Panasonic Microwave Oven Inverter HV Power Supply

This particular power supply comes from a circa-2000 Panasonic Microwave model NN-S550WF.

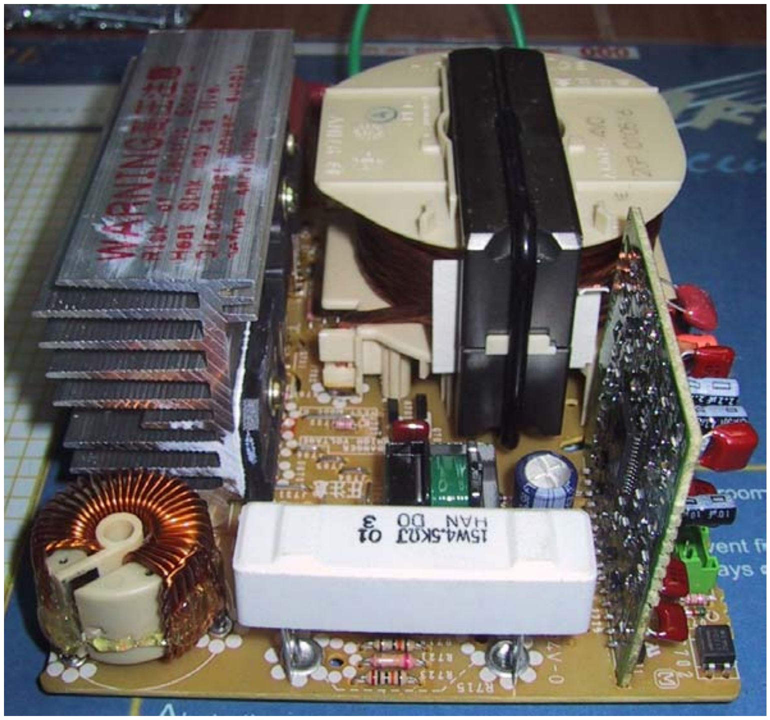
Nearly all Panasonic microwave ovens now use an Inverter, and are always labelled with “Inverter” on the front.

The High Voltage Power Supply Unit (HV PSU)

The HV PSU measures 165mm x 105mm x 60mm and weighs 650g.

At left is the control daughter board. In front of that on the main board are the opto-isolators for the control and status signals brought out to the green connector. Back left is the rectified mains filter choke. The mains rectifier and switching transistors can just be seen on the heatsink behind the transformer. The mains filter capacitor is at right rear. The HV rectifiers and filters (doubler) are right front – white wires are the HV output from the transformer. The green wire is for grounding the HV +ve. The two lugs at right are for connecting HV -ve and heater to the magnetron. The winding that can be seen on the transformer is the primary and is made from 3mm finely stranded wire.

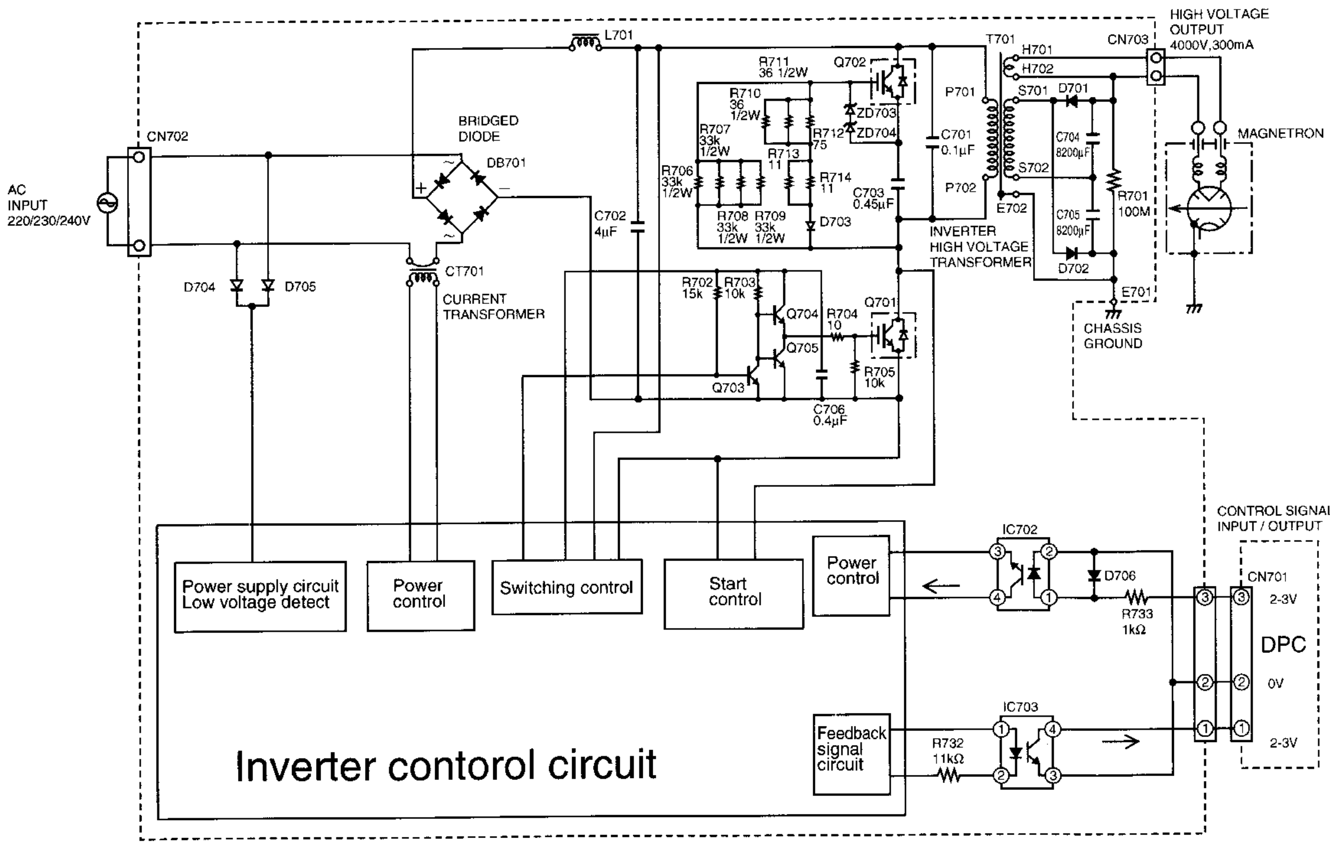
Here’s a view of the control end:



This is the high voltage end:

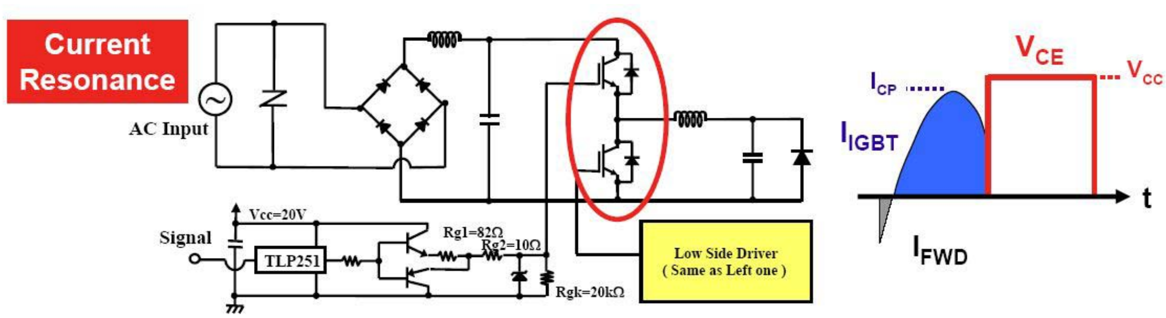
Circuit Notes

The circuit for the HV PSU is below (taken from the Panasonic Service CD):



Notes about the circuit:

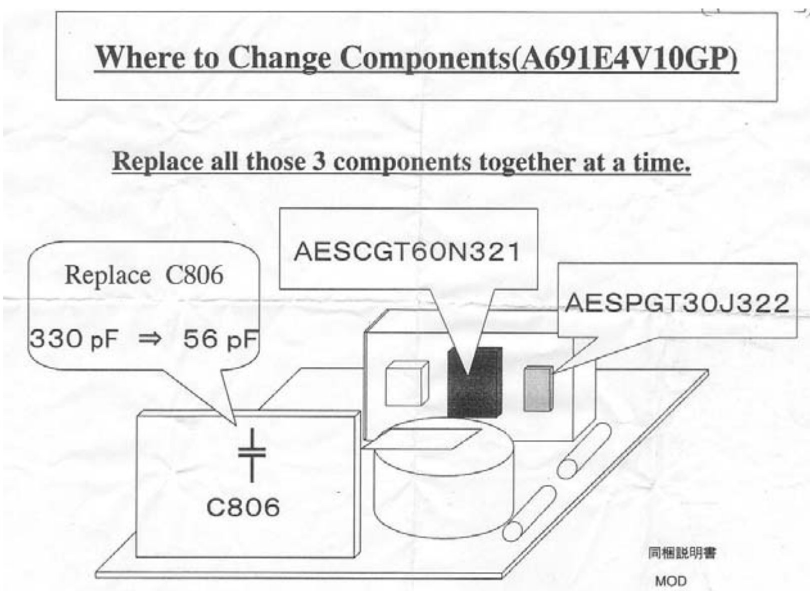
1. Apart from the block diagram, there is no information on the Inverter cont(o)rol circuit. The circuit itself is centred on one large, unmarked IC, so no help there.
2. The control and status signals seem to be a digital stream (2-3v suggests a 5V data stream). They are opto-isolated because the majority of the circuit is at mains potential **(**BEWARE**)**. The part that isn't is at 4kV **(*** REALLY BEWARE ***)**
3. The mains input side is monitored for both current and (under) voltage. No indication of what the control circuit does with this information.
4. The mains filter capacitor (C702) is very small – only 4uF. In a "normal" switching supply, there is usually 220 or 470 uF in this position.
5. Q701 that does all the hard work is a very heavy duty IGBT – a GT60N90 - 900V @ 60 A. Q702 forms some sort of flywheel circuit. This circuit from a Toshiba IGBT application note looks similar:



6. The HV side has a full-wave doubler rectifier and is marked 4kV @ 300mA. Unlike the classic microwave oven transformers (where one side of the winding is grounded), this means that the secondary must be well insulated from ground on both sides. A simple reconfiguration of the rectifier (replace the caps with diodes) into a bridge circuit should yield 2kV @ 600mA (depending on the diode ratings)
7. The HV filter capacitors are only 8200 pF each, effectively giving 4100pF in the doubler. Considering that the inverter runs at about 30kHz, the reactance is equivalent to that of a 5uF capacitor at 50Hz.
8. The positive side of the HV is grounded, so it's a –4kV supply. Don't simply swap the ground from the positive to the negative to get a +4kV supply, as the core of the transformer is also connected to this ground trace and will suddenly rise to 4kV above ground with disastrous results. Instead, reverse the polarity of the rectifier diodes to get +4kV.

Circuit Change

A modification has been issued by Panasonic for the HV PSU:



A kit is available consisting of two replacement IGBT's and a replacement capacitor. The GT60N90 has been replaced by a GT60N321 which has a 1kV rating vs. 900V. The smaller GT30J322 is unchanged, although a replacement is supplied in the kit (perhaps this is a post-blowup kit!). Also, a 330pF capacitor on the control board is replaced with a 56pF. Perhaps it would be wise to alter the value of that capacitor anyway, even if the bigger IGBT is not fitted.

Initial Measurements

I obtained the PSU from someone working in the servicing industry, so, I didn't have a complete oven on which to do testing. So, the first challenge was to get the PSU to operate standalone. The major unknown here was the format of the control signal required to get the PSU to do anything at all. It could have been anything from a variable frequency square wave up to a complex data stream.

The only solution was to obtain a working oven, and eventually, courtesy of eB*y, one was obtained quite cheaply. As an added bonus, I now had a spare inverter.

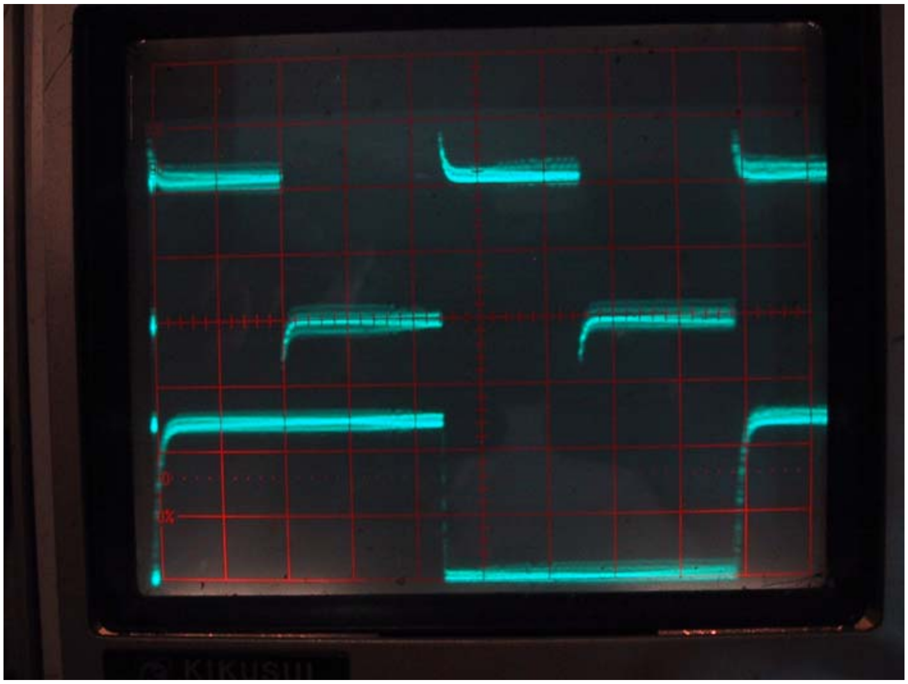
With the cover off the microwave oven and CRO connected, the control and status signals were measured with the oven operating.

The Control signal turns out to be a TTL-level 220Hz square wave where the duty cycle determines the "Power" from the Magnetron.

The Status signal from the PSU is a 110Hz square wave with a fixed 50% duty cycle. This signal seems to be present when there is a current drain, probably to signal that the Magnetron is warm and operating.

The Control and Status signals are synchronised to each other, but bear no relationship to AC mains frequency or phase.

Here's a pretty awful picture of the CRO trace showing the control signal (top) and the status signal (bottom).



The control signal duty cycles for different oven "Power" settings are shown in the table below:

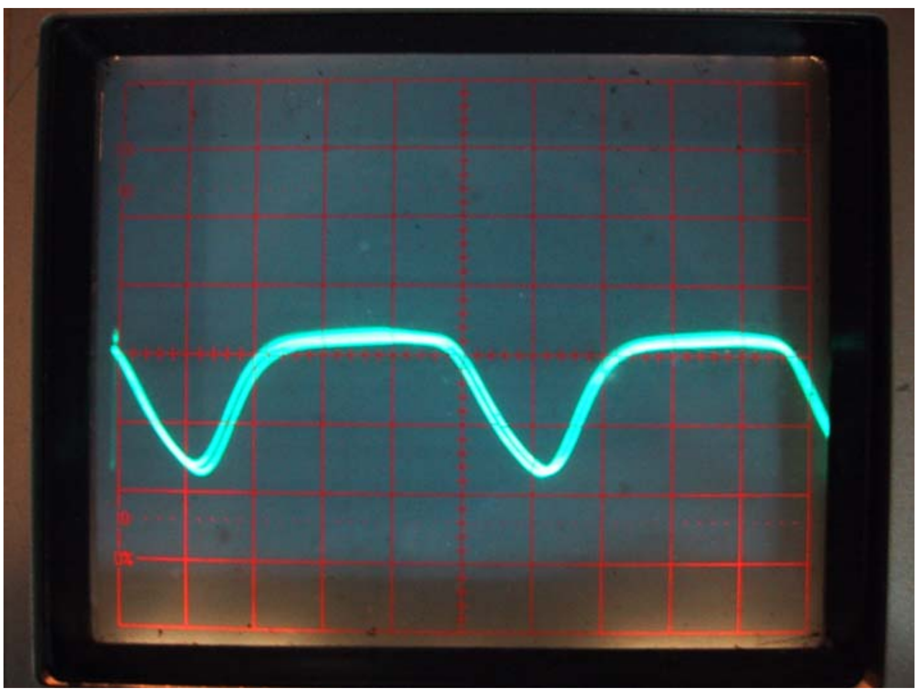
Power (%)	"On" time (mS)	Duty Cycle (%)	Cycle
10	1.5 / 1.1	33 / 25	4s on / 18s off
20	1.5 / 1.1	33 / 25	11s on / 11s off
30	1.5 / 1.1	33 / 25	18s on / 4s off
40	1.5 / 1.1	33 / 25	Continuous
50	1.5	33	Continuous

60	1.8	40	Continuous
70	2.5	55	Continuous
80	2.8	62	Continuous
90	3.1	69	Continuous
100	3.4	75	Continuous

Notes:

1. At low power levels, the PSU starts at a higher power level (50%) until the Status signal appears, then drops back to a lower level. This could be because the Magnetron filament requires at least the 50% power level for it to heat up, then it sustains itself from back bombardment once RF is being produced.
2. At low levels, the PSU is cycled on and off at the 40% power level over a 22 second period to reduce the average power output.

Turning now to the output side of the PSU, using a 1000:1 high voltage probe on the input of the CRO shows the following waveforms. Note that the probe was not designed for use on the CRO, so the waveforms could be somewhat inaccurate.



Vertical scale has 0 volts at the baseline and 1kV per division. Horizontal scale is 2mS per division.

This shows the PSU output at full power. The 100Hz ripple due to the small mains filter capacitor can clearly be seen. What is more difficult to see is the 30 kHz ripple from the inverter switching.

Although microwave ovens don't really care if there's ripple on the RF, it's worth speculating why the designers allowed so much 100Hz ripple. One theory is that the Magnetron would probably stop oscillating during the low parts of the voltage cycle, allowing other users of the 2.4 GHz spectrum (e.g. WiFi networks) to get a go.

Stand-alone Testing

The next step was to get the spare PSU up and running. To do this, two main things were required:

1. A circuit to generate the PWM control signal
2. A variable load, firstly to simulate a Magnetron and then to simulate a linear amplifier (the final use to which the HV Inverter supply is intended).

A simple PWM generator was built using a 555. Details may be found in the 555 datasheet. The potentiometer that varies the duty cycle has fixed resistors at each end to limit the adjustment to within the 25% to 75% to range generated by the microwave oven controller.

The load was a bit more problematic. It needs to handle 4kV+ (at low loads, the output voltage might soar) at 300 mA – that's 1200 watts. Plus, it needs to be variable for effective testing. I finally settled on using the RF deck from one of my linear amplifiers as the load. The GS-35b tube can handle up to 6kV and dissipate over 1500W (with the blower going). Also, the RF deck has a variable bias circuit so the current drain can be varied over a limited range easily.

The testing was done at each power level setting for the HV supply from minimum continuous (40%) to maximum (100%). At each setting, the RF deck bias setting was set to minimum and maximum and the voltage and current were measured for each of these.

