PWM Grid-Drive Applied to a CRT display.

Preamble.

One of the factors to consider when using a CRT as a display device is its inherent Gamma whereby the light output on the tube-face is not a linear function of the grid voltage. It's basically a squaring function, v_g^2, which is expressed as a Gamma of 2. Luckily early vacuum-state camera tubes such as Vidicons and the like had a complimentary Gamma of 0.5, a square-root function. The numbers are approximate, 2.2 and 0.45 were often used in practice.

Today virtually all photo-sensitive devices are linear, e.g. photo-diodes, photo-transistors and CCDs unless used in the photo-voltaic mode where it becomes a natural logarithmic function, *ln*. If using a linear light output device such as an LED in current drive all is well, linear to linear. But if using a mixture you need to Gamma-encode a linear photo-sensor or 'un-Gamma' a CRT.

There are a number of ways to do this in the analogue world but here we 'un-Gamma' the CRT in a different manner. Simply the CRT is on or off. A high-frequency square-wave is applied to the grid and this is pulse width modulated to achieve a linear output for a linear input. Only two points on the grid curve are used, cut-off or at a single current point. The curve itself now becomes irrelevant.

Here is this method as applied to a non-standard NBTV picture monitor, but it can be applied to virtually Any CRT picture or information display. In a colour CRT it would need to be the three separate cathodes that would need to be driven instead of the grid circuit, but the principle is the same.

An outline of the differences between this system and the more conventional mechanical display is in order, this is interim; and will be developed in time to cater for more lines and a higher frame rate:-

1). Scanning is left-to-right for the lines and top-to-bottom for the frame, the same as 525/625 TV.
2). The aspect ratio is 4:3, slightly landscape, again the same as conventional TV.
3). There are 48 lines each consisting of 64 pixels, the line rate is 600Hz and frame rate is 12.5Hz.
4). This is a sync-less system with (currently) the exception of a frame reference.
5). There is black-level clamping ensuring true luminance values.

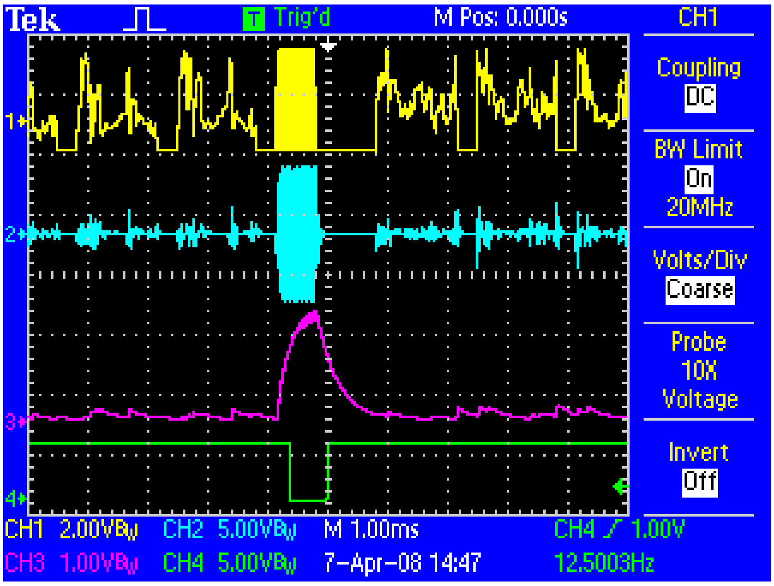
Caution.

This unit uses both high AC and DC voltages and the author of this in no way accepts any responsibility for any incident, injury or fatality of those attempting to replicate it. If you're not used to working with high voltages, get some experienced supervision. Although this is considered a low-voltage CRT, there is nigh on 1000V of potential difference in parts of the device. Do not work on this alone.

Basic Signal Characteristics.

The source material is from a .wav file played back on a PC; this is sampled at 48kHz with eight-bit video resolution. At a line rate of 600Hz this yields 80 pixels per line of which only 64 contain active video, the other 16 at the end of each line are set to black level. This was originally for black-level clamping but it proved unnecessary, more on this later.

There are no sync pulses used with the exception of a ‘frame reference’ consisting of 16 cycles of full amplitude 24kHz at the start of line 48. This is followed by a black reference for the remainder of the line where the black-level clamping is done once per frame. Sadly we lose one line in 48, but I plan to recover line 48.



The snapshot to the left shows the input waveform from the PC (yellow) with the video utilizing the entire 8-bit resolution and the 24kHz burst for line 48 identification followed by the black reference.

The cyan trace is the 24kHz bandpass filter output (IC204b pin 7, Fig. 1 below). The magenta trace is the envelope detector output (C210) and the green trace is the comparator output (IC205 pin 7).

This all relies on the exactitude of two oscillators, one in the PC which drives the audio D-A and the one in the display. The oscillator in my PC is around 32ppm off-frequency, whereas the displays reference is far more accurate.

This results in a slow drift in line-rates, around one line in 90 seconds. But with a refresh every frame results in an error of around one tenth of a pixel per frame. I did consider adding a 24kHz reference signal to the right audio channel which would have made things very easy, but I felt this would be cheating.

The circuits.

Figure 1 shows the input side of things where the signal from the PC is increased to 7V p/p and followed by a band-pass filter to extract the frame 24kHz burst. Flat-out my PC outputs 3.5V p/p, adjust R216 to suit other levels. IC204b is the band-pass filter that detects the 24kHz burst followed by a simple detector comprising D201 and associated components. See waveform above.

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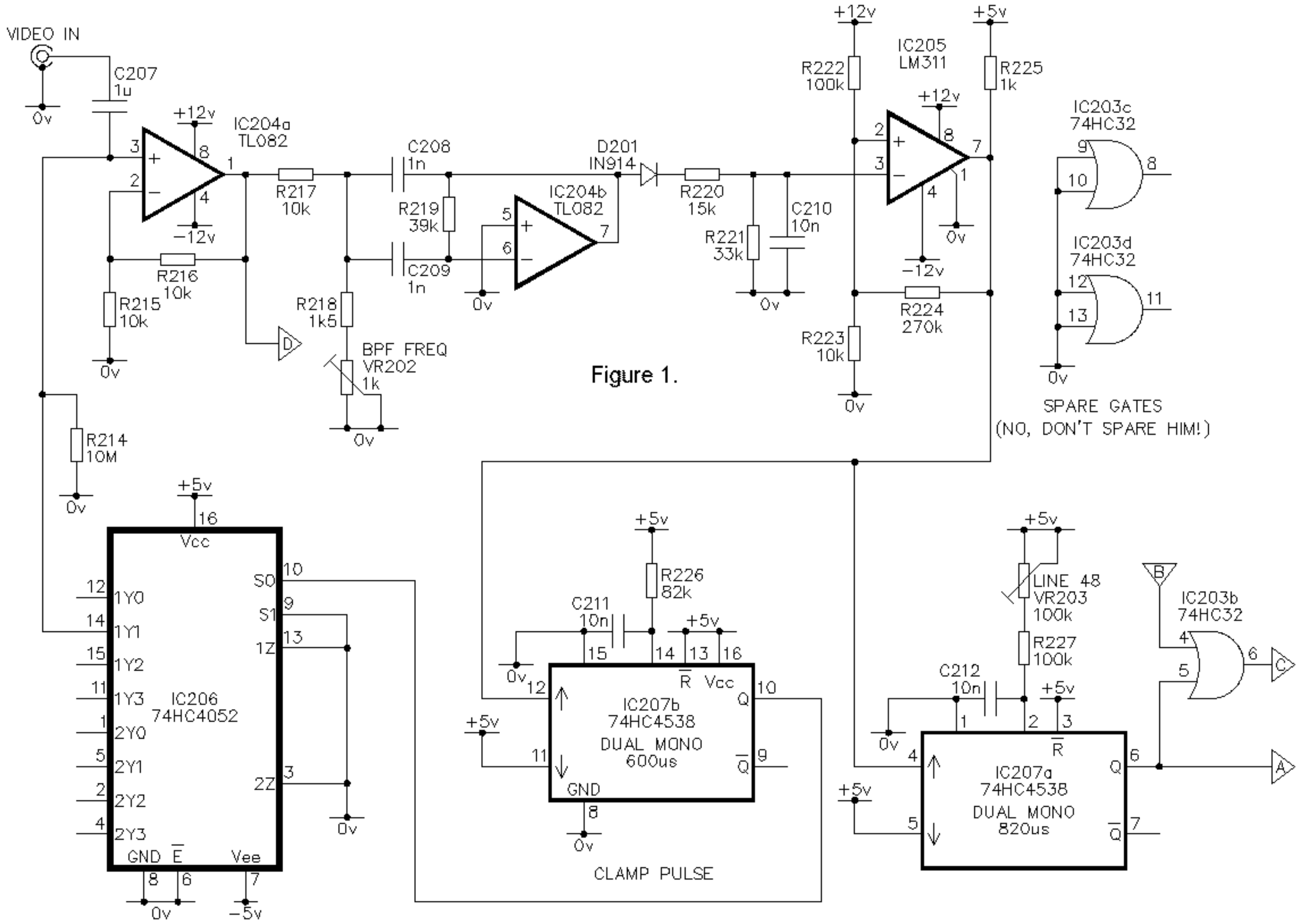

Figure 1.

This is then cleaned up by IC205, a comparator which generates a pulse that triggers IC207a and IC207b. IC 207b is the black-level clamping monostable that enables IC206 welding the black reference to zero volts that follows the burst in line 48. I did try a LM/NE567 tone decoder, but with only 16 cycles to work with it was susceptible to false triggering from the actual video waveform.

Once the 24kHz frame sync is detected IC201b is continually retriggered to illuminate a green LED which indicates the presence of a NBTV signal with frame reference.

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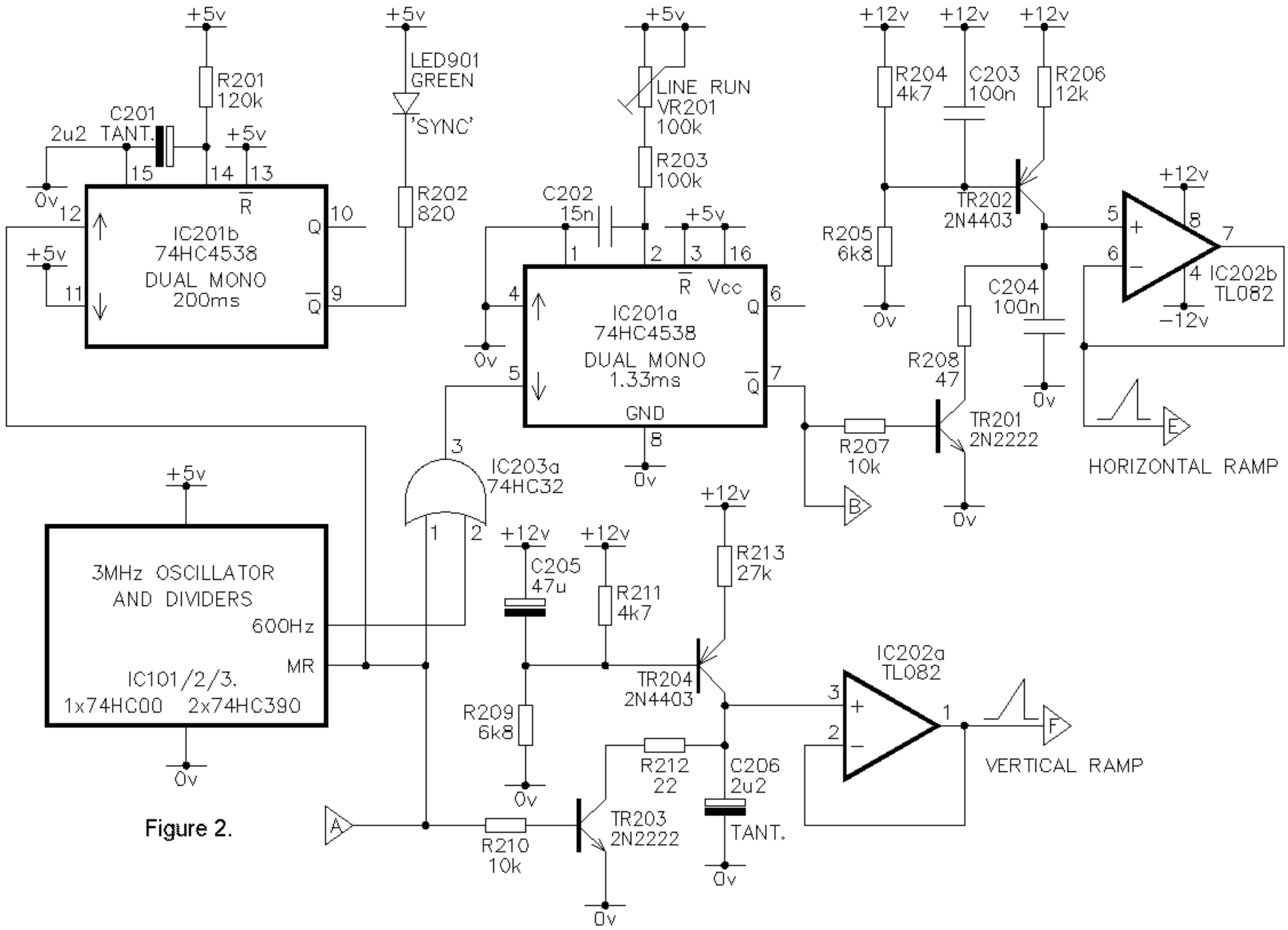
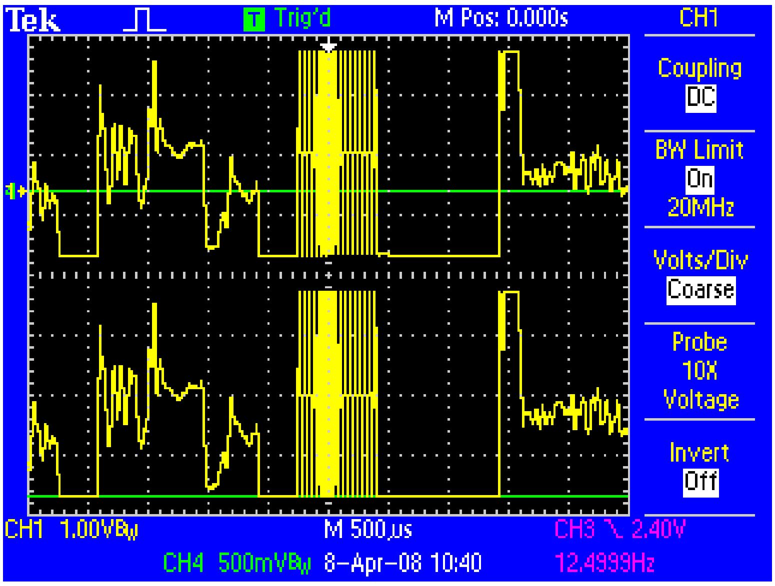


Figure 2.

Due to the slight difference in clock frequencies all the counters in the division from 3MHz that generate the timing of the timebase waveforms, both horizontally and vertically, are reset at each detection of frame sync (Fig. 2). IC207a generates a pulse to add the missing line one sync when the counters are reset to zero. IC203b is a 'leftover' from previous versions of this, it's not needed. Pin 5 could be at ground or IC203b could be omitted entirely.

IC201a in conjunction with TR201 and TR202 generate the horizontal deflection waveform at 600Hz. In a similar manner TR203 and TR204 generate the vertical ramp waveform.



Black level clamping is performed by IC206 (Fig. 1) driven by the clamp pulse from IC207b. The waveforms to the left show the normal AC-coupled output of the PC at the top, the green trace indicating ground/0V. The lower one shows the black being clamped to ground.

The deflection circuits that feed the CRT plates are conventional differential stages, TR301 to TR306 (Fig. 3). C301 and C305 were not necessary in this slow speed application.

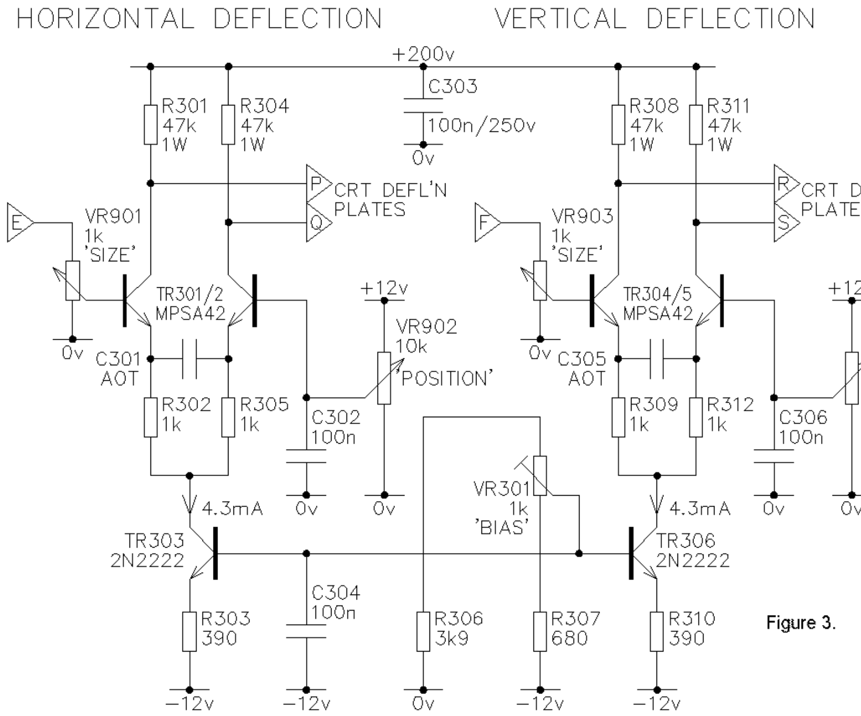


Figure 3.

Fig. 4 shows how the PWM of the grid is done via a fast logic opto-coupler to isolate the nasty voltages around the grid and cathode potentials of the CRT. TP1 and R417 were added to observe the PWM waveform at the grid without the scope probes capacitance slowing things down. TR402/3 stop the PWM oscillator during blanking/retrace time which makes it synchronous and shuts off the drive to the IR LED.

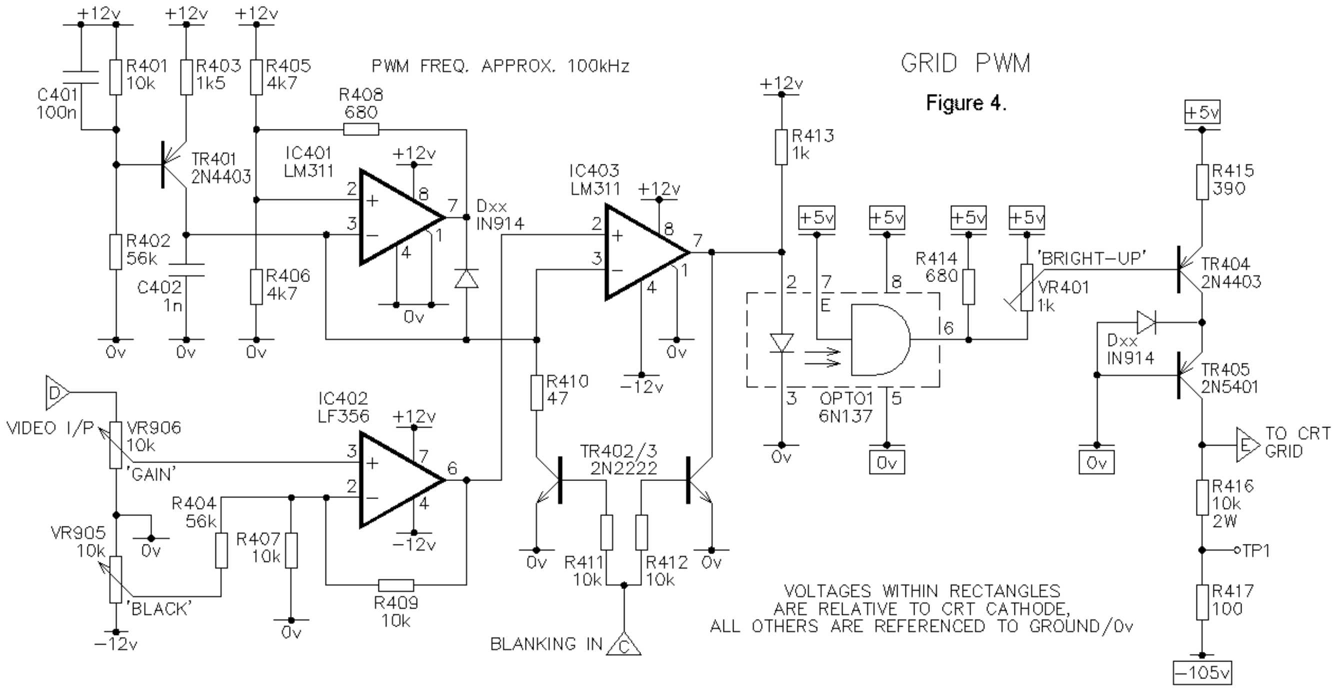


Figure 4.

As ever, CRTs need a handful of voltages in addition to the low-voltage supplies that are required, hence the complexity of the PSU and CRT circuit that follows (Fig. 5). This was not helped by the unavailability of suitable transformers, hence the use of back-to-back transformers and the requirement of voltage multiplication. The transformers used have some strange voltages, but I had them to hand. R909 and R910 were added to the CRT heater circuit to reduce the inrush current when first switched on cold.

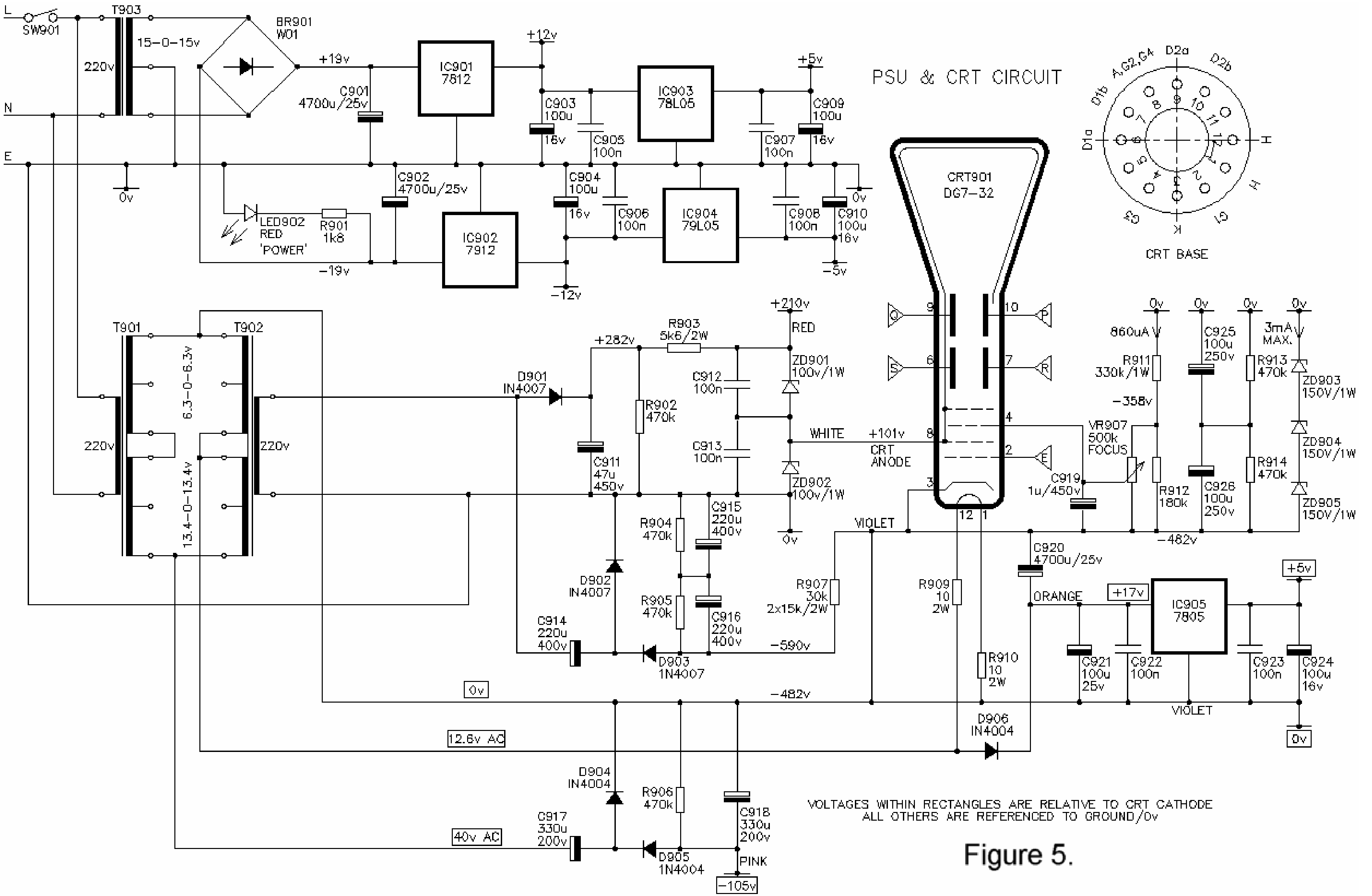

PSU & CRT CIRCUIT
L
N
E
SW901
T903
220v
15–0–15v
BR901
W01
+19v
C901
4700u/25v
IC901
7812
+12v
C903
100u
16v
C905
100n
IC903
78L05
+5v
C907
100n
C909
100u
16v
0v
C902
4700u/25v
LED902
RED
'POWER'
R901
1k8
-19v
IC902
7912
C904
100u
16v
C906
100n
IC904
79L05
C908
100n
C910
100u
16v
-5v
-12v
CRT901
DG7–32
CRT BASE
T901
T902
6.3–0–6.3v
13.4–0–13.4v
220v
D901
IN4007
+282v
R903
5k6/2W
R902
470k
C911
47u
450v
+210v
RED
C912
100n
C913
100n
ZD901
100v/1W
ZD902
100v/1W
WHITE
+101v
CRT
ANODE
D902
IN4007
C914
220u
400v
R904
470k
R905
470k
C915
220u
400v
C916
220u
400v
D903
1N4007
-590v
R907
30k
2x15k/2W
VIOLET
R909
10
2W
R910
10
2W
C919
1u/450v
VR907
500k
FOCUS
860uA
R911
330k/1W
-358v
R912
180k
C925
100u
250v
C926
100u
250v
3mA
MAX.
R913
470k
R914
470k
ZD903
150V/1W
ZD904
150V/1W
ZD905
150V/1W
-482v
C920
4700u/25v
ORANGE
+17v
IC905
7805
C921
100u
25v
C922
100n
C923
100n
C924
100u
16v
0v
12.6v AC
D906
IN4004
D904
IN4004
R906
470k
C918
330u
200v
PINK
-105v
C917
330u
200v
40v AC
D905
1N4004
VOLTAGES WITHIN RECTANGLES ARE RELATIVE TO CRT CATHODE
ALL OTHERS ARE REFERENCED TO GROUND/0v

Figure 5.

The Results.

So, after all that effort what's the upshot of it all? Pictures are worth a thousand words…

You can see the vertical burst in the first half of the last line. I deliberately didn't blank it as I wish to be able to see the visible effects as I modify it.

Further Developments.

Using a 7cm (3") tube with a nominal line-width of 0.5mm this is about the limit of resolution for a DG7-32, next it's going to be a 13cm (5") 5ADP1 with an increase in the number of lines to 60/80/96, and a minor increase in voltage to 3000V. Another advantage of the 5ADP1 is that it has a flat faceplate so the curvature distortion introduced by the DG7-32 should be reduced or eliminated.

However, seeing as the 3" display was already in operation it was a simple task to change it to being a 72-line display. This was done by reducing the frame rate to 6.67Hz, the flicker of course was greater than at 12.5Hz. Only one resistor needed changing, R213 was increased to 47k, VR201 and VR203 having enough adjustment range…but only just! The frequency dividers were altered to provide a line rate of 480Hz as opposed to 600Hz. Some sample screen-shots follow…

This display and the methods used were mainly a ‘proof of concept’ exercise; the display will again be torn down and used for something else.

If anyone should have any comments or questions please contact me at the e-mail address below.