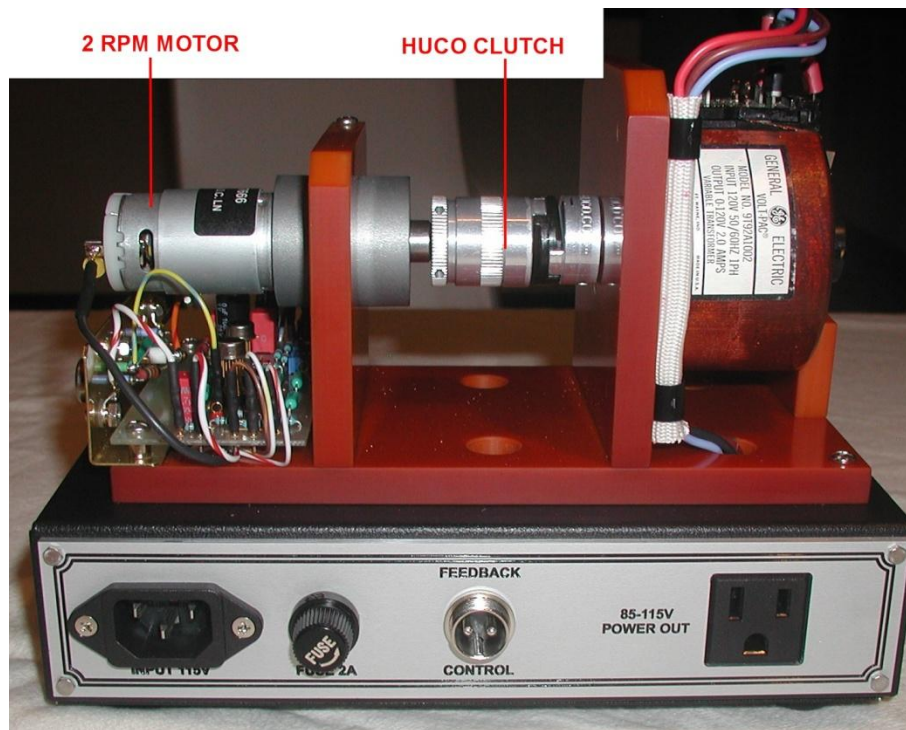


THE CONSTANT VOLTAGE MACHINE

H. Holden. October 2020.



BACKGROUND:

The idea behind this machine was to have an adjustable 115V stabilized power source to run vintage computer apparatus, such as S-100 Computers. It could be used to run many other types of equipment, radios, amplifiers etc.

The SOL-20 computer for example, common to many S-100 bus computers of the 1970's era, has a power transformer based analog power supply. These have full wave rectifiers and very large value filter capacitors.

The SOL has its own +5V and +/- 12V voltage regulators with an 18000uF filter capacitor for the motherboard's 5V supply. However, the power rail for the computer's backplane, from which most of the energy for the add in S-100 cards is delivered, is an 8V rail, derived from a separate winding on the transformer & bridge rectifier and 54,000uF filter capacitor.

In the case where the computer is fully loaded with S-100 cards, in my SOL-20 computer at least, with the line voltage adjusted for 94v, it results in 8V on the rail feeding the S100 card backplane. Due to wiring voltage drops there is about 8.6V across the 54,000uF reservoir capacitor.

Measurements also show that in this condition there is about 7.3V across the 18,000uF capacitor, feeding the SOL's own power 5V regulator system. This is about as low as it is wise to take the **pre-regulator voltages** and still allow for some voltage fluctuations, while keeping all the regulators to a minimum of heat dissipation.

The standard 7805 regulator, so common on S-100 cards, requires at least a 7.5V input, or a minimum of a 2.5V input to output drop.

The SOL's 5V discrete component regulator is essentially an LDO design. It starts to produce output ripple on the 5V rail when the voltage across the 18,000uF filter capacitor, at the regulator input, has dropped to an average of about 6.3V. For this to occur, the line voltage on my SOL-20 is about 84V.

The heat generated by the 7805 regulators on S-100 cards and added heat from the IC's, which can be numerous, can be quite significant and add up especially when there are more than three or four S-100 cards stacked as they are horizontally, in the SOL-20.

The power dissipation of the 7805, is equal to the input voltage minus the output voltage of 5V, times the current. Therefore higher input voltages result in higher heat dissipation.

In my SOL for example, if I apply 110V line voltage to it, the 8V rail is around 9.5V. This increases the heat evolution from the 5V regulators on the S-100 cards and also the

heat evolved in the SOL's own 5V regulator system. The power transformer in my SOL was clearly designed for "Brown Out" conditions where the line voltage can fall low at times.

This is a common problem, overheating of the environment inside the SOL-20 enclosure. Some people added an extra cooling fan and I have seen holes cut in the covers of some SOL-20's to help cool the S-100 cards.

(I added an additional cooling fan but with no modifications or holes cut, it blows air across the s-100 cards and assists with the original internal fan, it mounts on two existing screws).

One solution was a "bucking transformer" to lower the primary voltage applied to the SOL-20's power transformer. However, running my SOL-20 from a Variac (variable voltage transformer) I noticed that there were moderate fluctuations on the line voltage of more than 5V at times across the day and the 8V "pre-regulator" voltage was also affected by the number of S-100 cards in use.

I found myself adjusting the Variac from time to time. Part of this is due to the reduced quality voltage regulation using a 230:115V step-down transformer and line voltage fluctuations across a day have increased of late, I think, with solar inputs to the grid.

So I decided to build and design a "constant voltage transformer " or a "Regulator Machine" to power my SOL-20 to control the Line input voltage to close to 94V and keep it stable, regardless of line voltage fluctuations and varying loads with different S-100 cards too.

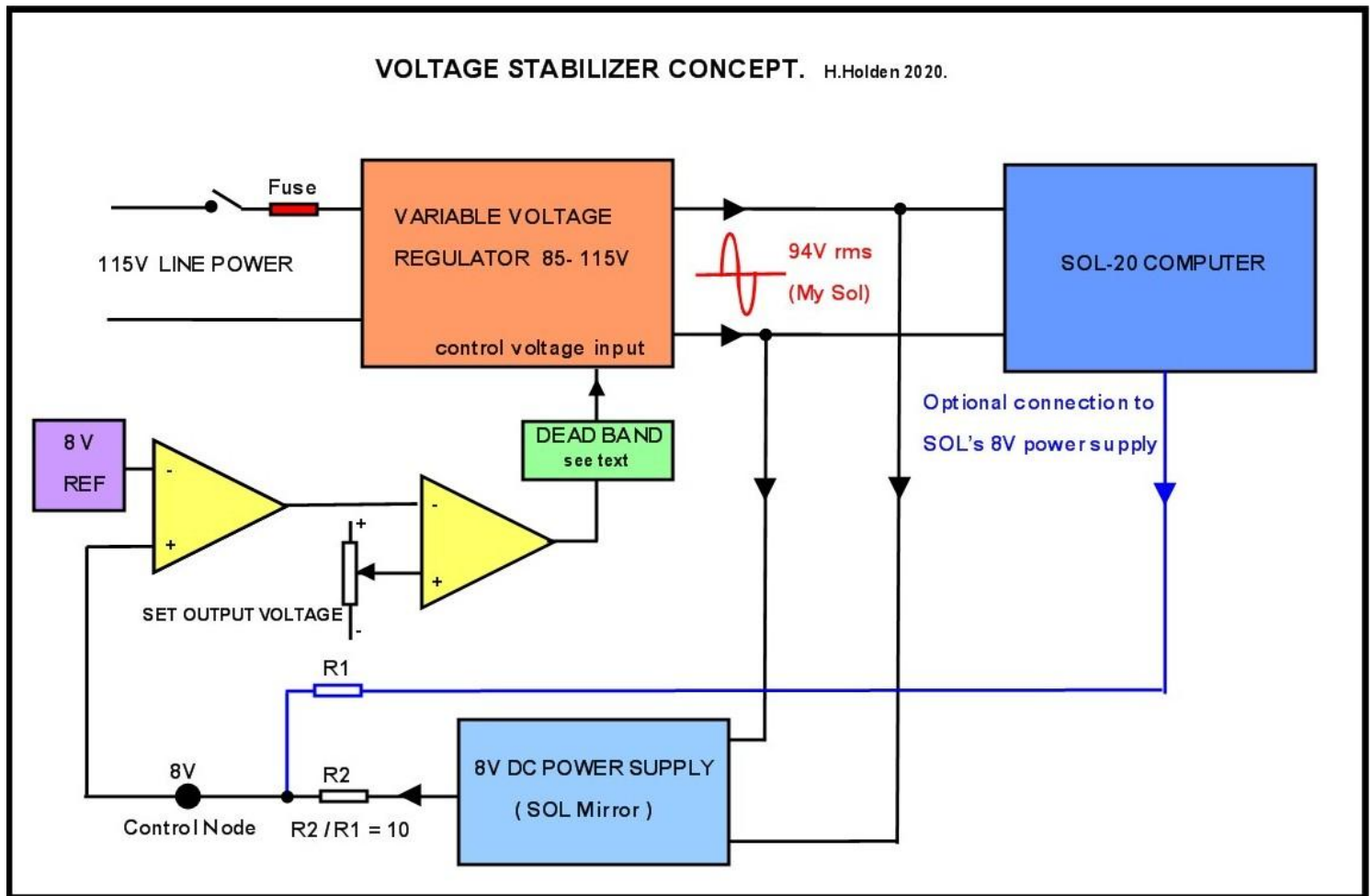
The voltage set knob on the front panel of this machine has a mechanical locking ring, so it cannot get accidentally bumped out of position. This was harvested from a defunct laboratory amplifier.

DESIGN CONCEPT:

A machine to generate or regulate a 115V rms 50 or 60Hz adjustable voltage stabilized source and at least 200 Watt capable, could be designed in a myriad of ways and is limited only by the imagination of the designer.

For my design I wanted it to be physically impossible for a malfunction of any kind to deliver an output voltage higher than its input voltage. This is not necessarily the case for other designs with all electronic controls, so.....

The design configuration of the machine looks like it was created from a combination of early 1900's vintage electro-mechanical engineering and 1970's vintage OP amp technology combined with some new manufacture switch-mode PSU's. However, since it is 100% safe for the vintage computer, I might be forgiven for the oddball cocktail of components used to create it.



The big question of course, looking at the block diagram above, is the contents of the orange box. In this case it is electro-mechanical.

The machine accepts the typical 115V line input voltage (in my case derived from a 230:115v step-down transformer, but in the USA, standard line voltage) and outputs a constant voltage, which is adjustable from 85V to 115V with the “Set Output Voltage” control.

The closed loop gain of the servo is around 23.5:1. To get an output from the right hand OP amp to exceed the dead band (see below) of $\pm 1.2V$, the input voltage offset

on from the SOL-20's supply, or the SOL-20 mirror supply, has to be about $\pm 50\text{mV}$. And then to get the voltage up enough to start the motor rotating and make the correction is in the order of another 50mV or thereabouts, because it takes about 1.3V to start the motor's shaft slowly rotating.

Therefore the 8V rail (From the SOL mirror or the real Sol 8V supply) becomes regulated to approximately $8 \pm 0.1\text{V}$. This corresponds to the output voltage of the Variac varying by about $94\text{V} \pm 1\text{V}$.

With a sudden step in the input line voltage of say 5V the motor is forced to near full speed and makes a more rapid correction. Since it's a 2 RPM motor, on account of its gearbox, it takes it a few seconds to make the correction, but this is not a problem.

(The "mirror 8V supply" is merely a small power supply built into the Machine which uses a full wave rectifier, capacitive filtering and a moderate load, to mimic the electrical behaviour of the loaded 8V supply in the SOL-20 computer)

There are small 100Hz (or 120 Hz in the USA) ripple voltages on the control node, but with the filtering, the ripple voltage from the output right hand OP amp is about $\pm 125\text{mV}$ when the mirror supply is in control and about $\pm 250\text{mV}$ with the SOL's 8V supply in control. So this falls inside the $\pm 1.2\text{V}$ dead band and causes no difficulties. It could be easily filtered to a lower value, but this lengthens the response time of any voltage corrections.

The "centre voltage" output of this machine is easily set by a front panel control. It can be dialled down to result in lower pre-regulator voltages of 7.5V or 7.6V . I am trialling this, so far no difficulties and this further minimises the heat dissipation inside the SOL-20, but 8V seems a satisfactory setting too.

The feedback electronics is very simple and based on a pair of OP amps. It was undecided initially whether to include the SOL-20's 8V supply in the feedback loop, or whether the control would be tight enough just to use a "mirror" of the SOL's 8V supply. So the design allows for both.

If the SOL's 8V supply is used it is just a matter of connecting a pair of link wires between the SOL and this unit to its rear panel socket and due to the mixing resistor ratios of $10:1$ at the node, the SOL's 8V takes control of the feedback loop when it is connected, so no switching between the two possible feedback sources is required.

Experiment indicated that the option to control the feedback loop via the SOL's 8V supply, rather than the mirror supply, was not to be absolutely necessary. When the SOL's 8V supply is in control, this allows for changes in loading (and hence the 8V supply voltage) when a different number of S-100 cards are used. However, I found that

without including the SOL's 8V supply in the feedback loop, the supply stability was more than satisfactory just using the Sol Mirror supply built into the Machine. So in practice it requires no link wires to the SOL, but the option is there.

A fully electronic design could consist of a an input rectifier, then a Sine wave or modified Sine wave inverter, with a negative feedback loop sampling the output level to stabilize the voltage. While I could have designed a version like this, I chose not to, because the failure modes are more complex (risky) and more of a threat to the computer.

For example a failure in the control loop could result in a very high output voltage, higher than the line voltage. This could be mitigated with additional over-voltage detect and shutdown circuitry, but more components and more risks. In addition, for anything other than a sine wave output, there are more issues with harmonics in the output to deal with and RFI and the design of a high voltage switching converter or SMPS is never quite as simple as it appears at first glance. I know because I have designed a few and as Mr. Dylan would say there are Molotov cocktails and rocks behind every curtain.

Instead I decided to go for an "Old School" electro-mechanical approach with a real Variac as the voltage control device.

With this design, it is impossible for the output voltage to exceed the line input voltage, with any sort of failure mode. Despite the vintage nature of a Variac, the sine wave amplitude (output voltage) is very well and smoothly controlled, efficiently too.

The Variac is merely a Toroidal Auto-transformer where a carbon brush taps off the winding. On account of being a toroidal configuration and an autotransformer too, it is highly efficient. I chose a high quality vintage General Electric Variac that has gold plated copper where the carbon brush contacts the winding turns and rated to supply around 240W.

A 240 to 300W Variac is quite a compact animal, at about 3 inches in diameter and 2 inches deep. The power consumption of a "fully S-100 board stocked" SOL-20 computer is in the range of 60 to 80 Watts.

The shaft of the Variac is coupled via a Huco Clutch and combined Oldham coupler to a 2 RPM output 12V DC motor. The purpose of the clutch is to allow slip when the Variac reaches its maximum or minimum voltage mechanical stop points. The minimum mechanical stop point was crafted so that the lowest output voltage is in the order of 85V. The maximum voltage stop point is a pre-existing stop on the Variac and is the Line voltage applied to the unit, typically 115V.

The motor is driven by a pair of medium power Darlington transistors (vintage T0-66 case types, as I have a fondness for these over plastic transistors and have many in my parts box). These Darlington devices very conveniently provide a $\pm 1.2\text{V}$ “dead band” due to their B-E junction voltage drops. Also they have enough current gain to allow direct control of them from a 741 style OP amp.

I have a good number of mil spec 741 OP amps which are type 10101 and I tend to use these in precision gold plated pin sockets, probably on the quality front, these may well be better made than many modern jelly bean OP amps in plastic cases. One great thing about the 741 OP amp, it is completely deaf at radio frequencies and not much use above 20kHz either where it is intrinsically slew rate limited, making it perfect for very low speed servo applications.

The 741 is out spec'd by a modern day OP amps with rail to rail output and input voltage ranges, which is the first thing everyone says when they see a 741 used in this day and age. But for this particular application I cannot see a better part than these high quality mil spec OP amps.

In many electronic feedback motor servo control systems, take a rotating head drum in a VCR as an example, the loop filtering is designed to prevent hunting and correction overshoots. And the loop filtering components often take the form of those seen in a typical PLL circuit with a main loop filter capacitor and anti-hunt RC network. Also, the high frequency responses of the OP amps used are often rolled off to make the system interference immune, especially if it is a low frequency range application.

However, in an electromechanical servo feedback system, ***where it is not a continuously rotating machine***, one does not want constant activity of the motor, hence the notion of a “Dead Band” which solves the hunting issue differently and the anti-hunt network is not required in addition to the usual loop filtering.

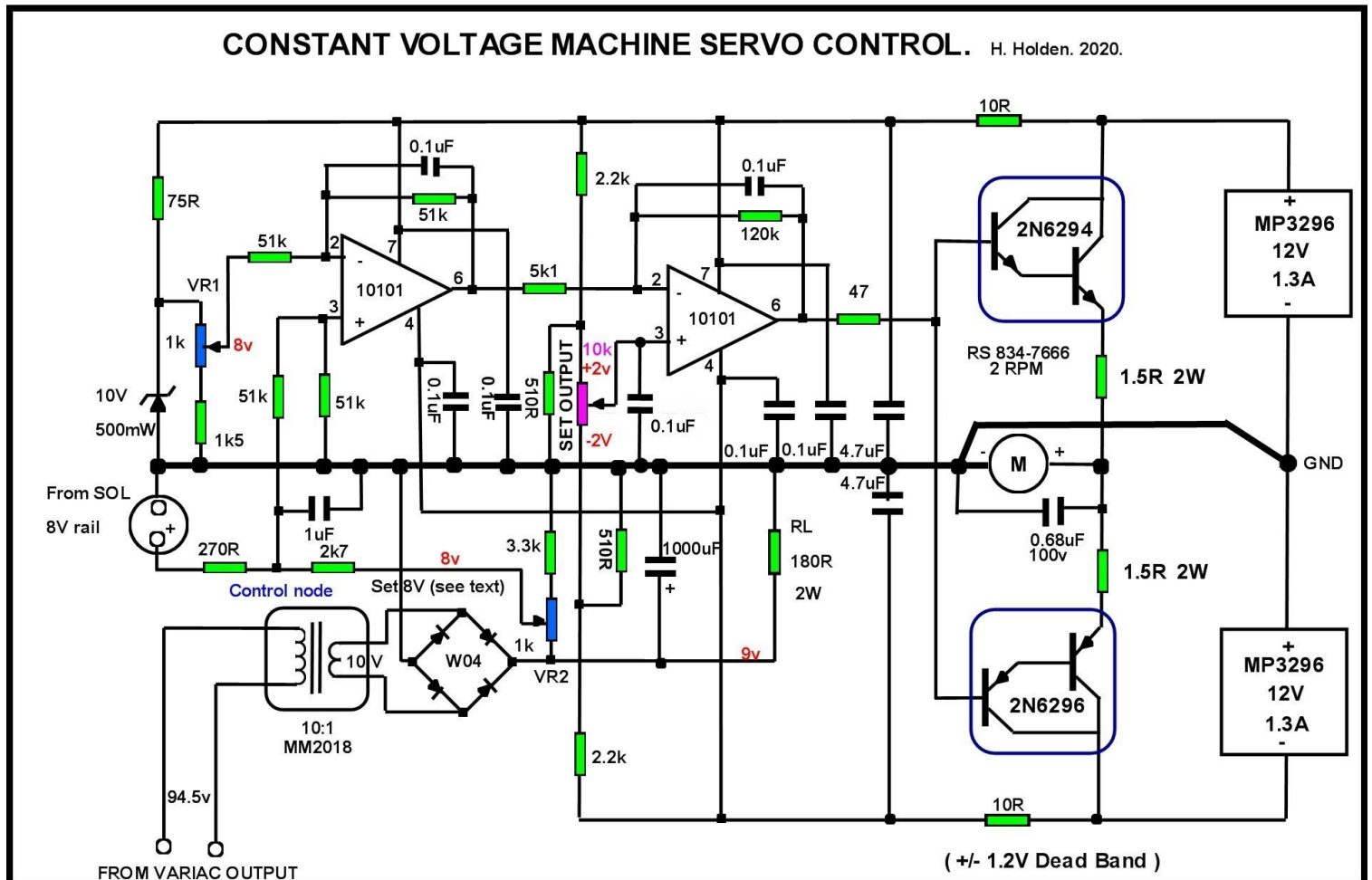
The motor shaft is required to move to the correct output position, then the motor current stops. This was also discovered in the early days of Radio Control systems for model aircraft. Whether the control system itself be a digital or analog design, it requires a “Dead Band” to kill the motor activity when the output shaft has reached its target position.

The “dead band” is required so that most of the time the motor is not running. Only when the output variable (voltage in this case) steps significantly away from its set target value, does the motor start up to make the position correction, to correct the Variac's shaft angle in this particular case.

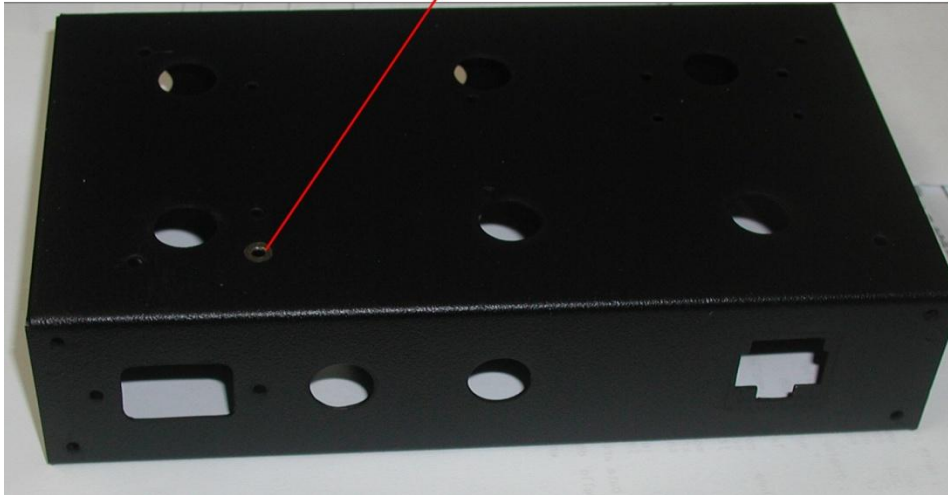
The servo's loop gain was set so the motor makes a correction only when the Line voltage change causes a deviation of about 1V or more. So the system keeps the line voltage around $\pm 1V$ of the set output value. In use, the motor only starts up occasionally as the incoming line voltage fluctuates. To make it less sensitive if required the 120k feedback resistor on the right hand OP amp can be lowered in value.

The remainder of this article shows the schematics and various photos of the unit.

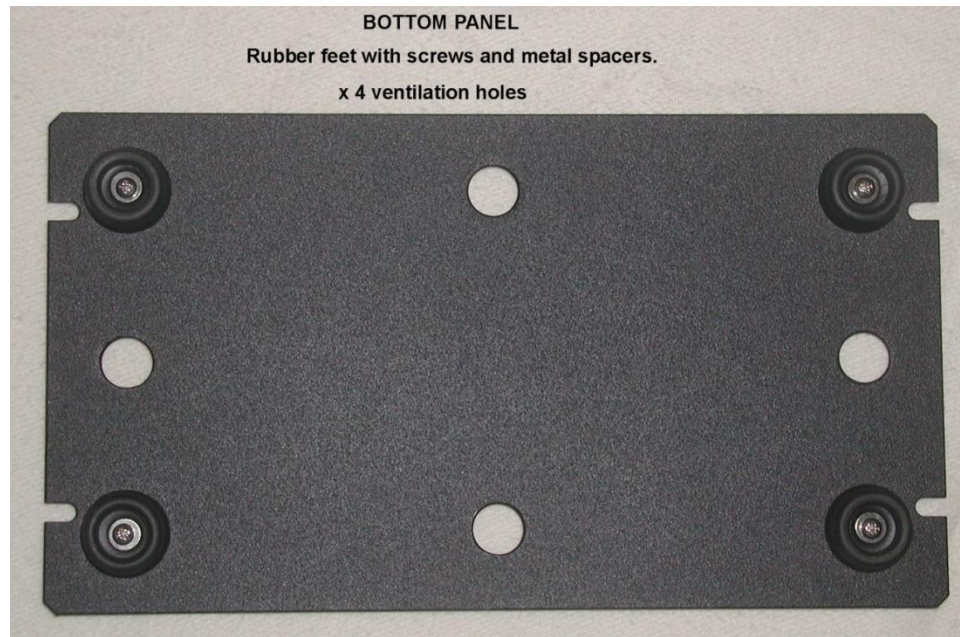
The Schematic:



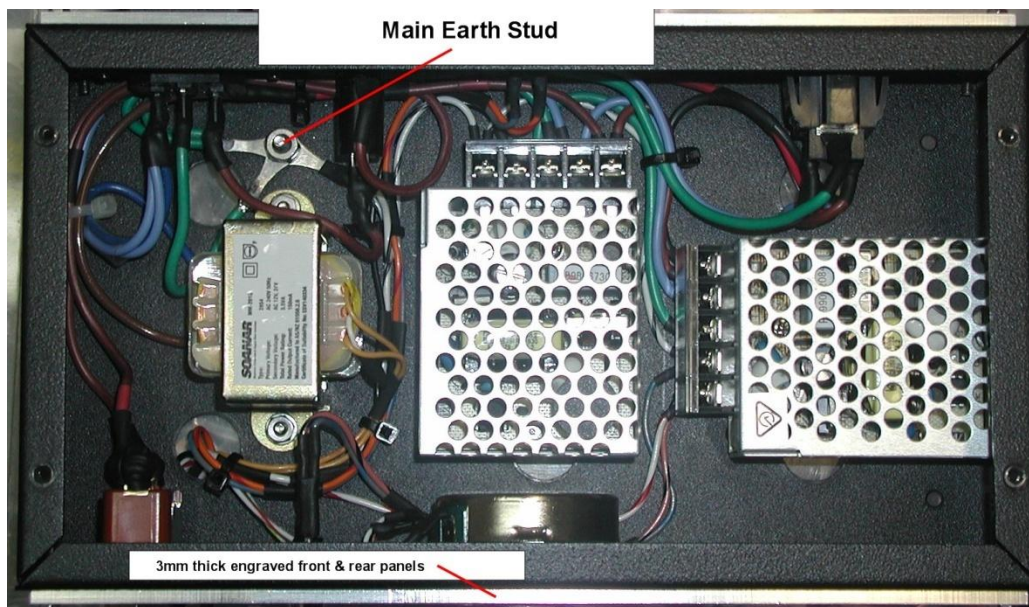
All Cut Edges Painted Except For Earth Stud Position:



Added 4-40 UNC Stainless Steel Captive Nuts



When rubber feet are fitted it pays to use metal spacers so that the rubber is not excessively compressed and the screws can be tightened up so that they don't come loose later. Also, stick on rubber feet as an option are a waste of time as the glue fails and they fall off, so don't be tempted to use them, even though it appears to save you time and it appears to be a plausible idea.



It is important to have a solid main earth stud for reliable chassis earthing. The head of the screw is not accessible and it is tightened up with a socket wrench and lock washers and at least 2 nuts. The paint is cleaned off the chassis where it fits. (I made a tool to neatly clean off a disc of paint from the chassis surface)



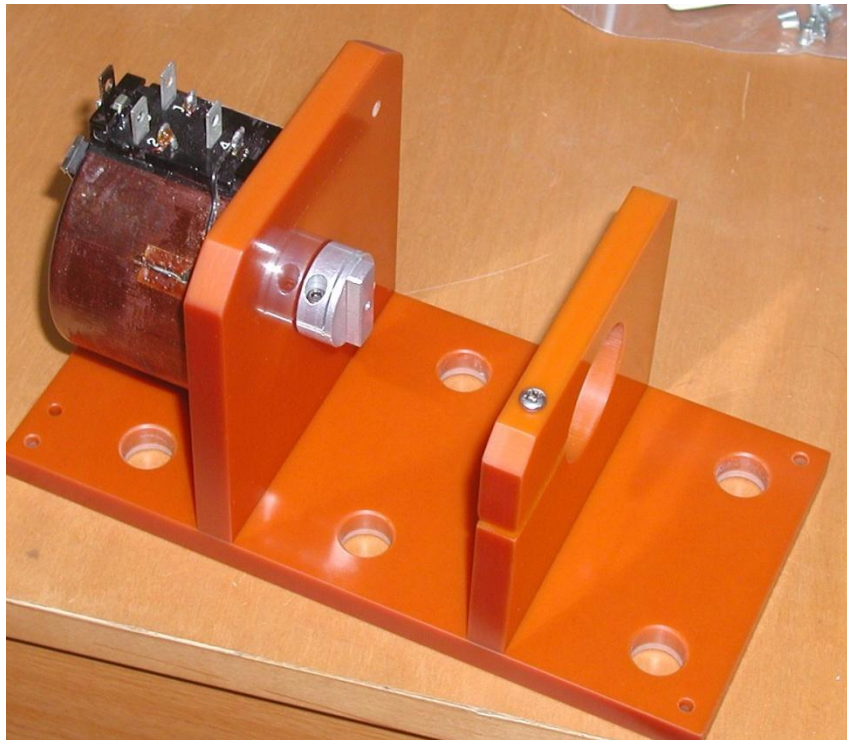
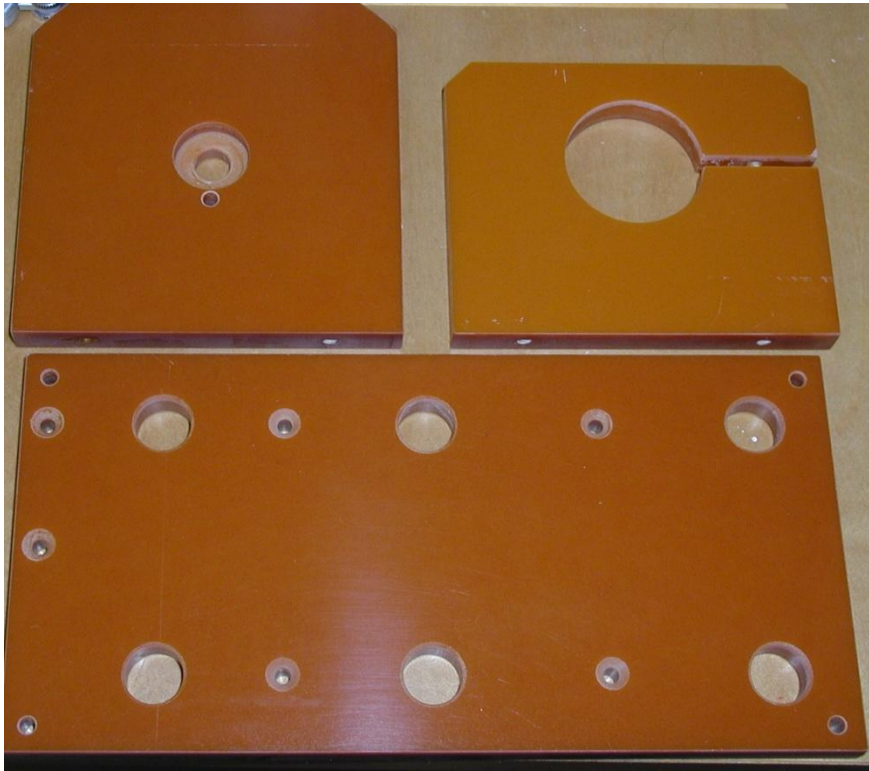
The rear view above shows the Variac's low voltage mechanical stop.

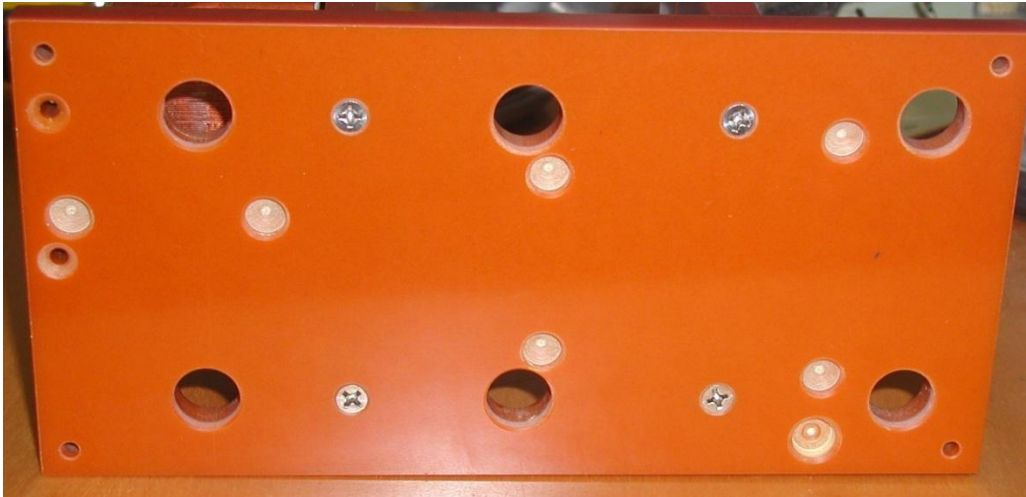
The insulation material is 10mm thick phenolic electrical panel. The appliance wire is silicone rubber covered "harsh environment" wire (from RS components). I use this for all projects involving line power. It is extremely temperature resistant insulation and does not retract on soldering and is far superior to PVC covered appliance wire in every way (more expensive of course, but much better). The low voltage wire in the unit is mainly Teflon covered. Though this whole unit only barely warms up in use due to the high efficiency of the Variac and the SMPS supplies.

The two output transistors were mounted on a folded brass bracket:



The following images show the machine under construction:



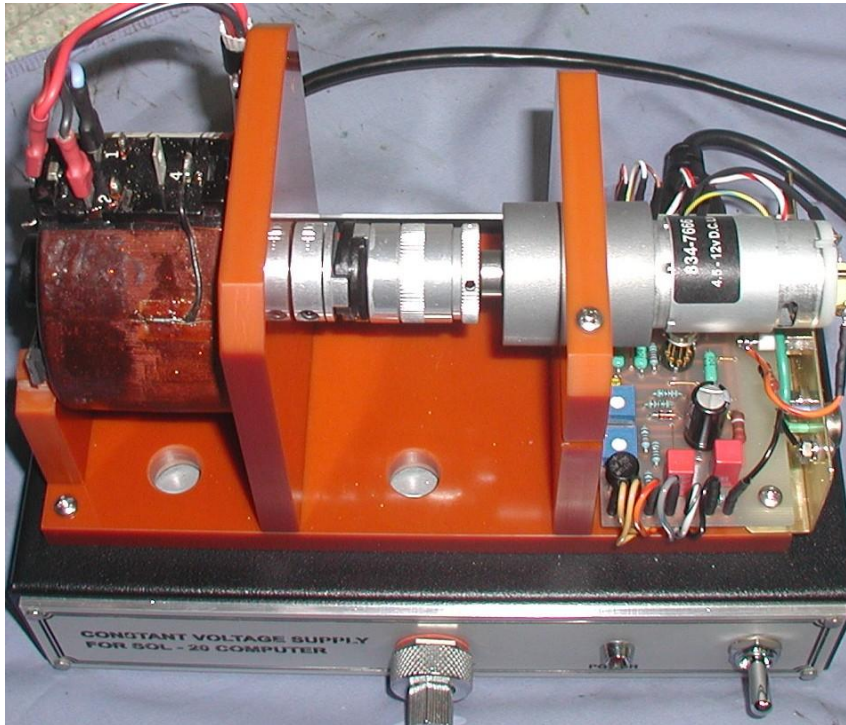


The phenolic insulating material takes a 6-32 UNC thread very well and this simplifies the construction using CS head stainless steel machine screws.

The front and rear panels are engraved (and filled with black ink) satin silver anodized 3mm thick aluminium retained by four 4-40 hex head stainless steel screws along with the objects that pass through them also retaining them.



The recessed holes in the top insulating panel allow for the seven screw heads projecting from the chassis surface, one of which is the Earth stud.



How to set up the machine:

The output of the OP amp is disconnected from the transistor bases to disable the auto-correction function, by unplugging the link connector. VR1 is set so the output of VR1 is exactly 8 volts.

Then, the SOL-20 computer is powered via the machine. The shaft of the Variac can be manually rotated from the clutch body (thanks to the Huco Clutch) so that the output of the unit is around 94V, but more importantly adjusted so that the supply to the SOL's back plane is exactly 8.0V +/- 0.1V with the current S-100 cards in use.

Once this is done, VR2 is adjusted so that the voltage on the control node is 8V, matching up with the Sol's backplane voltage. That completes the setup. The drive to the transistor bases is re-connected and if required the "set voltage control" on the front panel is adjusted to return the SOL's backplane voltage, or the control node voltage to 8V.
