The Scope Clock TTL (aka SCTTL)

An Oscilloscope Clock that Doesn't **use a Microcontroller!**[1]

[1] Take that MicroChip…

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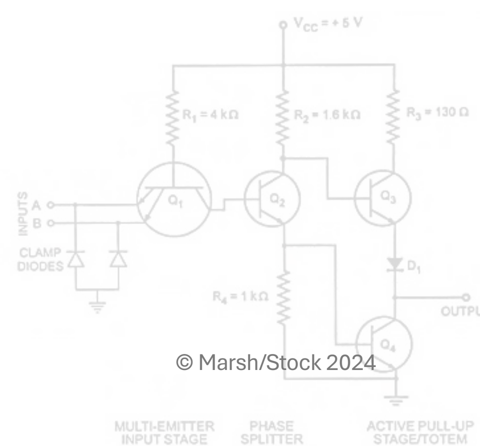
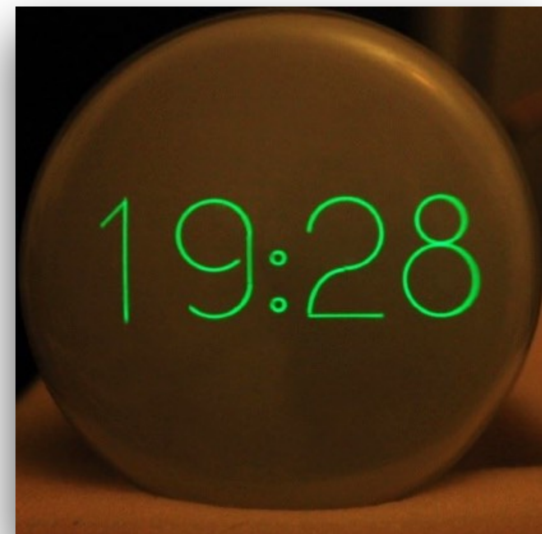


How did I get here?

Over the past few years I have built many oscilloscope clocks and a few I have published instructions to build. One version I sold as a complete kit.[2] All the designs follow an Open Source[3] and Open Design/Open Source Hardware[4] philosophy. Many people have tackled one or more of these clocks and it has been very gratifying helping people around the world with their builds.

Scope Clock 1 - Steam Punk and *Small*
(http://www.sgitheach.org.uk/scope1.html)



Scope Clock 2 - An Essay in Circle Drawing
(http://www.sgitheach.org.uk/scope2.html)

One thing that all these clocks (and many others you find on the Internet) have in common is that they all seem to use a microcontroller[5] to perform the image drawing operations. I had been pondering my next scope clock design and hadn't thought about anything else other than a microcontroller based scope clock.

Scope Clock Due
(http://www.sgitheach.org.uk/scope3.html)

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[2] Being a bit *modest* here aren't we? ... Ed
[3] https://en.wikipedia.org/wiki/Open_source
[4] https://en.wikipedia.org/wiki/Open-source_hardware
[5] https://en.wikipedia.org/wiki/Microcontroller

"Ping" went my PC as an email from Martin Forsberg (in Sweden) appeared. Martin had sent me an AEG[6] Telefunken paper from 1967 (right):

TELEFUNKEN

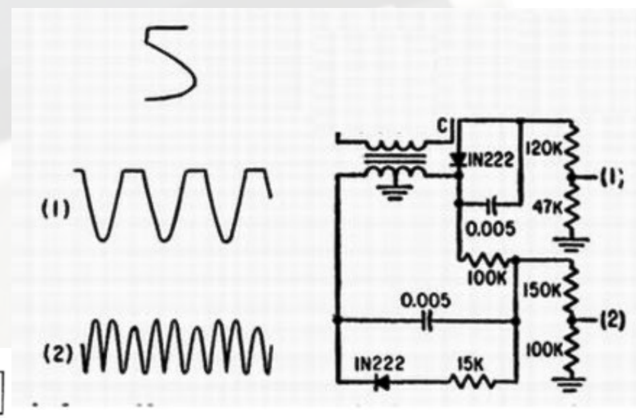
RÖHREN- UND HALBLEITERMITTEILUNGEN

Which translates to <u>***Numerical display on oscillograph tube***</u>[7].

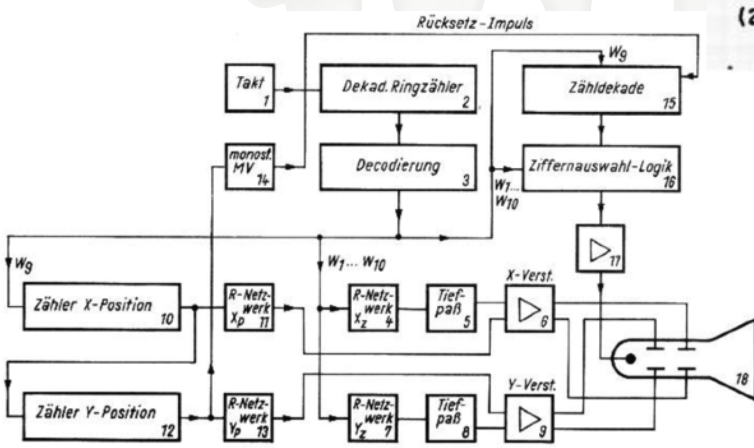
Ziffernanzeige auf Oszillografenröhre

The original paper (in German) and my rough translation of it into English is available on the project Dropbox[8]. It describes how, by using just a bunch of transistors, diodes and passive components, you could generate a display of 4 rows of 16 numbers:

There are a variety of techniques that have been published for drawing characters on a CRT[9,10,11,12]. The last reference uses a cunning combination of resistors, capacitors and diodes to form character X/Y shapes, such as a figure 5.



The AEG paper creates the numerical display using the common 7-segment character layout through logic circuits to position and draw the individual lines. This may look complex but resolves into a number of simple tasks implemented in logic with some analogue processing.



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[6] https://en.wikipedia.org/wiki/AEG_(German_company)
[7] According to Google translate anyway… 😀
[8] http://www.sgitheach.org.uk/scope4.html#documentation
[9] https://en.wikipedia.org/wiki/Cathode-ray_tube
[10] Jons, E. D.: Character generator for digital computers. Electronics (1960), V.3 (12.2.60), pages 117 to 120.
[11] Chao, S. C.: Character display using analog techniques. Electronics (1959), V. 20 (23. 10. 59), pages 116 to 118.
[12] Wire, R.L.: Forming handwritten-like digits on CRT display. Electronics (1959), V. 5 (13. 3. 67), pages 138 to 140.

From a Technical Paper to a Built Design[13]

Since I was only thinking of a 7 segment clock display I needed only 1 row of 8 characters (to include two "colon" characters) rather than a 4 x 16 readout. My aim was a typical HH:MM:SS type clock display. Unlike the AEG paper, that used discrete transistors, I decided to use TTL[14,15,16] chips for the logic and then OPAMPs[17,18] for the analogue signal processing. Then I needed a simple TTL based clock for timekeeping. Nick (Stock) suggested the KoolKlox[19] for the time keeping section which, being already TTL based, was easy to adopt.

Therefore, the tasks for a clock breakdown into:

- Logic to determine which character to draw,
- Analogue process to convert the character position into an analogue voltage for the CRT,
- Logic to determine which line to draw within the characters,
- Analogue process to convert the line position into an analogue voltages for the given character,
- An accurate timekeeping clock generating hour, minute and second data,
- Logic to convert the time into a character to draw.

Then you need to add all the CRT paraphernalia:

- 300V supply for the CRT deflection amplifiers,
- -1.5kV[20] supply for the CRT operations,
- A beam unblanking arrangement,
- Supply for the CRT heater.

Open Design/Open Source Hardware

All of the physical design files to build this clock are available in the project Dropbox, including:

- Circuit schematic diagrams as Eagle[21] 7.7.0 SCH files and PNG images,
- PCB layouts as Eagle BRD files and PNG images,
- Case designs as Fusion 360[22] F3D files,
- 3D printed components as STL files,
- Laser cut acrylic case components as DXF files.

If you find that I have missed any file or information then please let me know so I can make it available!