Test results are shown below:

		Minimum Bias			Maximum Bias		
Power (%)	**"On" time (mS)**	**Voltage (V)**	**Current (mA)**	**Power (W)**	**Voltage (V)**	**Current (mA)**	**Power (W)**
40	1.1	3730	147	548	2560	210	538
50	1.5	3890	175	681	2720	250	680
60	1.8	3980	192	764	2820	275	776
70	2.5	4200	240	1008	3020	330	997
80	2.8	3650	300[1]	1095	3020	365	1102
90	3.1	3930	300[1]	1179	3080	385	1186
100	3.4	4120	300[1]	1236		Note 2	

Notes:

1. I was reluctant to exceed 4kV output, so, for the Minimum Bias tests for 80% to 100%, the current drain was set to 300mA and voltage measured.
2. Working current from the HV PSU is listed as 300mA on the circuit diagram. For the Maximum Bias tests, that current was exceed by the 70% power level and the output voltage had flat-topped beyond that current, so I didn't test at 100% power.

My initial reaction after measuring the voltage and current was that the output voltage from the HV PSU was extremely poorly regulated. However, when I entered the data into a spreadsheet and calculated the power, it all became clear. The power supply is delivering constant power into the load, and doing a very good job of it. (For example, at the 50% power level, with a variation of almost 50% in current drain, the power output varies by just 1 watt.) I know little about magnetrons, but I assume the constant-power characteristic is to cope with variations in magnetron characteristics. Regardless of whether a magnetron operates at 3500V or 4000V, the power input (and hence heating output) will be the same.

However, the constant-power function is not very useful for powering a linear amplifier where power input varies widely (in my case, from 130 watts (idle) to 750 watts (peak)).

Required Modifications

My requirement is for 2kV @ 370mA. Therefore, the first step would be to obtain two more of the HV rectifier diodes and reconfigure the output to a bridge rectifier. The diodes must be the same type (UX-C2B), which are high speed to cope with the 30 KHz switching. Of course, the diodes must also be reversed so that the negative output goes to ground.

The 100Hz ripple problem would be relatively easy to overcome. The obvious way to do this is to increase the value of the rectified mains filter capacitor. Rather than just replacing the cap (it's a special non-polarised type), it may be better to leave the original in place in case it is also providing some special high frequency bypassing for the inverter. A 220uF capacitor would be added directly across the output of the bridge rectifier.

The 30kHz ripple would be solved in a similar manner. A standard (non-inverter) microwave oven HV filter capacitor (1uF @ 2700 VAC) would probably work OK.

Voltage regulation is the major issue. The Inverter control circuit senses the current and hence the power in to the power supply. It probably adjusts the switching duration until the current reaches the required level.

There are several possible solutions:

1. Regulate the output by sensing the HV output voltage and adjusting the control signal duty cycle.

   Several things need to be considered here regarding the "normal" operation of the HV power supply in the microwave oven. The power output of the HV supply is never reduced below about 550 watts. The lower power levels are achieved by cycling the 40% power level over a 22 second period. Is this because the magnetron needs a certain power level to keep the filament going or is there a problem with running the power supply below 40%? Also, the control signal is a 220 Hz square wave. Therefore, there will be a significant delay (5+ mS) between any change in the control signal duty cycle and the HV supply responding, possibly leading to substantial spikes in the high voltage as the load changes.

2. Regulate the HV by generating an artificial current-sense signal to fool the Inverter Control Circuit into thinking that it is delivering a different power level to actual.

   The comment above about minimum power level also applies here. This could be tricky to implement and, if the current-sense signal ever disappeared for any reason, the HV supply could well self-destruct as it tries to push as much power as possible into the load.

3. Use a fixed load on the power supply

   If a linear amplifier is required, then it could be operated in Class A. To switch off the amplifier during receive periods, the HV supply is simply turned off. Thus there is always a constant load in the power supply when it is operating.

Interim Conclusion

Using a Panasonic HV Inverter power supply to power a linear amplifier has many interesting possibilities:

- Much lighter and more compact than a power supply using an iron-core transformer
- High efficiency
- 1200W of power (although continuous rating would probably be less)
- Simple control of power level

However, the constant-power characteristic of the power supply output is not compatible with the varying power load drawn by a linear amplifier, unless the amplifier is operated in Class A in which case the heat dissipation may become an issue.

Further experimentation is required for conversion of the power supply to constant voltage.