases are high quality gold anodized and contain sockets for two TO-3 power transistors. The off-cut of the transistor heat-sink part of the case was saved and added to the rear case assembly behind the rectifiers.

The PCB for this unit was arranged to slot into the case just as the original PCB’s in the Delta MK10B unit did. The PCB is fitted with brass eyelets where the wires connect:
The transistor heat-sink part of the case is shown with its original riveted TO-3 sockets. The view below shows the ASZ17’s.

The photos below show various stages in the construction:
The brass bushes/inserts ensure that when the screw connections are tightened it’s a metal vs metal compression rather than compressing the insulation material. Lucas did this with the original spade connections on the RB106 (except they used brass rivets).
Brass straps (1/4 inch wide and 0.8mm thick) make the connections on the bottom plate. The screws are 4BA nickel plated brass. The 6mm thick Bramite spacers have a captive nut, so the final Bramite base plate can be retained to cover all the connections. The photos below are of the PCB during assembly:

The photo below shows a view looking down into the completed unit. The Zener diode used is a vintage Mullard OAZ212. (All zener diodes of the 1960 era were silicon). The other photo shows the base plate fitted, also made from a 6mm thick Bramite panel.
The photo below shows another view of the unit under construction and the diagram for the artwork for the top cover. The pattern of the germanium atom is engraved into the 3mm thick satin silver anodized aluminium plate and the engraving filled with black paint:

CALIBRATING THE ELECTRONIC RB106:

Due to the fact that the unit is an electronic facsimile of the original RB106 electromechanical unit therefore it is calibrated in the same way. The open circuit output voltage is set at 16V @ 20 deg C (with the A &A1 terminals disconnected). Then at full load of 20A the compensation pot is set so that the D voltage is 13.2 Volts. The process is repeated twice as there is a small interaction between the controls. In use the output voltage with typical loads in the car is in the order of 14.4 to 14.8V day driving and around 13 to 13.8V night driving typical of the compensated system.

One interesting advantage of this particular design is that both the open circuit (unloaded) output voltage and the full load (20A) output voltage independently adjustable. This means that this behaviour of the charging system can be adjusted for local conditions or the proportions of day or night and night driving. For example if the driving pattern is predominantly daytime the unloaded output voltage can be decreased.

The following image shows the Germanium RB106 being tested in the RB106 test machine:
The following photo shows the typical waveform from the F terminal driving the field winding of the C40 dynamo with the regulator use with a dynamo shaft rpm of 3500 and an output current of 5 amps also an under bonnet photo Germanium RB106 Regulator running in 1966 TR4A: