

The IBM 5155 COMPUTER POWER SUPPLY.

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Introduction:

This document describes the vintage switch-mode power supply used in the IBM-5155 portable computer.

IBM, nor the makers of this power supply, Zenith, saw fit to publish official documentation on this supply at the time it was made. Perhaps this was because the many innovations that this supply contained were not yet the subject of patents. Or perhaps it was just overlooked. Now the ideas used in this supply are commonplace in most modern switching computer power supplies.

It has become clear to the vintage computing community that computers such as the IBM-5155 represent critical steps in the evolution of "Portable Computers". Therefore every remaining 5155 computer needs to be preserved and cared for, so that future generations can see and understand the evolution of computer technology, perhaps many hundreds of years into our future.

As computers have been so rapidly replaced by new and faster models with more memory, literally millions of old computers have been thrown away or turned into "E-Waste". It is obvious now that this might have been a bad move, especially for the very early models.

It can be difficult for a technician to repair a faulty switch-mode power supply at the best of times, even with good support documentation. However, without a schematic diagram and functional description of the circuit and expected oscilloscope waveforms and circuit point voltages, the task is even more difficult.

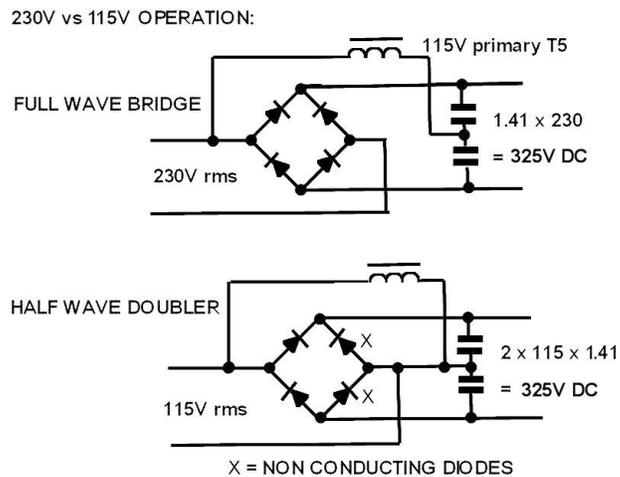
Hopefully the information presented here will help professionally trained & qualified Engineers with the IBM-5155's power supply repairs. Untrained people and those unfamiliar with mains operated switch-mode power supplies should never attempt repairs themselves, because the voltages inside these units are potentially lethal, so to tamper with them, without the required knowledge, skill, training & experience, is begging for electrocution.

The IBM-5155 power supply, by any standards, past or present, is a well built device and a very futuristic design from the early 1980's.

Switch-mode power supply design overview:

Firstly the incoming mains line voltage is rectified and the peak value of it appears across the main filter capacitors in the input section of the supply. Since many practical power supplies have to run from either 115V or 230V AC rms power systems (depending on the country) the supply has a rear switch to set the two standards.

The diagram below shows the two essential configurations for 230V versus 115V operation, depending on the position of the mains voltage select switch on the power supply's rear panel:



The diagram shows the DC voltage developed across the filter capacitors. In both cases theoretically close to 325V, but in practice with the supply under load it is a little lower at around 312V DC for example with a 230V AC rms input.

There are two interesting things to note:

In 230 V mode the arrangement is that of a full wave bridge rectifier. In 115V mode it is a half wave voltage doubler.

Notice how it becomes possible, in 230V mode, to run a transformer T5, which has a 115V primary winding, from a 230V source. This is because the bridge rectifier and filter capacitors create what amounts to a low impedance artificial centre tap (or virtual zero) on the incoming 230v line voltage. The reactance of the large value filter capacitors at mains frequencies is very low.

The transformer, T5, has a secondary that generates a 12V power supply to power most of the electronics in the switch-mode power supply to get the supply started

at power on. Once the 312V DC voltage is generated from the incoming mains power supply, it is then chopped up with a variable duty cycle scheme into the primary of the unit's main transformer (labelled T1 in this unit). Low AC voltages are then derived from T1's secondary windings and rectified and averaged by filters to create the low voltage outputs for the computer. These include +5V, -5v, +12V and a -12V supply.

A critical part of the function is that the output voltages from the + 5V and +12V low voltage DC supplies are fed back (negative feedback) to the circuitry controlling the duty cycle (On-Off) pulse waveform that ultimately drives the main transformer T1. In this way the voltages are stabilized and become largely independent of the load current drawn by the computer or its peripheral devices.

A number of additional systems or sub-circuits also exist in the power supply. One system detects whether the supply's output voltages are within an acceptable range. If they are too high or too low, the supply is shut down. In addition the current being fed to the main transformer T1 (which correlates the supply's power output in Watts) is monitored. If a maximum is exceeded the supply is shut down. The shut down circuit is mediated by an SCR (Silicon Controlled Rectifier). Once the SCR is triggered by an abnormal condition, the supply stays shut down until it is de-powered & re-powered (the only way to reset the SCR in this case).

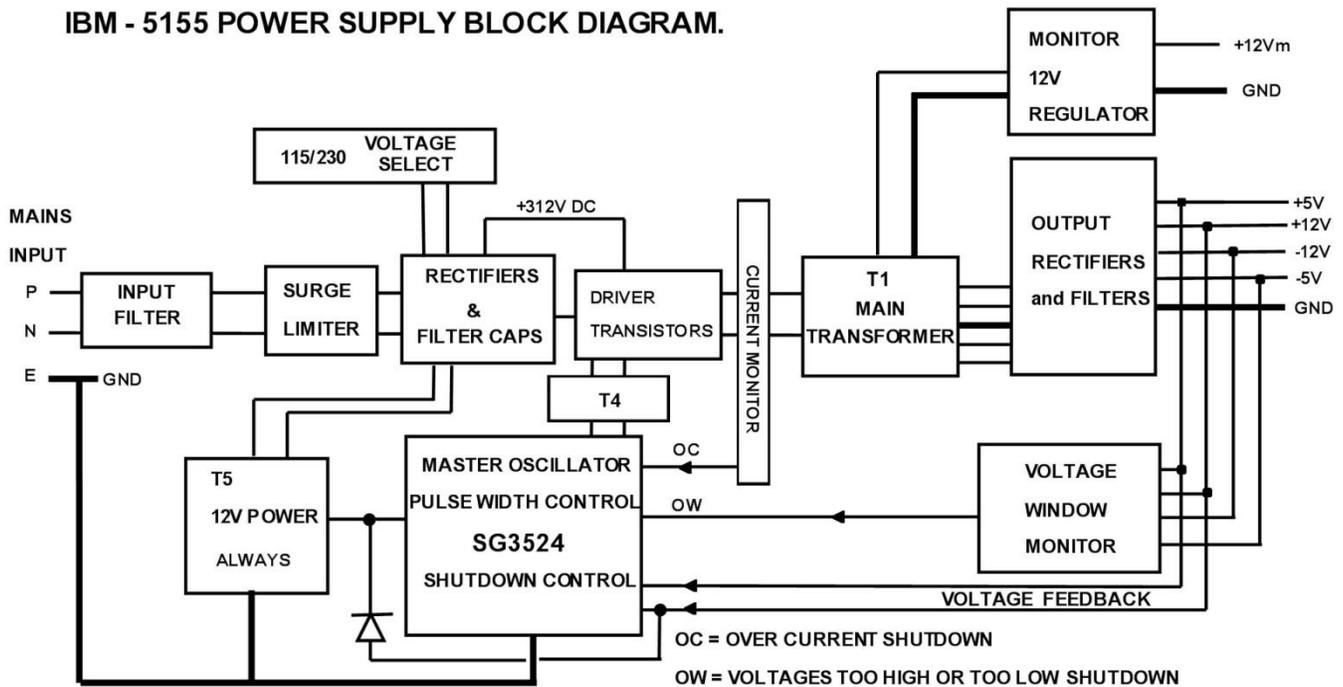
Another sub-circuit includes a current inrush limiter. When high value capacitors are charged via silicon rectifiers from low impedance sources (such as the mains power) the initial inrush currents can be very high. So a circuit limits these currents with a series resistor. The resistor is then shorted out by relay contacts with a delay after the supply unit is switched on. This circuit also makes use of a PUT (Programmable Unijunction Transistor) and a charge stored in a capacitor that remains for a time after supply switch off, to reset this delay circuit. This allows for the scenario if the supply's power switch is being rapidly toggled on & off.

One of the more interesting aspects of the 5155 power supply is that this particular unit has a unique 12V source to power the Amber coloured CRT monitor in the 5155 computer. Rather than using the existing regulated +12v supply output, which might seem like an obvious choice, the designers chose to take the pulsed AC voltages directly from T1's secondary, step them up a little and control those downward again with an additional switch-mode circuit which controls the reactance of a series transformer. A very unusual circuit, but it works very well. Therefore this power supply includes an additional preset potentiometer for setting the supply voltage for the Amber CRT monitor in the computer.

5155 power supply Architecture:

It doesn't hurt initially to look at a block diagram of the power supply. Block diagrams contain little detail, but they can give an overview of the way the important sub-circuits fit together.

IBM - 5155 POWER SUPPLY BLOCK DIAGRAM.



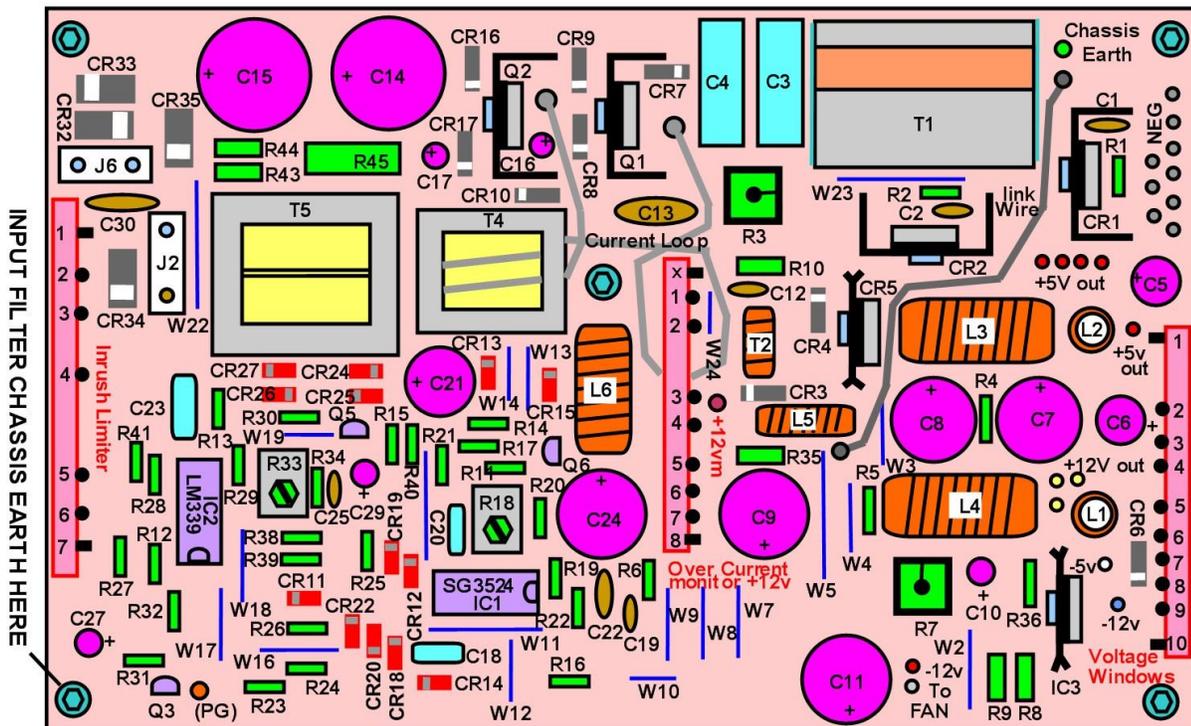
One thing of note is that all switch-mode power supplies have a safety dilemma. This is because the approximately 300V DC power supply is derived from the mains power and is live above ground. This also poses isolation problems of not only for the output supply voltages, but also the electronic sub-circuits in the unit. This problem is solved with isolation transformers which also provide step down functions.

As noted in the block diagram above, the 312V DC output, derived from mains power, is ultimately isolated from the output of the supply by the main transformer T1. The electronics associated with the SG3524 switch-mode controller IC, is isolated from the mains by T5 and at its outputs isolated by the driver transformer T4.

Once the power supply starts, if the 12V supply from T5 falls too low, due to low mains voltage, the power supply's +12V output voltage can take over.

An overview of the main pcb showing the location of the parts is helpful. Fortunately, the parts are well labelled on Zenith's pcb. Of note; many of the component designators are the same on the sub-boards as the main board, for an example there is an R7 on the inrush current limiter board and an R7 on the main board, different parts, so be aware of this.

IBM-5155 POWER SUPPLY - MAIN BOARD LAYOUT.



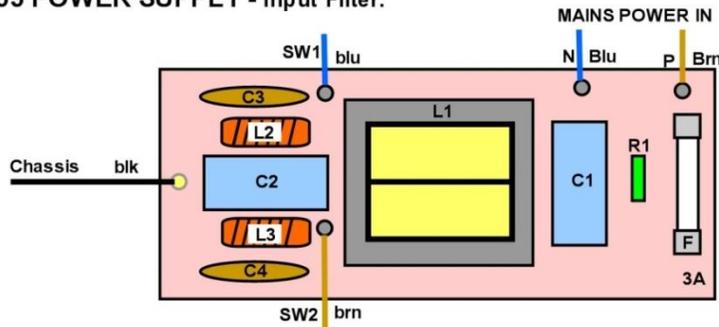
On the circuits drawn in this document, voltages shown in *red in brackets* are those tested with a digital meter with the supply running from 233Vrms AC mains and powering a single 1 Ohm 50W rated power resistor loading one of the +5V output connectors, giving an external 25W load.

The +12V rail in this unit is pre- loaded by power resistor R7, 24R on the main board, giving a 6W load. Therefore the +12V supply output does not require an additional load to ensure the power supply starts normally. If there is no load on the + 5V output, or it is

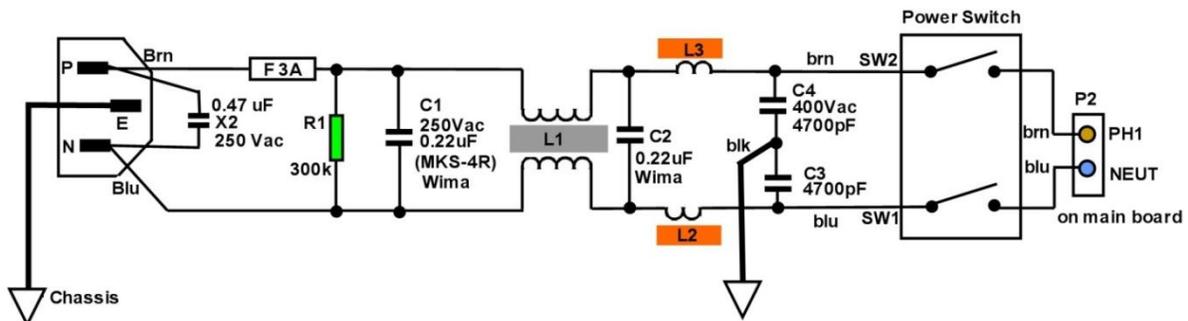
under loaded, the voltage overshoot at start up, trips off the over-voltage window monitor and the supply shuts down immediately at turn on.

Voltages seen on the schematic diagrams in *blue* are expected voltages at those points based on calculation, not measurement.

IBM- 5155 POWER SUPPLY - Input Filter.



MAINS INPUT FILTER.

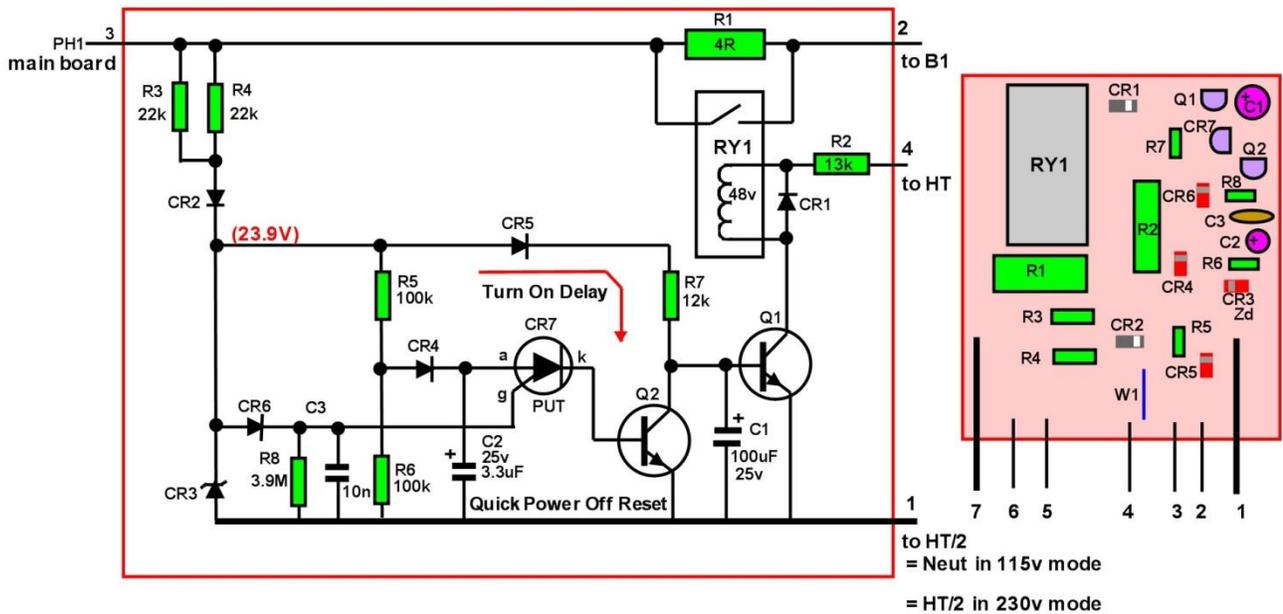


Operation:

The purpose of the mains filter is to prevent radio interference (switching noise) exiting the power supply to the mains power line and it also helps isolate the power supply from mains borne interference.

The filter assembly is wired between the mains input IEC power connector and the rear panel power switch and conducts the fused & switched mains power to the main board by plug P2. (Of note the connections to the mains switch and IEC socket are exposed inside the unit with no insulation and represent another electric shock hazard inside the unit).

IBM - 5155 POWER SUPPLY - INRUSH CURRENT LIMITER



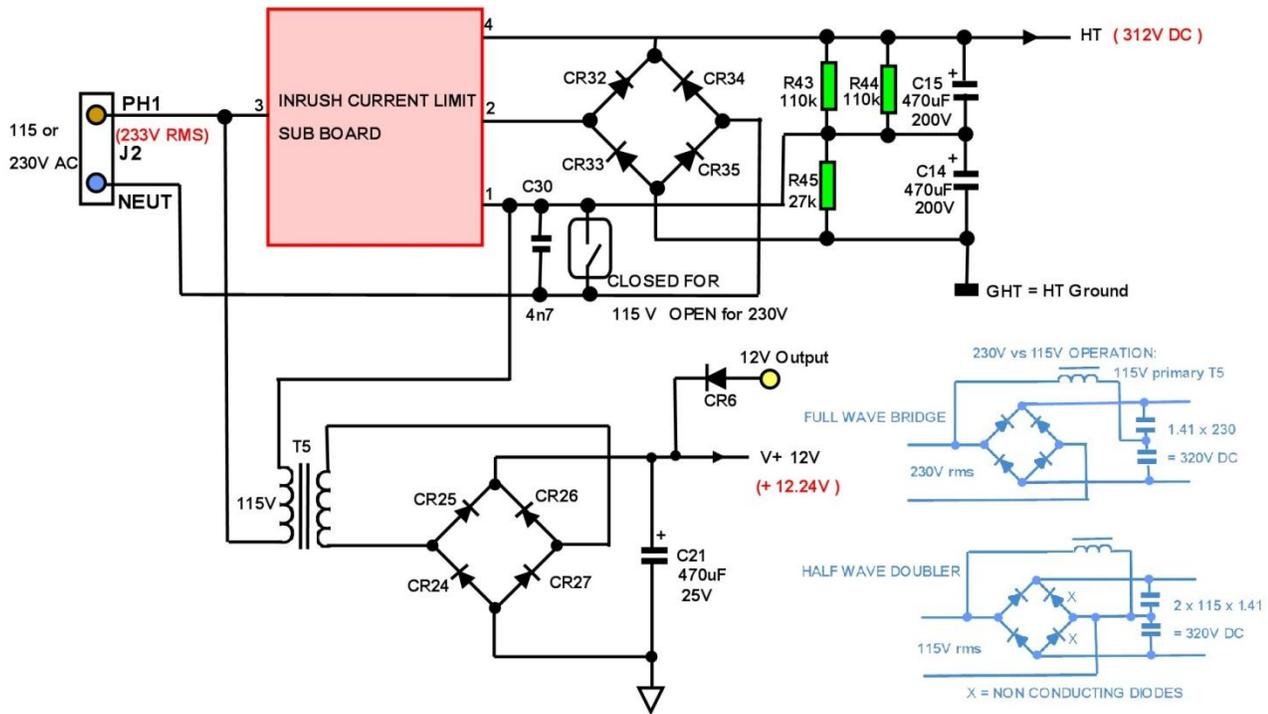
Operation:

When mains power is initially applied the relay RY1 is not energised and its contacts are open. The surge current feeding the bridge rectifier's and main filter capacitors is limited by R1. After a time C1 charges via R7 and CR5 and Q1 switches on energising the relay and shorting out R1.

If the supply was turned off & on quickly, the circuit needs to be reset. When the supply voltage falls quickly CR4 is reverse biased (non conducting) and C2 holds the anode voltage of the PUT (programmable Unijunction Transistor) for a while at around 12 volts. The gate voltage falls below the anode voltage and the PUT conducts current into the base of Q2, sourced from the stored charge on C2, turning on Q2, rapidly discharging C1. Then the delay circuit is then reset ready for then next power up event.

In a sense, the charge on C2 acts as a memory for the fact the computer was previously turned on and therefore RY-1 contacts closed. At power off it is C2's charge that supplies the energy for the reset function, even though the power is off at that point.

IBM - 5155 POWER SUPPLY - MAIN BOARD CIRCUITRY.

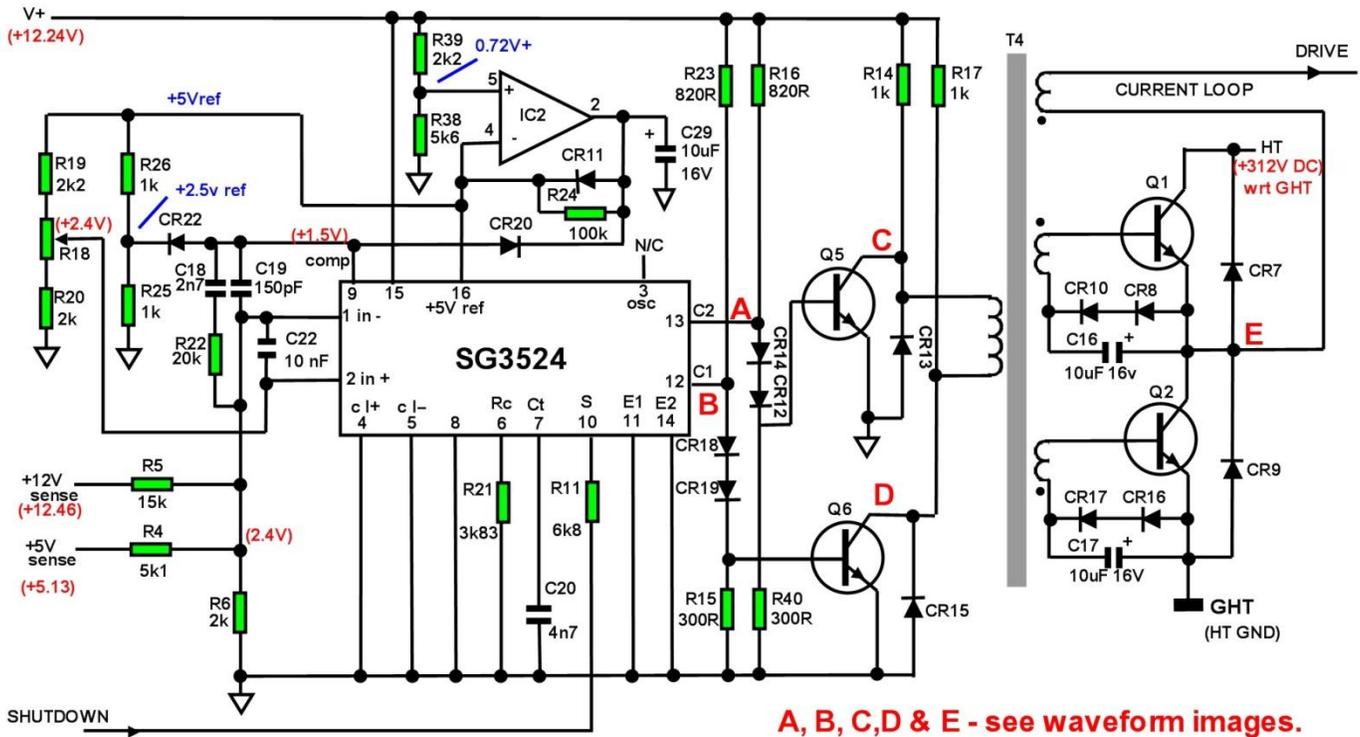


Operation:

After the mains input passes via the inrush current limiter, it is rectified to charge the main storage capacitors C14 and C15. As noted, in 230V mode the arrangement as shown is a full wave bridge rectifier, however in 115V mode it is a half wave voltage doubler. In either case a theoretical 325V is generated. Under load though, the measured output voltage was close to 312VDC.

Notice the very clever arrangement to power the primary of T5, so regardless of whether the supply is set and powered by 230V or 115V, T5 still gets the appropriate 115V on its primary. This is because the output of the bridge rectifier creates an artificial voltage midway between the phase and neutral voltages, so it becomes possible to create a 115V supply from a 230V source to power T5. T5 supplies the V+ 12V that runs the supply's driver electronics, if that voltage falls too low after the supply has started due to low mains voltage, the 12V supply output takes over via CR6.

IBM - 5155 POWER SUPPLY- MAIN BOARD CIRCUITRY



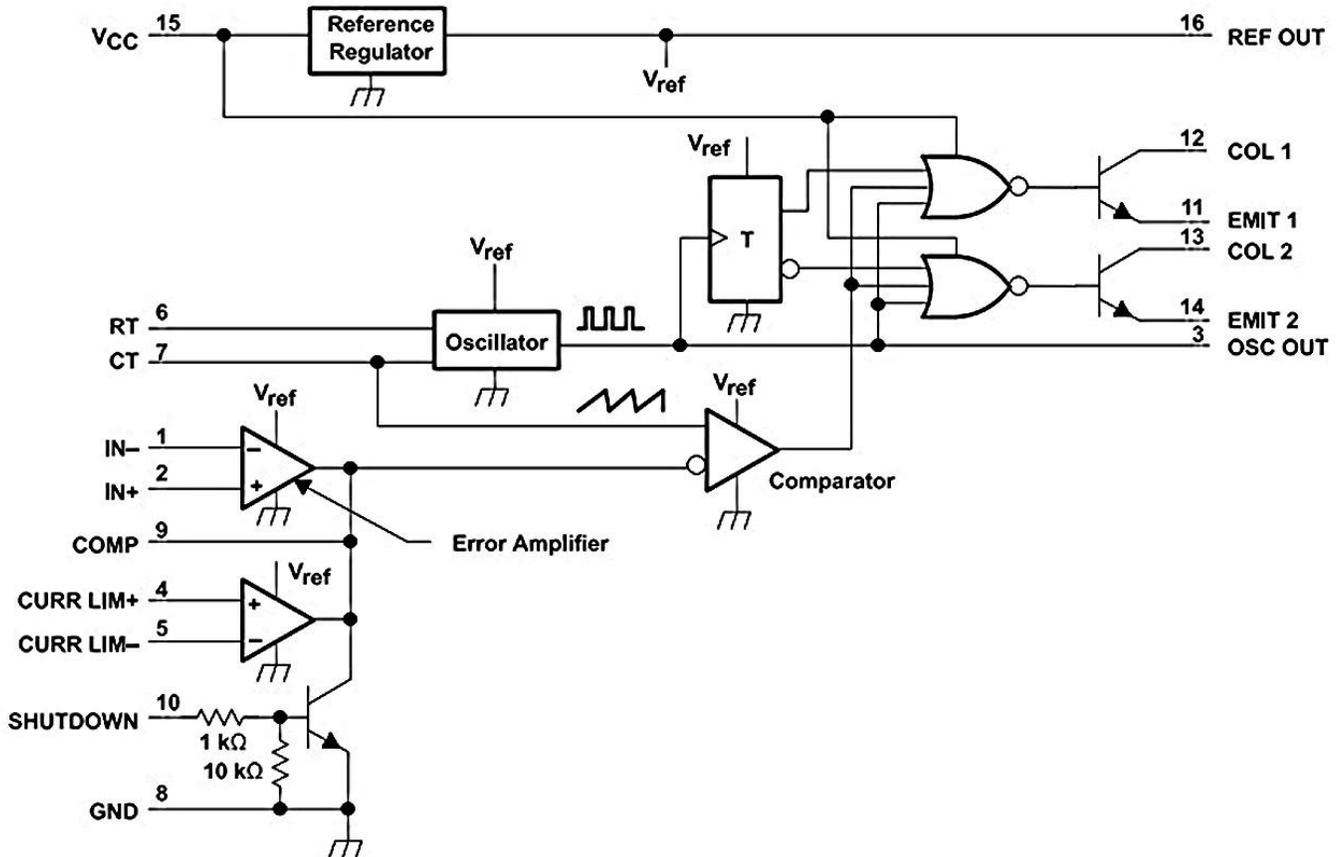
Operation:

The Signetics SG3524 IC generates pulse width modulated rectangular waveforms. They feed the driver transistors Q5 & Q6 for a duration that is required to establish the correct output voltage from the supplies output terminals. This is achieved with feedback from the +12V output and the +5V supply outputs, which are fed back and mixed onto resistor R6. The voltage here is compared to the preset potentiometer R18 (which sets the supply's output voltage) inside the SG3524.

The purpose of the comparator, output pin 2 of IC2, appears to be a turn on delay, which delays the production of any output pulses from the SG3524 until the V+ voltage (from T5) is established to at least 7V. Once this has occurred, the comparator (open collector type) releases and allows R24 to charge C29 taking pin 2 high. When pin 2 of the comparator IC2 was previously low, the SG3524 is inhibited via CR20 taking pin 9 low, in a similar manner to when the shutdown input is taken high, it produces no output pulses. At power off, the start up delay created by R24 & C29 is rapidly reset by

CR11, discharging C29 into the +5V reference rail. This process ensures the drive voltage amplitude out of the SG3524 will be a satisfactory peak value before any drive pulses from the SG3524 are produced at its outputs.

The internal workings of the Signetics SG3524 are shown below:

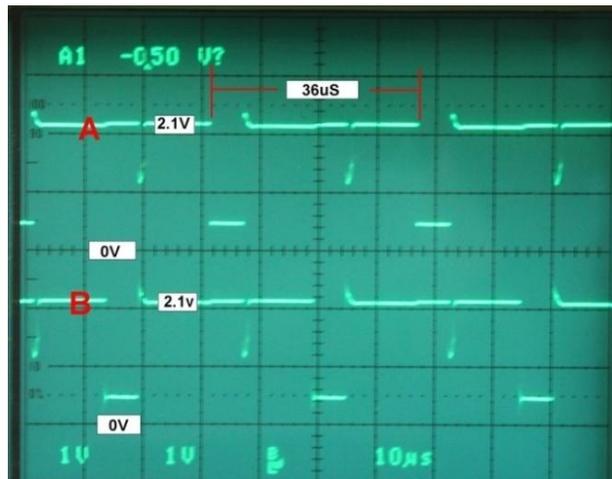


The three input NOR gates inside the SG3524 ensure that the outputs can not be on at the same time. The internal error amplifier, driven with + and – inputs on pin 1 and pin 2 controls the duty cycle or “on time” as a percentage of the operating cycle, of each output pulse. An output pulse (considered separately from pin 12 or pin 13) corresponds to a half cycle used to drive the main transformer T1.

The designers chose not to use the additional internal error amplifier on pins 4 & 5 for detecting the power supply’s output current and grounded these. Instead, as will be shown, the 5155 power supply has a separate current detector based on a current

transformer. The switched power output, from point **E** in the diagram on the previous page passes via a single loop of wire, passing two turns around the driver transformer core T4, to reinforce the drive currents with increasing load and then through a toroidal ring (current transformer on a sub board) and then to the main transformer T1.

The following shows oscilloscope waveforms of the circuit points labelled **A, B, C, D & E**. The recording below is from circuit point A & B directly out of pin 13 and pin 12 of the SG3524. The output transistors (inside the IC) saturate down to about 400mV and the output voltage, when they are off, rises to about $3 \times 0.7V$ or 2.1V on account of the two diodes and the base-emitter junction of the driver transistors (Q5 & 6):

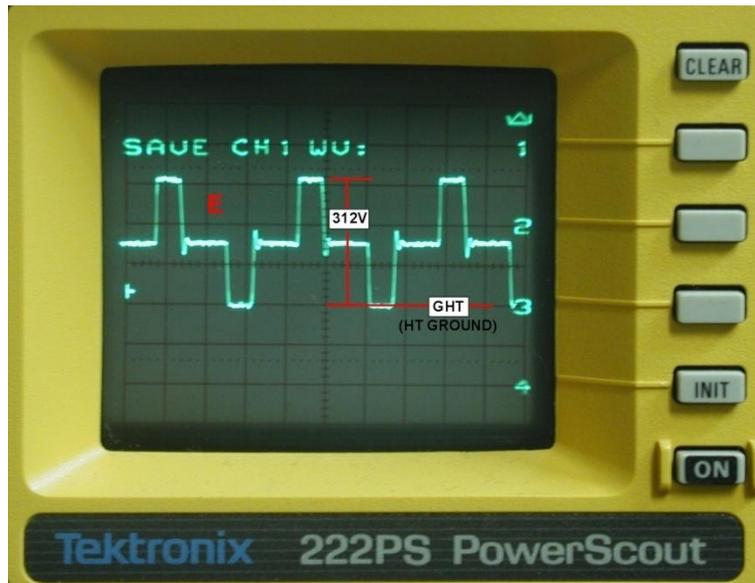


Of note the frequency of operation of this supply is close to 28.5kHz. This is slow compared to many modern computer switch-mode supplies. However, it has the advantage that there are less switching events per unit time, so the efficiency is a little higher and probably the high frequency harmonics do not extend as high up into the radio frequency spectrum.

The recording below shows the voltages on the collectors of Q5 and Q6 which shown on time of around 5µs and a peak voltage of just over 10V. The supply had a modest load of 25W (a 1R power resistor on the +5V output). With increasing load, the on time obviously increases:



The following recording, from the output stage comprising Q1 and Q2 (point E) was made with a Tek222ps scope. This is a special oscilloscope, able to probe live mains voltages. Without this, this test is better avoided, although it is possible to do it with an ordinary scope, if the power supply is powered via an isolating transformer. However, for the most part, this test is best avoided and its better to check the secondary of the main transformer T1 instead, where the voltages are low and it is mains isolated:



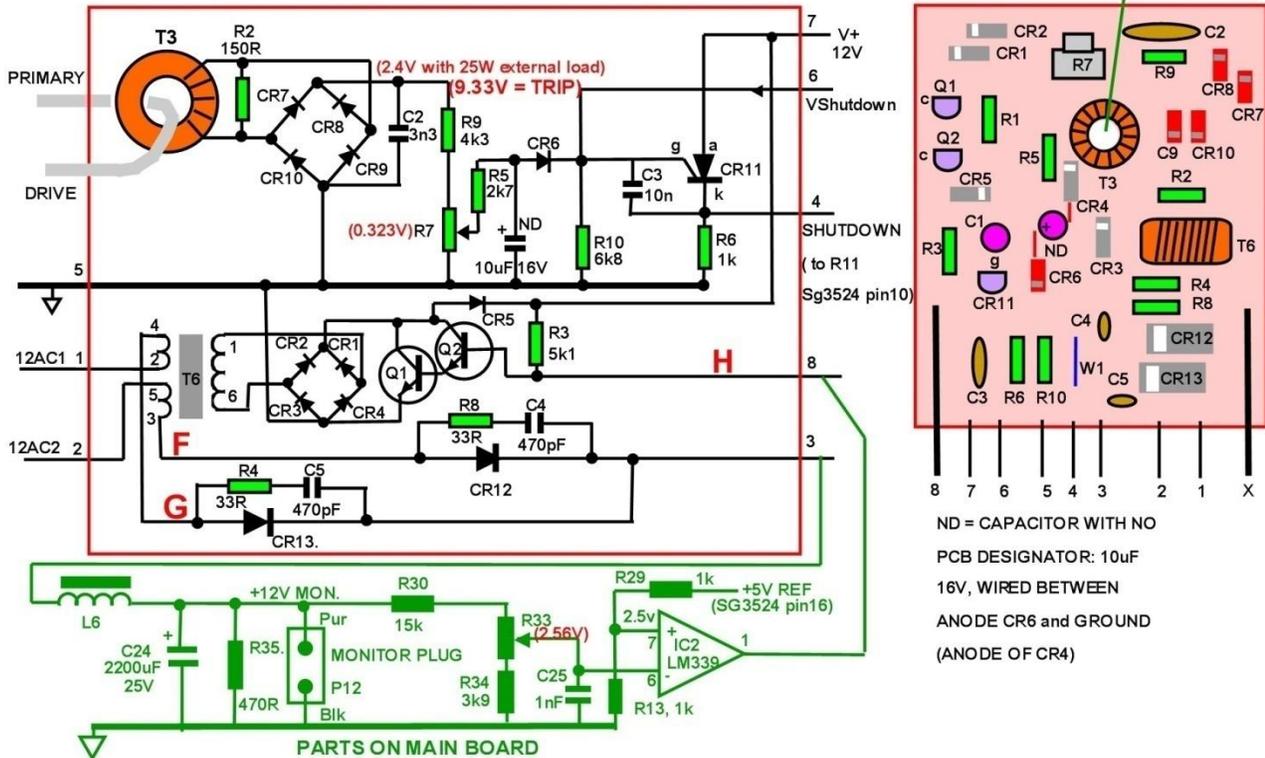
Notice how this output waveform (from Transistors Q1 and Q2) has a 156V DC offset. Before this waveform can drive the main transformer T1, this offset must be eliminated. This is the job of capacitors C2 and C4 which will be seen later on the circuit which includes T1 and the output filter components.

At this point it is worth examining the current limiter circuit. As noted the output from Q1 & Q2 passes as a loop of wire which is wrapped (2 turns) around the driver transformer core (T4) that drives Q1 and Q2. As the output current load increases this reinforces the base-emitter current drive to Q1 & Q2, to ensure they stay in a saturated state when conducting. With lower supply loads and lower collector currents in Q1 & Q2, less base drive is required to keep them saturated. This is a form of positive feedback.

The current loop also passes through the hole in the core of a toroidal current transformer:

IBM - 5155 POWER SUPPLY - OVER CURRENT DETECTOR & 12V AMBER CRT MONITOR SUPPLY REGULATOR:

HOLE FOR CURRENT LOOP, SEE TEXT.



Operation:

The intention of the circuit with the current transformer T3 & SCR CR11 is to trip the power supply to off, if the load current (and output power) is exceeded OR the final output voltages of the supply are outside specified limits, via the "Vshutdown" input on pin 6 of this sub board (see further below for voltage window circuits). Reminder again about component designators in this supply; for example CR6 here is a different CR6 to another CR6 on the main board.

The current loop passes via the core of the current transformer T3. The output voltage from the current transformer T3, developed across R2, is full wave rectified by CR7,8,9 &10 and filtered by C2.

With a 25W external load (1 ohm power resistor) connected across the +5V supply (a requirement for the supply starting) the voltage measured across C2, as a result of the primary loop current, was 2.4V and the voltage on the slider (output) of R7 measured 0.323V. It takes the supply some 5 to 10 minutes to warm up before these voltages stabilize.

1) Where to set R7, if it has been tampered with?

The potentiometer R7 measured about 920R in total, and the setting with the slider such that the upper leg of its resistance was 205R and the end to negative 715R. This agreed with the voltage measurement of 0.323V on the slider when 2.4V was across C2.

One method to re-set this is to have the supply switched off, apply a separate 2.4v DC source to the cathodes of CR7 and CR8 and negative (across C2), so that the voltage seen on the slider (output) of R7 is 0.323V.

2) What voltage on C2 triggers shut-down ?

This is vital information to know, because if this circuit is repaired, for example the SCR (CR11) is replaced and the new SCR has different trigger threshold, then R7 needs to be re-set to the correct level to safeguard the power supply. Since it appears that R7 in my test 5155 supply had not been tampered with and was a factory setting, I applied a variable voltage across C2: At precisely 9.33V the SCR triggered, shutting down the supply.

3) What output power corresponds to the trip level ?

This question is difficult because as the supply's external is load increases, the supply losses increase in the rectifiers (forward voltage drop x current) and I^2 losses in the transformers & chokes increase. On the 12V supplies the rectifier losses are lower because the currents are lower for any given power output than for the 5V supplies. For example for a 25W load the 12V supply current is 2.08A, but for the 5V supply the current is 5A, so the rectifier power losses are proportionally higher for the 5V supply.

On the average the power losses in components inside the supply could easily be in the order of 2 to 4 Watts per 25W of external load averaged across the 5V and 12V supplies.

According to the label on the 5155 supply and adding up the numbers, it can supply at least 140W of power to external loads. Including losses the actual power transferred could be around 165W or more. So obviously the trip level for the load current in the loop, which is proportional to the total delivered power to both the losses & the external loads, would need to be set higher than that figure, so the supply was not tripping out near its maximum rated output power delivery.

Since the manufacturer's data is not available on the power figure the unit was intended to trip at, I would simply set R7 in the manner described above and checking that R7 is set so that when 9.33V is applied across C2 the SCR is just triggered and the supply just trips out.

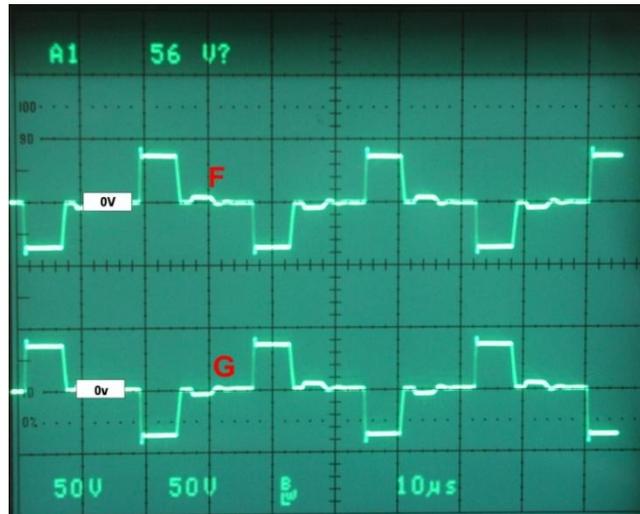
It would be possible to measure the trip power with external loads carefully distributed across the 5V and 12V supplies and *overloading them all proportionally* (to avoid damage to one of them) and the manufacturer's "trip power" could be found. Whatever that power value, probably in the range of 200W to 250W, the loop current is such that it corresponds to 9.33V across C2.

UNIQUE REGULATOR FOR THE AMBER MONITOR:

The circuit on the lower part of the diagram above shows the unique voltage regulator that the designers made to power the Amber CRT monitor in the 5155. Stepped up voltages are supplied to the reactor transformer T6 and pass to rectifiers CR12 and CR13. Part of this circuit is on the main board (shown in green) the rest on the same sub-board as the shutdown circuit. Q2 & Q1 (when conducting) and the bridge rectifier CR1, CR2, CR3 & CR4 short out a winding on T6 and while that is happening the output voltage from T6 increases.

When Q2 and Q1 turn off, the output voltage decreases feeding the rectifiers CR12 & CR13. A feedback loop is formed with the comparator, so that Q2 and Q1 are continuously switching. Due to the inherent 28.5KHz ripple, this ***switch-mode supply inside a switch-mode supply*** locks at a switching rate of twice that frequency.

The recording F & G below shows the voltages at the output of T6 at the anodes of CR12 and CR13. The small waveform steps are due to the activity of this unique regulator. The main wave is +/- 39V



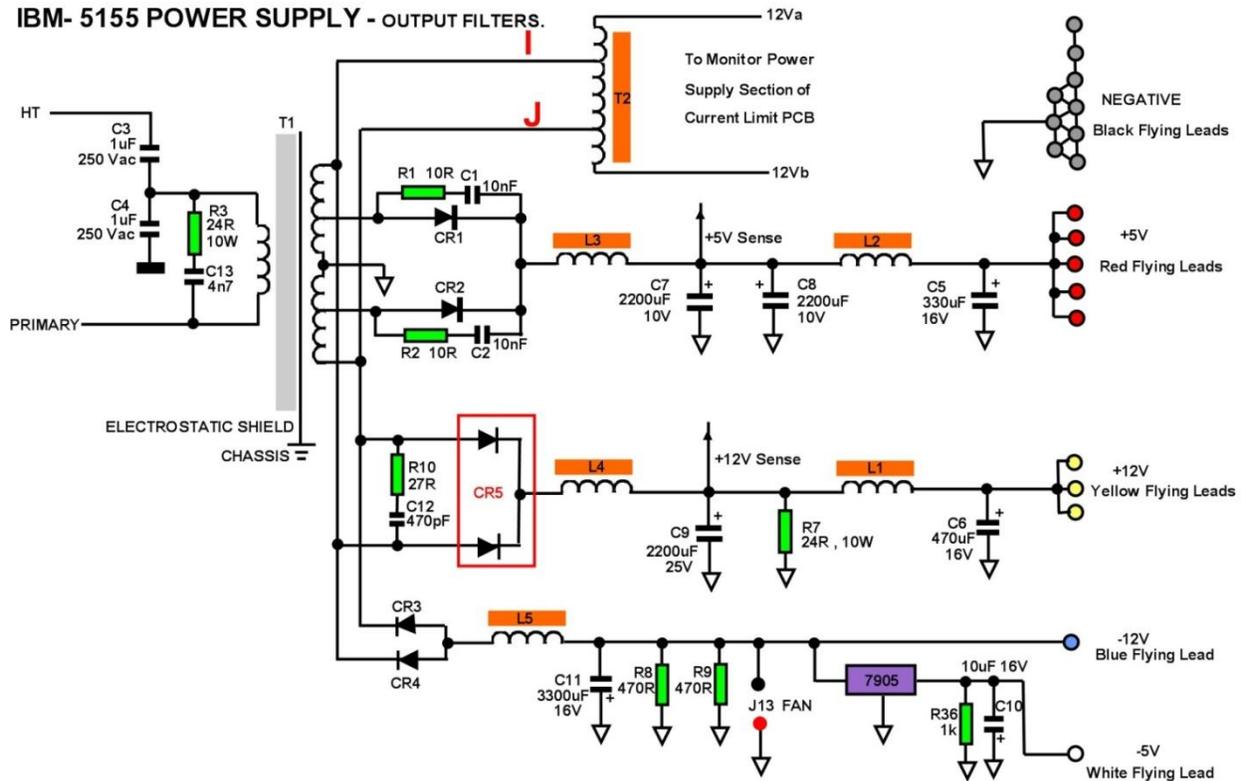
A recording at the comparator output H is shown below, the voltage only rises to about 1.4V due to the base-emitter junctions of Q1 and Q2. Notice how this circuit is switching at twice the supply's fundamental 28.5 KHz:



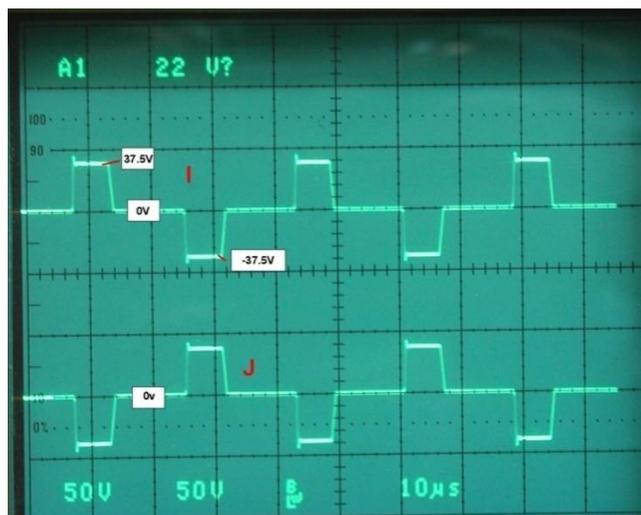
NOTE: WARNING ABOUT THE MONITOR 12V SUPPLY:

If the 5155 power supply unit is out of the computer for testing, the +12V monitor supply output on P12 malfunctions. The voltage rises to about 24V. It requires to be loaded with at least a few hundred milliamps for its regulator circuit to function normally and produce a regulated and controlled 12V, adjusted by R33. A 24V 20W auto lamp makes a good test load at running on half voltage this draws about 630mA. This supply is rated at 1.5A.

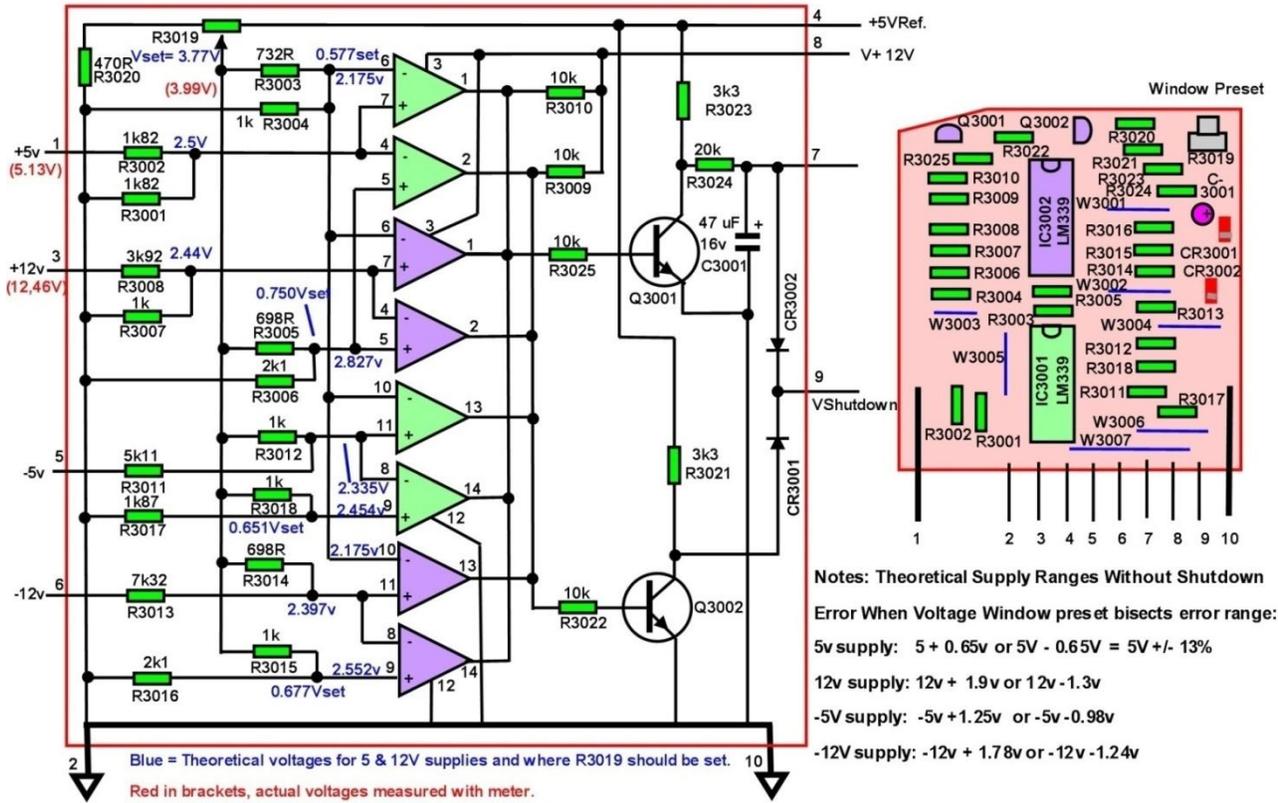
IBM- 5155 POWER SUPPLY - OUTPUT FILTERS.



The diagram above shows the output filter arrangements. All the supply's output energy is supplied by T1's secondary. The output is stepped up a little by T2 to supply the monitor regulator circuit previously described. The voltages present on I & J are shown below. The voltages on the 12Va and 12Vb connections of the step up auto-transformer T2, are nearly identical, just +/- 39V instead of +/- 37.5V. Again the pulse width seen here is that which corresponds to a 25W external load on the +5V supply rail.



IBM - 5155 POWER SUPPLY. VOLTAGE WINDOW CENTER PRESET.



Operation:

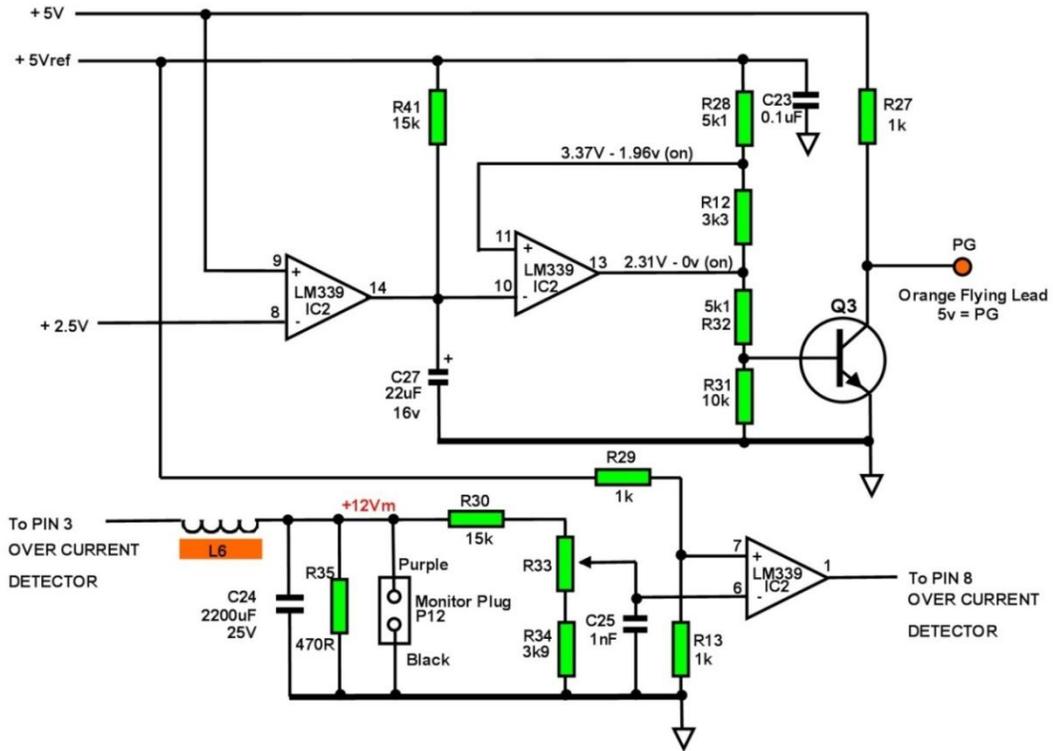
Voltage comparators are set up so that if the power supply's output voltages are above or below a specific threshold, the supply is instructed to shutdown. This creates a "Voltage Window" of acceptable power supply output voltages.

If the power supplies were 12 and 5 volts exactly, then the theoretical voltages are shown in Blue and the voltage at the wiper of R3019 should be set at a theoretical 3.77V to centre the voltages inside the window.

In practice though, since the voltages at the supply end of the cabling are set a little higher than 5.00 and 12.00 volts (to allow for voltage drop in the cables) I noticed that the manufacturers had set the voltage at the wiper of R3019 just a little higher at 3.99V. So if R3019 has been tweaked, re-set it to this voltage and all should be well.

The output of this circuit, Vshutdown, triggers the SCR on the current shutdown board previously described.

IBM-5155 POWER SUPPLY - POWER GOOD CIRCUIT & AMBER CRT MONITOR PARTIAL CIRCUIT.



The circuit above shows the monitor 12V supply regulator partial circuit again.

Operation:

The circuit above that uses two comparators of IC2 on the main board and is a “power Good” detector circuit. This has an output (orange wire) that signals the computer’s motherboard that the power is ok. When the +5V supply comes up pin14 (which is an open collector output comparator) releases and allows R41 to start charging C47. In the meantime pin 13 of IC 2 is still 2.13V because its open collector output is not conducting yet, so Q3 is turned on and the PG voltage is low.

When C27 charges to 3.37V, pin13 falls low. This also reduces the voltage on the positive input IC2 pin11 (positive feedback or hysteresis) to about -1.96V, to ensure the comparator output is stable and doesn’t jump between states. Q3 turns off, as it now has no base current and the PG line is pulled to +5V (logic high) by R27.

This power good circuit is not wonderfully selective in that the PG line will be high if the +5V line is anything over +2.5V.
