XR-2206 5Hz to 300kHz Function Generator

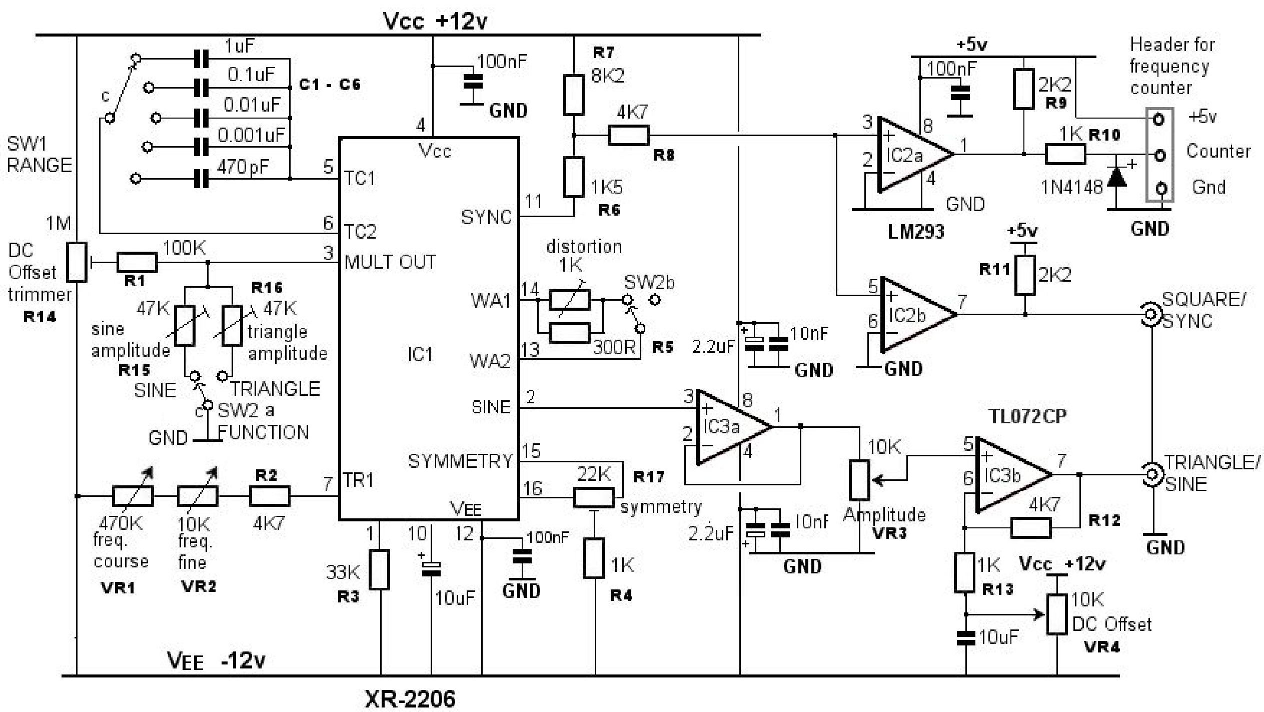
After making a couple of waveform generators based on Direct Digital Synthesizer (DDS) chips (AD9850 Waveform Generator & AD9833 Waveform Generator) I wanted to build something which uses an older 'analogue' function generator IC. There are two main contenders - the Intersil ICL8038 and the Exar XR-2206. Although neither chip is in current production, both are still widely available - either as old stock or, perhaps, as 'clones'.

Although I've seen circuits and even commercial project kits claiming several MHz frequency range, in practice I think somewhere around 400kHz or 500kHz maximum frequency is more realistic for these ICs while still maintaining a reasonably low-distortion sine waveform. For this project, I was more interested in producing a clean undistorted sinewave rather than pushing it to the limits in terms of frequency.

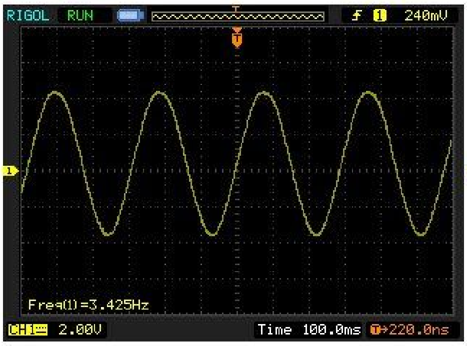
After breadboarding both the XR-2206 and the ICL8038, I decided to build a decent function generator using the XR-2206.

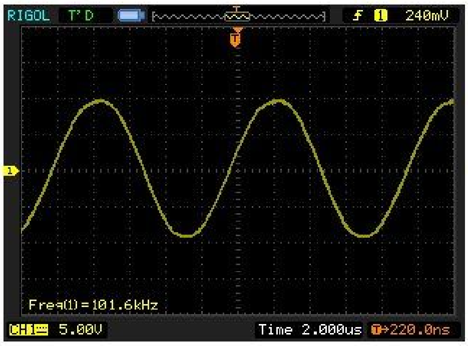
Although this is an analogue IC, this project just made it into the Arduino section of my website because it uses an ATmega328 as a frequency counter and to drive an 8-digit 0.36" LED SPI module (although only 6 digits are used).

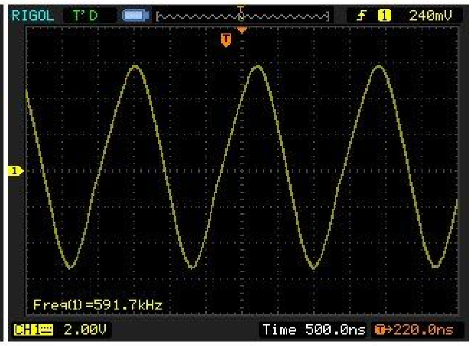
Part 1 ~ The Function Generator



The circuit around the XR-2206 is based on the ExarTAN-005 XR-2206 Application Note which describes a "High quality 1Hz to 100kHz function generator." After playing with some of the component values and adding a couple of OpAmps, I think the sine wave quality is acceptable up to 550kHz although the triangle wave starts to get rounded peaks at around 300 kHz.







Frequency control

The frequency range is controlled with the timing capacitor (connected between pins 5 and 6 of the XR-2206) and the timing resistors VR1, VR2 and R2 (conencted in series between pin 7 and -12v). With the component values shown above, the overlapping frequency ranges are shown in the following table: The overlapping of the ranges isn't ideal but it hasn't proven to be a problem in practice. The TAN-005 Application Note recommends a log-taper for the frequency adjustment (VR1) although I've used a linear one and added the "fine" frequency control (VR2).

Capacitor	Minimum Frequency	Maximum Frequency
1uF	2.25Hz	225Hz
0.1uF	20Hz	2kHz
0.01uF	225Hz	22kHz
0.001uF	2.0kHz	186kHz
470pF	4kHz	375kHz

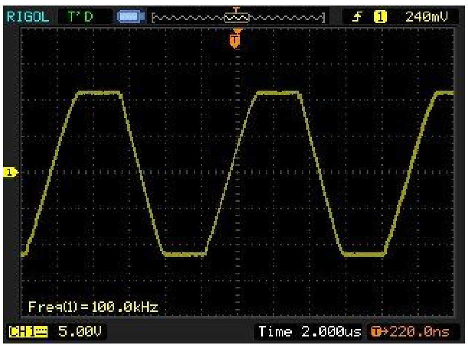
The Exar XR-2206 datasheet recommends 1000pF (0.001uF) as the minimum value for the timing capacitor connected to pin 5. I've found that the square wave, in particular, tends to become 'jittery' and unstable between approximately 23kHz and 50kHz with a timing capacitor smaller than 400pF. As I'm using the square wave output for the frequency counter/display, I've limited the smallest capacitor to 470pF which results in a top frequency around 375kHz. If the capacitor is reduced to 100pF, the highest frequency is around 500kHz still with acceptable waveforms - except for the jittery square wave and resulting unstable frequency display between 23kHz and 50kHz.

Output Amplitude

Selection between sine and triangle waveforms is accomplished with switch SW2b connected across XR-2206 pins 13 and 14. When the switch is closed, the output is a sine wave. With the switch open, it is a triangle wave.

Unfortunately, the output voltages of the sine and triangle are not the same. The maximum sine wave is about 6 volts peak-peak and the triangle wave is about twice that. In my circuit, I've added two pre-set trimmers - R15 and R16 - to adjust the waveforms so they're the same voltage. When SW2b is closed, the output is a sine wave and SW2a connects R15. When SW2b is open, the output is triangle and R16 becomes the 'active' pre-set.

R15 and R16 both need to be "backed off" from maximum otherwise the TL027CP OpAmp is overloaded when the main `Amplitude` control - as part of the TL072CP circuit - is turned to maximum. Once R15 and R16 are set correctly, the output from the TL027CP is fully adjustable from near zero to about 10 volts peak-peak (ie ±5v about the centre ground 0v). Although about 20 volts peak-peak can be achieved, 10 volts peak-peak is preferable to avoid excessive clipping when `DC OFFSET` is applied.



This image shows the effect of having the sinewave's Amplitude preset trimmer set too high.

DC Offset

R14, which is connected to the XR-2206 via R1, is used to set the DC Offset of the waveforms. As the circuit uses a split power supply (±12v), R14 can adjust the waveform's centre to be slightly positive or negative of ground. In practice, the amount of adjustment is fairly limited so I've used R14 as a pre-set trimmer instead. The Sine/Triangle output on pin 2 of the XR-2206 is connected to a TL072CP OpAmp which has its own DC Offset adjustment via VR4 so the pre-set trimmer R14 is only used to"centralise" the adjustment of VR4 - ie the waveform is centred about 0v when VR4 is centred.

The TL072CP

The first half of the TL072CP OpAmp (IC3a) is used as a unity-gain buffer . IC3b provides about 5.7x gain [`(R12/R13) +1`] and a wide DC Offset adjustment.

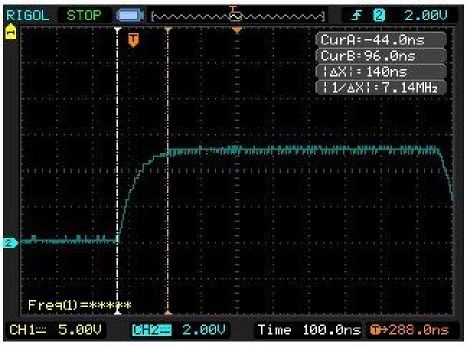
Choice of the TL072CP was quite critical. Initially, I used an LM6172 which has a better frequency response but I found I could get a higher un-distorted output frequency using the TL072CP. As the chip is socketed on the PCB and OpAmps tend to be pin-compatible, it's easy to try different ICs.

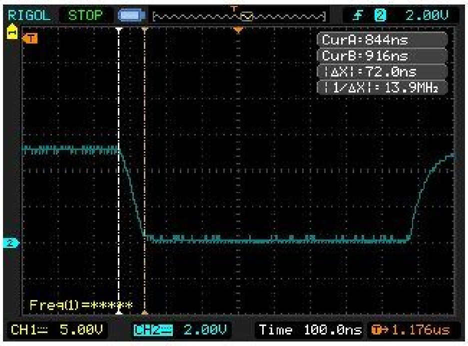
The Sync/Square wave Output

The XR-2206 provides a separate output for the sync/square wave and it's virtually a rail-to-rail output at over 20 volts. It's useful for synchronising the oscilloscope while probing a circuit with the sinewave but I also wanted to use it to drive a frequency counter. In either event a more manageable output voltage seemed sensible. R6, R7 and R8 provide an 8v peak-peak signal with about -0.1 volts below ground.

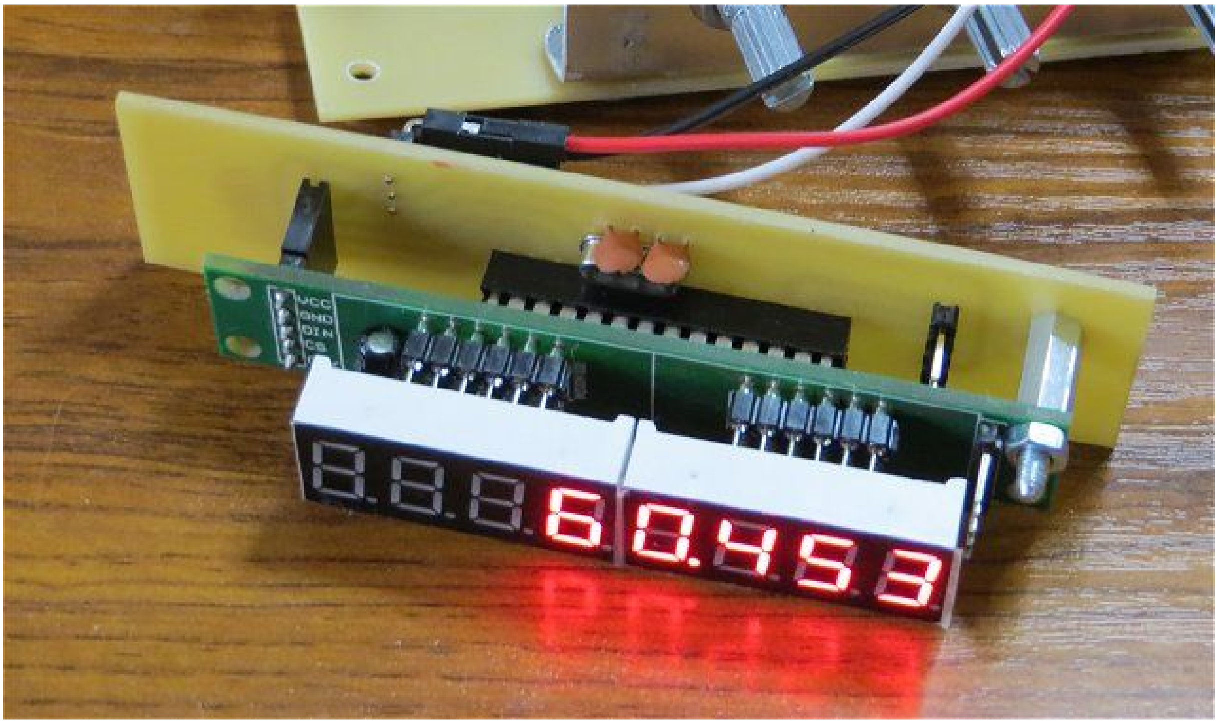
This signal is fed to both halves of the comparator - LM293. The outputs at pins 1 and 7 swing between ground and 5 volts. The output on pin 7 is taken to a front panel BNC socket (for 'scope sync or other uses) and the output on pin 1 is taken to a header - together with +5v and ground - for connecting to the ATmega328-based frequency counter. The 1N4148 helps protect the ATmega328 input by removing any negative spikes that may be present on the square wave.

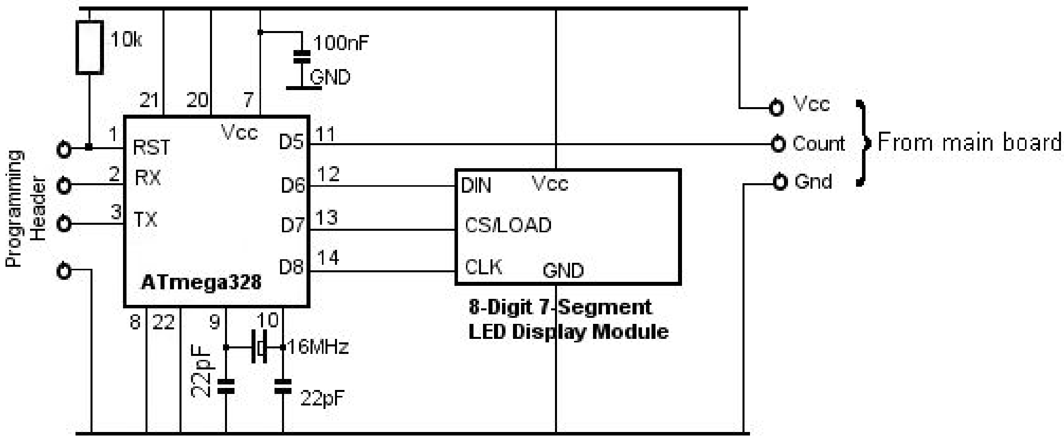
At 590kHz, the square wave has a rise time of about 140ns and a fall time around 70ns. A faster comparater could be used if faster rise and fall times are required. However, as I've noted above, I've restricted the upper frequency limit to about 310kHz because of the square wave's instability between 23kHz and 50kHz when using the smaller timing capacitor.





Part 2 ~ The Frequency Counter





The 8-digit 7-segment LED display circuit is very simple and straightforward. An ATmega328 microcontroller uses an Arduino library (FreqCounter) to count the rising edges of the +5v square wave pulses from the waveform generator at digital pin D5.

The count per second (hence frequency in Hz) is displayed on a widely available 7-segment LED display module using another Arduino library - LedControl.

I tried several different Arduino frequency counter libraries and they all use more-or-less the same principle of setting up an ATmega328 internal 16-bit counter and measuring the pulses on pin 'T1' - which maps to Arduino pin D5. Luckily, it's all taken care of in the FreqCounter library.

The counter works reasonably well but, being implemented in software, there is a one-second delay between frequency measurements so isn't quite as responsive as a hardware implementation might be.

I'll show a simple PCB layout on Page 4.

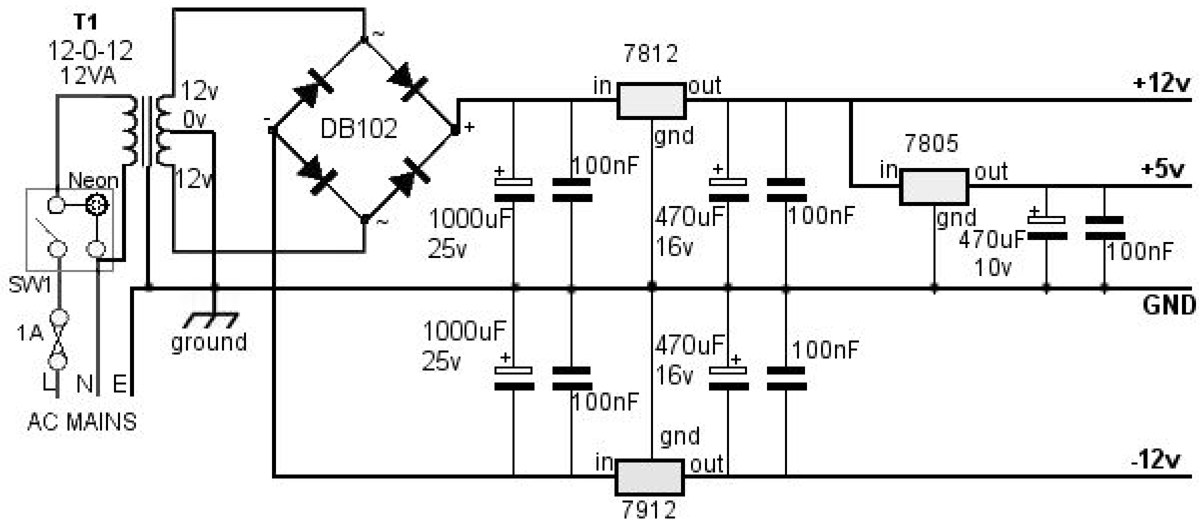
One slight problem with the specified LED display module is that it's supplied with the pin header already soldered in place and, as it faces forward, it would make mounting the display flush with the front panel difficult. One solution would be to ignore the pin header and solder wires directly to the back of the PCB.

I took a chance and desoldered the pin header and fitted a new one facing to the rear. I say "took a chance" because plated-through holes can be difficult to desolder. It's easier if you cut off the header's black plastic spacer/separator so you can deal with each pin one at a time.

The Arduino Sketch

```
#include "LedControl.h"
// https://github.com/wayoda/LedControl/releases

#include <FreqCounter.h>
// http://interface.khm.de/index.php/lab/interfaces-advanced/arduino-frequency-counter-library/
// Counter input must be D5.

//LedControl lc=LedControl(DIN,CLK,CS,1);
LedControl lc=LedControl(6, 8, 7, 1);

unsigned long frq;

void setup() {
  lc.shutdown(0,false);
  lc.setIntensity(0,4);
  lc.clearDisplay(0);
  delay(2000);
}

void loop() {
  FreqCounter::f_comp=10;              // Cal Value - Calibrate with professional Freq Counter
  FreqCounter::start(1000);            // 1000 ms Gate Time for 1Hz resolution.

  while (FreqCounter::f_ready == 0);   // Wait for counter to be ready

  frq=FreqCounter::f_freq;
  lc.clearDisplay(0);                  // Clear LED display.
  printNumber(0, frq);                 // Break number into individual digits for LED display.
}

void printNumber(int addr, long num) {
  byte c;
  int j;
  int d;
  num < 1000 ? d = 4 : d = countDigits(num);
  for (j=0; j<d; j++) {
     c = num % 10;                     // Modulo division = remainder
     num /= 10;                        // Divide by 10 = next digit
     boolean dp = (j==3);              // Add decimal point at 3rd digit.
     lc.setDigit(addr, j, c, dp);
  }
}

int countDigits(long num) {
  int c = 0;
  while (num) {
    c++;
    num /= 10;
  }
  return c;
}
```

Part 3 ~ The Power Supply



XR-2206 Function Generator Power Supply

The power supply circuit is fairly conventional. It provides plus and minus 12 volts for both the XR-2206 funtion generator IC and the TL072CP OpAmp. It also provides plus 5 volts for LM239 Comparator, the 7-segment LED display and the ATmega328 display controller.

Although the XR-2206 and the TL072CP *can* be used with a single supply, the resulting sine and triangle waveforms would always be positive voltages with respect to zero volts. By providing a split power supply, the waveforms can be true AC waveforms with positive and negative excursions about the zero volts (ground) point.

The square wave output from the XR-2206 is always a DC voltage above 0v regardless of the power supply.

Safety Considerations

This project uses potentially lethal mains voltages. Do NOT skimp on safety arrangements such as earthing (grounding), fuses, ventilation and preventing access to live parts through ventilation slots.

AC mains is applied to the primary of the transformer through a 1A fuse and an illluminated switch. There doesn't seem to be any particular standard as to whether the fuse should come before or after the switch. My personal view is that the fuse should come first in case the illuminated switch becomes faulty.

Use a *good quality* screw-in type panel fuse and ensure that the design is such that, when removing the fuse holder, it is well clear of live internal contacts before there is sufficient clearance to be able to touch the fuse (or the holder's metal parts) with your fingers.

The mains earth (ground) lead is connected to the enclosure through one of the transformer mounting bolts. Although I used a plastic enclosure, the mains transformer mounting bolts are exposed on the underside so *must* be connected to mains earth.

Note that any parts of the enclosure that are attached separately (such as the front & rear panels and the top attached with self-tapping screws, for example) should have their own earth wire back to the same transformer mounting bolt. ***Do not rely on the self-tapping screws for earth continuity.*** Try to leave the incoming earth conductor longer than the live and neutral conductors so that, if the cable does get forcibly pulled, the earth will be the last conductor to break.

All exposed mains-voltage connections - to the illuminated switch, the fuseholder and the transformer - must be insulated with heat-shrink sleeving and/or access prevented with insulating covers. It should not be possible to make contact with any high voltage connections - *even with the top cover removed*- without a determined and conscious effort!

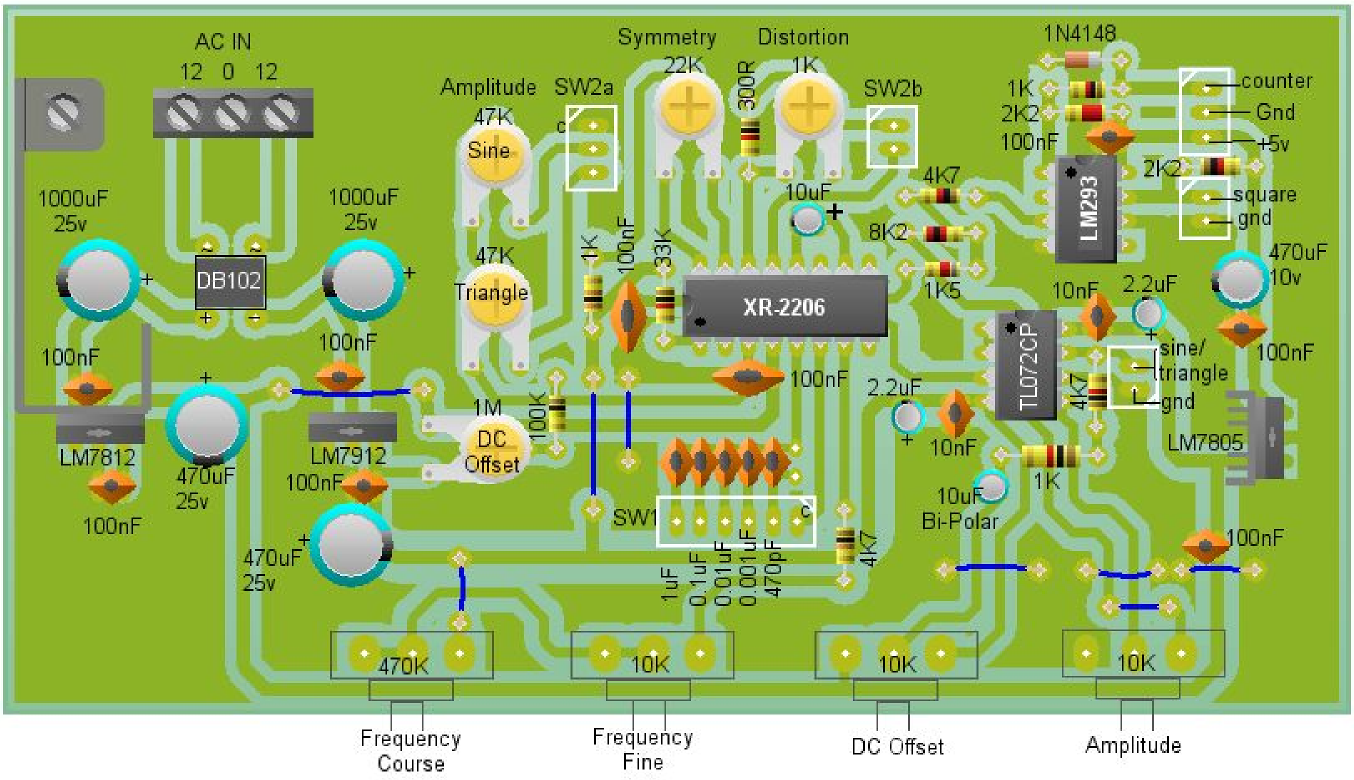
The mains cable entering through the rear panel must be protected from chafing with a rubber grommet and the cable must be clamped against moving inside the enclosure to prevent the connections being pulled or twisted and to prevent the grommet being pulled from its hole.

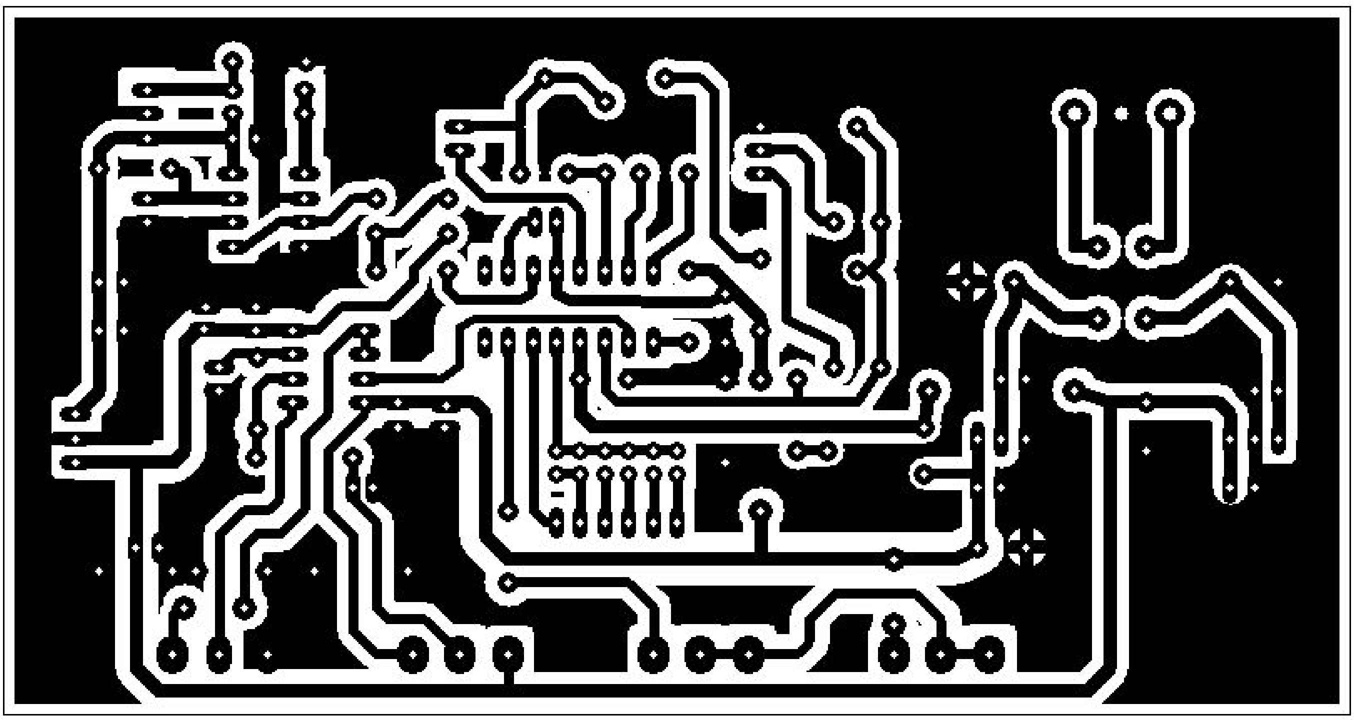
Despite what commercial products may do, ***do not*** use the printed circuit board for any mains voltage part of the circuit.

The low voltage components of the power supply are mounted on the main function generator PCB. The +12v and +5v regulators require small heatsinks. Due to lack of space, I fabricated a heatsink for the +12v regulator from a small strip of aluminium. Constructional details are shown on the next page...

Part 4 ~ Construction

The Main PCB





[Download/View PCB Artwork in PDF Format](#) (Actual size)

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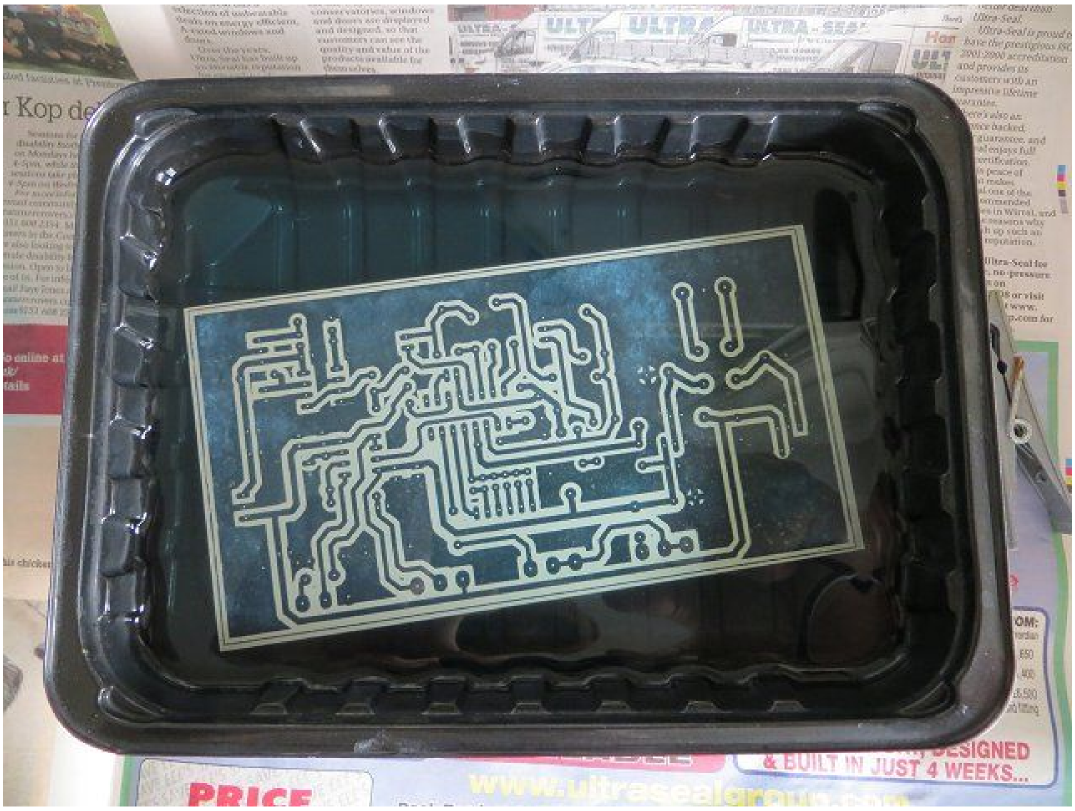
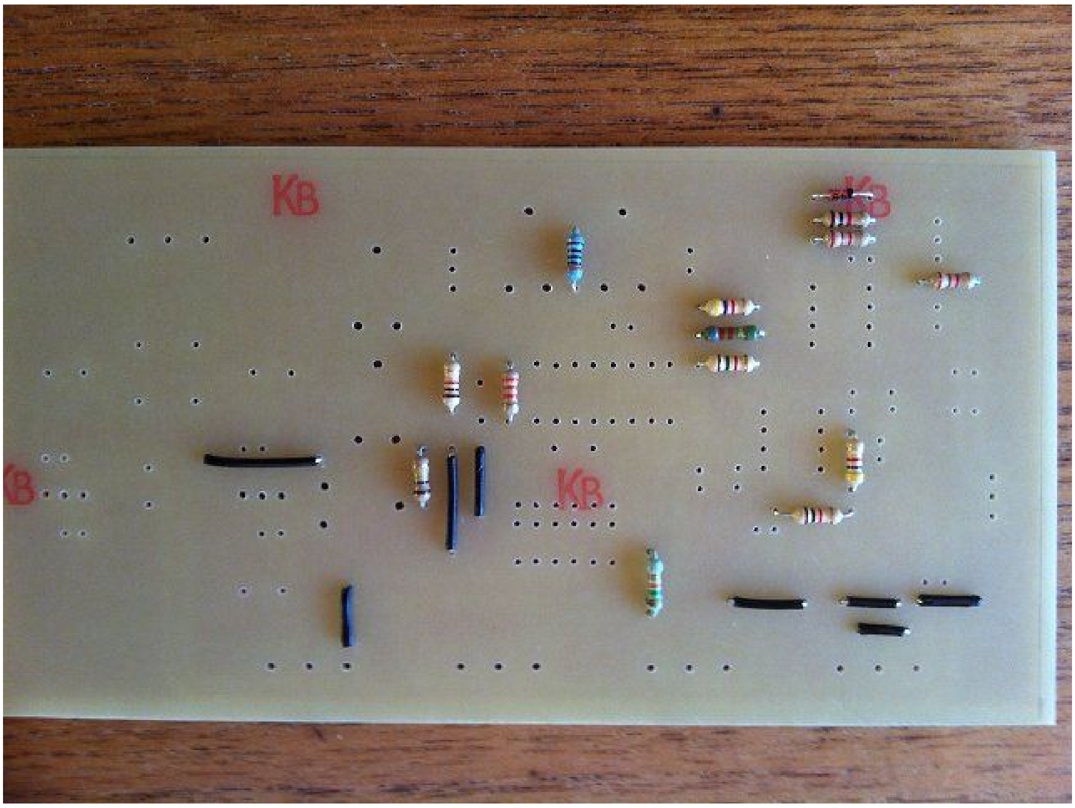

& BUILT IN JUST 4 WEEKS...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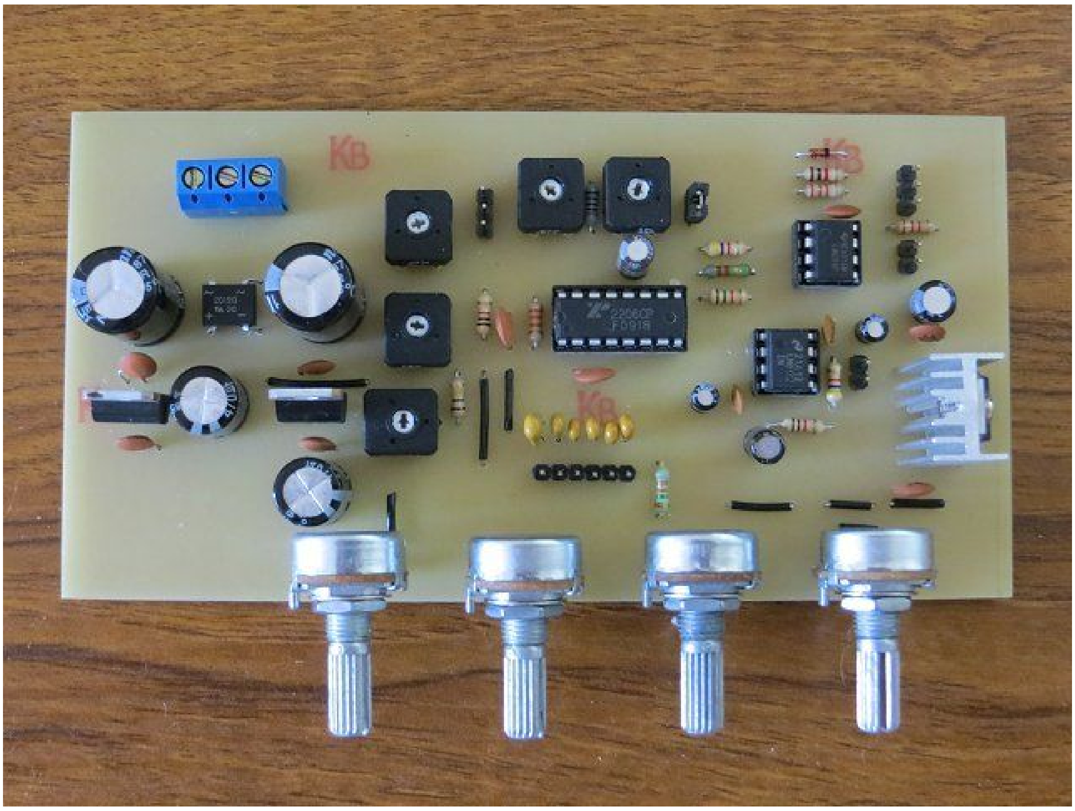
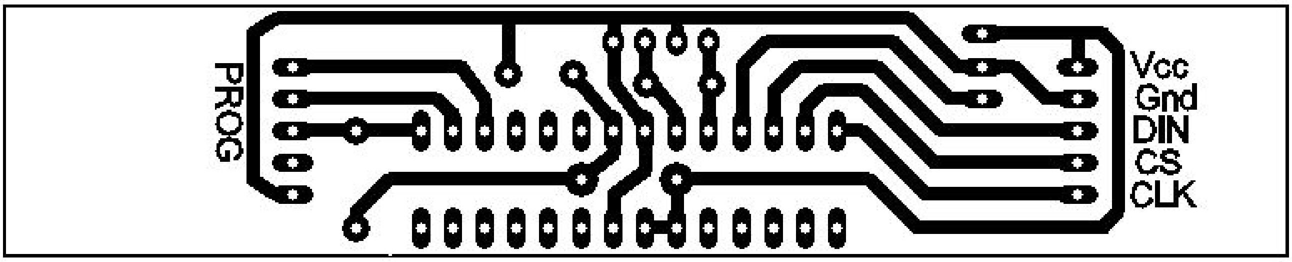


The LED Display ATmega328 Driver PCB



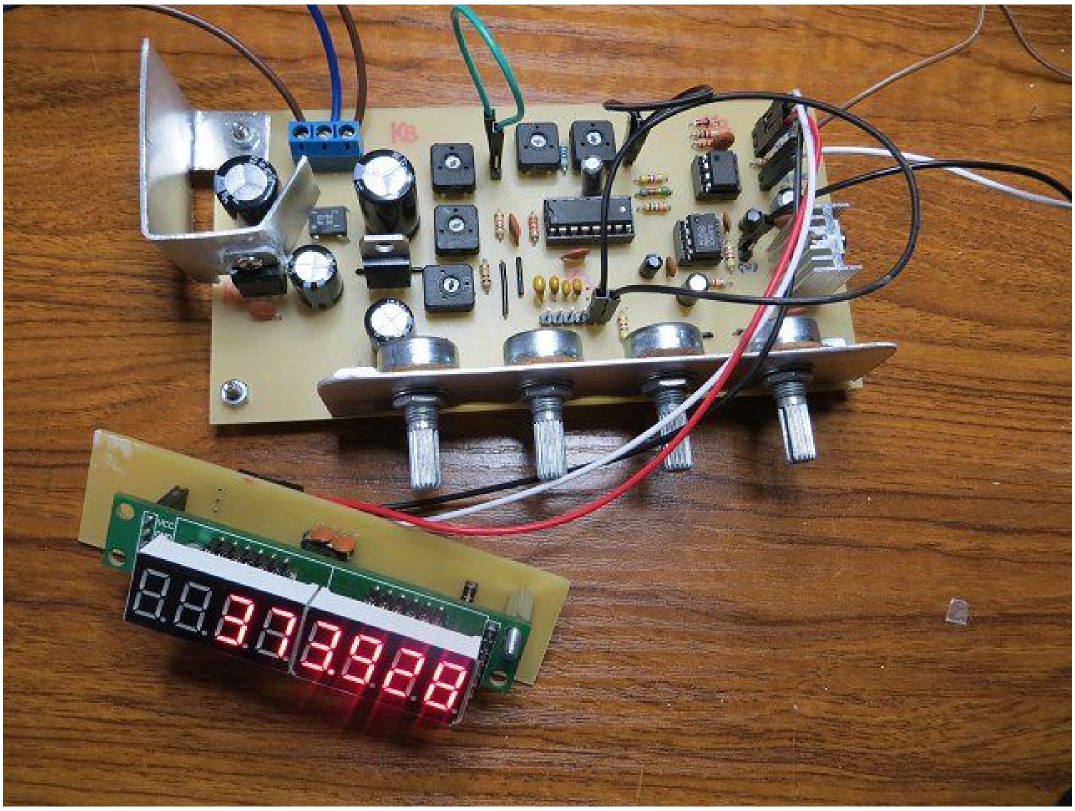
[Download/View LED Display Artwork in PDF Format]

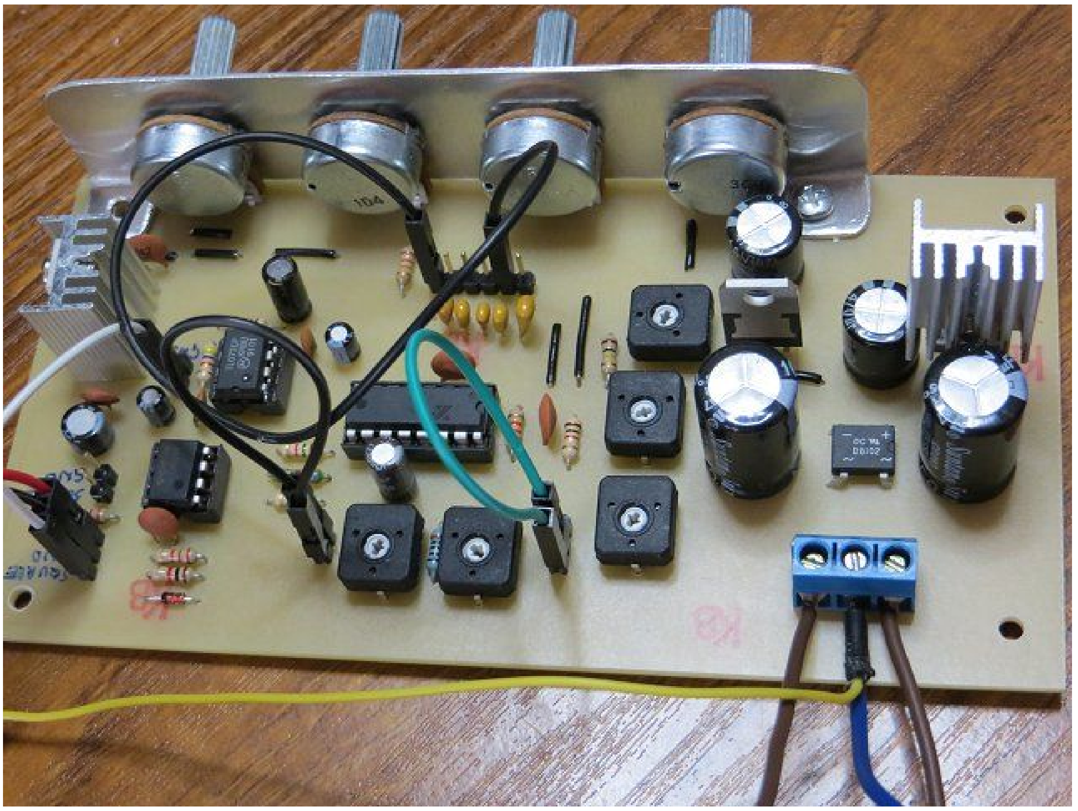
[Download LED Display Layout and Artwork as a Circuit Wizard File]

General Views

The fabricated heatsink for the LM7812 can be seen at the top left corner of the PCB in the image below.

As the potentiometers I used didn't have any "mechanical" attachment to the PCB, I wasn't happy allowing the solder connections to flex so I stiffened their mounting with a small aluminium bracket attached to the PCB.





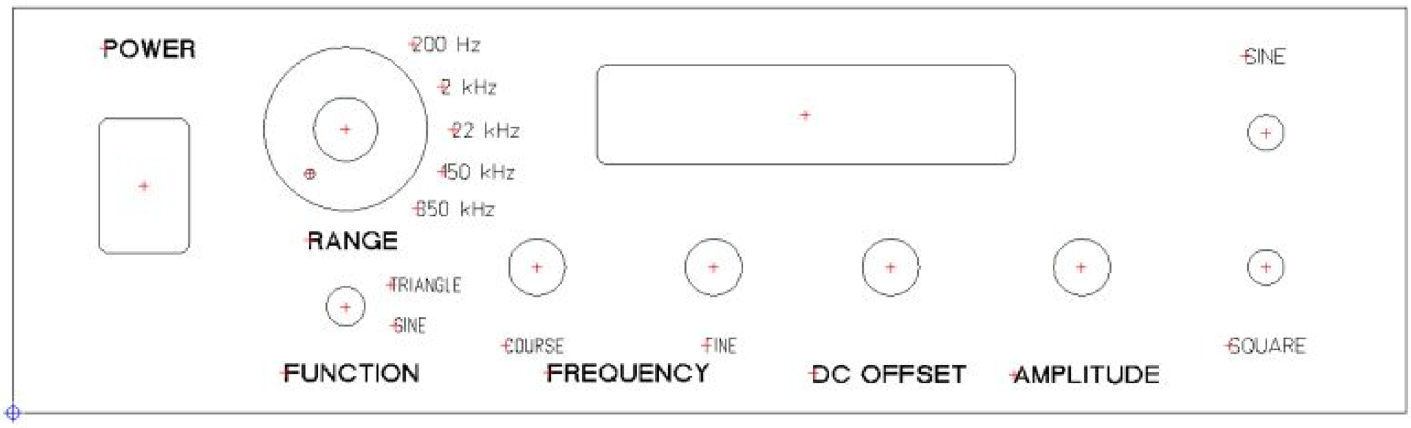
Part 5 ~ Final Assembly & Calibration

Front Panel Template

Creating the front panel for DIY projects is always a bit of a challenge. For this project, I tried something different:

I printed a mirror image of the panel layout using a laser printer and ironed it onto the thoroughly cleaned and de-greased aluminium front panel - in a similar way to making a printed circuit board etch mask. I followed it with a couple of coats of clear varnish. It isn't perfect by any means but it did allow for some flexibility in font size - which rub down lettering, for example, doesn't really allow.

I designed the panel layout using a free program called *Front Panel Designer* which makes positioning the labels easy.



Download front-panel template mirror image

Download Front Panel layout in *Front Panel Designer* Format

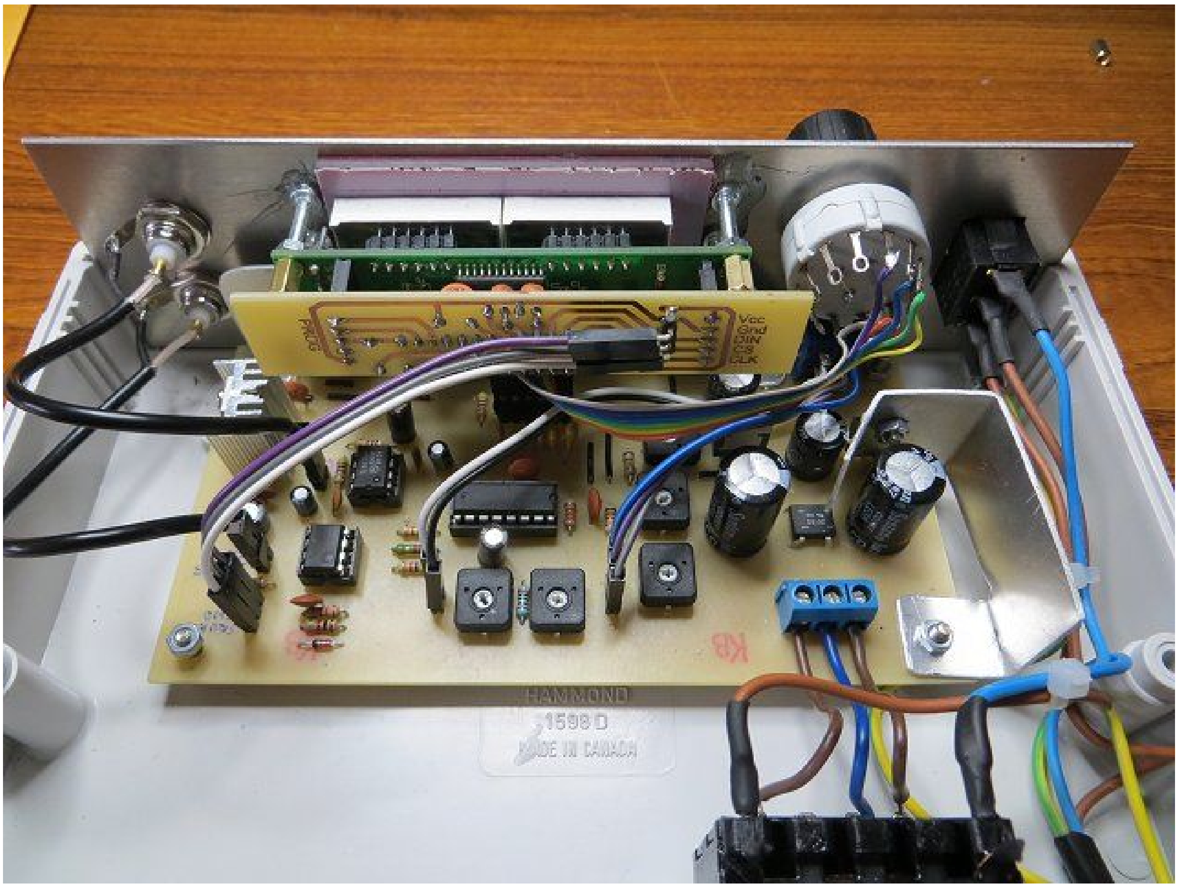
Download *Free* Front Panel Designer program

General Views

The enclosure is a Hammond 1598D which I found on eBay.

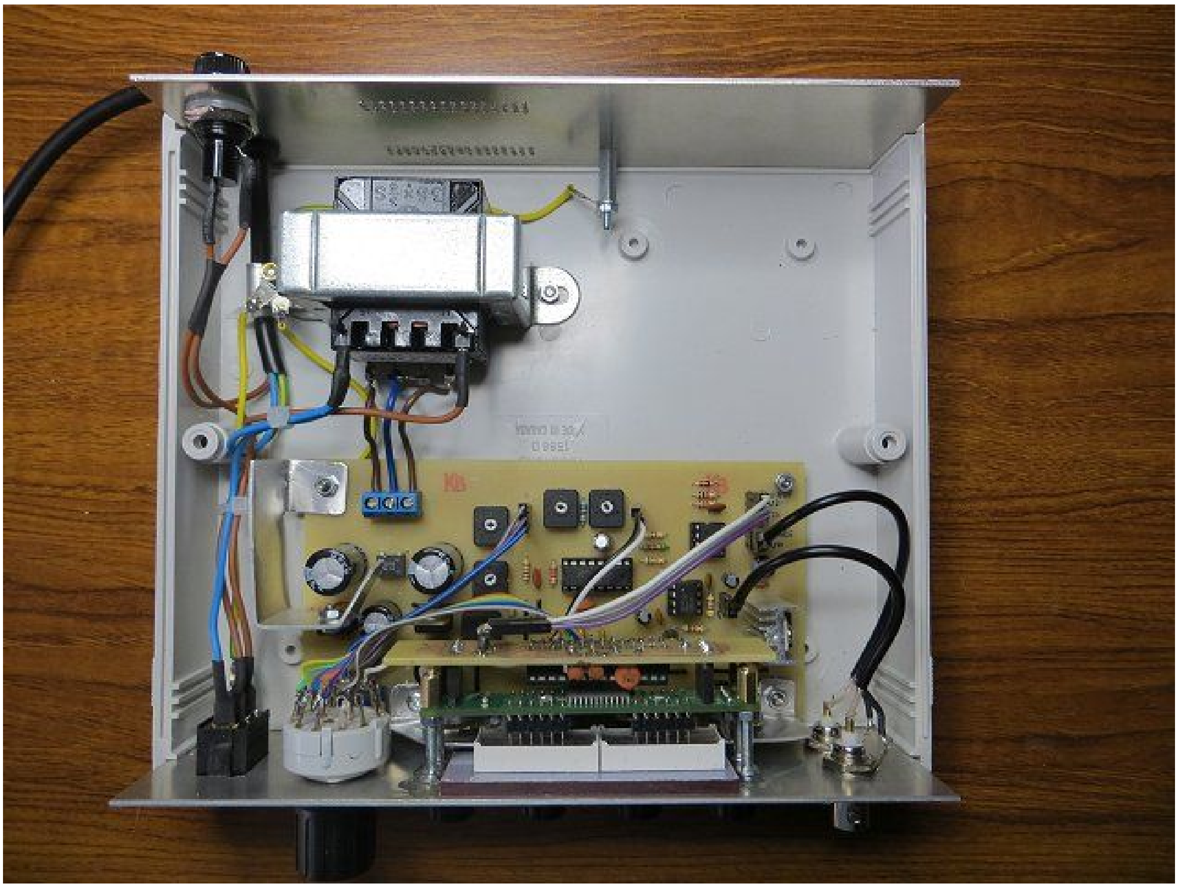
The 3mm thick red transparent acrylic sheet was also from eBay. Cut a couple of millimetres larger than the panel cut-out and super-glued to the front panel. I retained the protective plastic film on the rear face as it obscured the individual unlit segments of the 7-segment LEDs but allowed the illuminated digits to shine through well.

The display board itself is attached with long M3 screws with their heads Araldited to the front panel and M3 nuts run down the threads to position the 7-segmet displays to be just touching the back of the acryllic.



The front and rear panels both have mains-voltage components and ***MUST*** be earthed (grounded) to the same transformer mounting bolt as the incoming mains earth wire. Heat shrink sleeving covers exposed mains-carrying connections as much as is practicable.

Although the mains transformer runs fairly cool, I drilled a few rows of 1mm diameter holes in the rear panel (using an old piece of Veroboard as a drilling template).



Calibration

1. Connect the Sine wave output to an oscilloscope and allow the function generator and the oscilloscope to warm up for about 15 minutes.

2. On the function generator, switch `SW2` to `SINE`, turn the `DC OFFSET (VR4)` to the central position and `AMPLITUDE (VR3)` fully clockwise (maximum).

3. Set the `Sine Amplitude` preset (`R15`) for a peak-peak voltage on the 'scope of 10 volts.

4. Switch `SW2` to `TRIANGLE` and set the `Triangle Amplitude` preset (`R16`) for a peak-peak voltage on the 'scope of 10 volts.

5. Switch `SW2` back to `SINE` output. Set the 'scope input to `DC` and the `DC OFFSET (VR4)` to the central position, then adjust the `DC OFFSET TRIMMER (R14)` until the waveform is vertically central about 0v.

6. Adjust the `DISTORTION (R5)` and `SYMMETRY (R17)` trimmers alternately for minimum distortion of the sinewave viewed on the oscilloscope.

7. Repeat all the steps at various frequencies to find the best overall settings.