[13] I was hooked on the idea by now
[14] Transistor-Transistor Logic
[15] https://en.wikipedia.org/wiki/Transistor–transistor_logic
[16] It has been ages since I did something substantial in TTL…
[17] OPerational AMPlifier
[18] https://en.wikipedia.org/wiki/Operational_amplifier
[19] https://stocksclocks.com/index.php/koolklox-ttl-nixie-clock/
[20] 1.5kV is a good voltage to operate a large selection of CRTs, especially the rectangular ones I intended to use
[21] https://en.wikipedia.org/wiki/EAGLE_(program)
[22] https://en.wikipedia.org/wiki/Fusion_360

Important Safety Information

Safety Statement

Like all CRT clocks, the SCTTL uses high voltages in order to operate the beam and deflection plates in the tube. You need to respect this and other hazards inherent in these circuits.

Caution! This scope clock must only be operated with the case securely in place around the electronics. Keep the internals away from prying hands and stray pets!

Caution! This device uses 12V DC to operate which will be from an external power pack operated from mains/line. This external power pack must be of good quality as it provides the isolation from mains/line voltages.

Caution! The SCTTL generates very high voltages in the region of several kilovolts during operation. These voltages are present on the power supply board and base of the cathode ray tube; These voltages may be maintained for a period of time after input power is removed.

Caution! Some components may be warm to the touch during use. This is a perfectly normal consequence of their operation, but you should remember it when handling the board or considering alternative clock enclosures.

Caution! The cathode ray tube envelope is made of glass and may be broken if the clock is dropped or inadvertently struck.

Caution! If a metal enclosure is used as a case, the enclosure itself must be earthed/grounded.

Legal Statement

The SCTTL clock is built and documented with an Open Source philosophy in mind. All the source files including circuit diagrams, board design, software and other design files are provided under a Creative Commons ShareAlike 4.0 International license.

The SCTTL clock may be hazardous if not assembled and operated by suitably knowledgeable and practiced persons or if abused. It is your responsibility to carefully review the documentation, the design and the kit contents, and to assure yourself that you have the necessary expertise to construct and/or operate the clock safely. In particular, it is also your responsibility to ensure that the completed clock meets any necessary safety and other regulations or guidelines for such items in your jurisdiction. In that respect, any supplied enclosure is intended as a basis for you to customise the final clock to meet such regulations. It is possible that in some jurisdictions, a completely different type or construction of enclosure may be required to obtain regulatory compliance. Assembly instructions in the kit documentation are intended as a starting point, to be amended or not according to the judgement and expertise of a suitably qualified constructor.

The hazards of this kit include, but are not limited to, high voltages, the generation of heat during operation, the presence of toxic substances within the components of the kit and the presence of sharp and/or fragile glass and metal items. Not all components within this kit comply with the Restriction of Hazardous Substances regulations (RoHS), though compliant components have been selected in most cases.

In summary, you own, construct and use the SCTTL clock entirely at your own risk. To the maximum extent permitted by law, we disclaim all liability for any and all adverse outcomes associated with your ownership, construction and use of this item.

Warranty Information

Upon receipt of the kit of parts, any missing or broken pieces will be replaced. It is incumbent upon the recipient to check the contents in a prompt manner against the supplied parts lists found within the construction manuals. As a kit of parts, no warranty can be provided pertaining to the quality of construction and operation of the final product as this is the duty of the purchaser and is dependent upon their skill. The SCTTL clock may be hazardous if not assembled and operated by suitably knowledgable persons and it is the owners responsibility to carefully review all the supplied documentation. The authors have made their best attempts to explain and detail the construction and hazards associated with operation of the clock within the supplied manuals. Due to the nature of the obsolete technology employed in the SCTTL clock (primarily the cathode ray tube), certain hazards are present, namely high voltages and fragile glass under vacuum and due care and attention should be paid when handling said items. If you have purchased a complete operational clock, then a limited warranty is provided in a separate document supplied with your documentation. If the clock kit or complete clock has arrived in a damaged state such that an insurance claim is likely to be made, then please notify us immediately (within a few days of receipt). It is likely that photographic evidence will be asked for to make an insurance claim. No refunds on partially or fully constructed kits are possible.

About Open Source

The Scope Clock TTL is built and documented with an Open Source philosophy in mind. All the source files including circuit diagrams, Eagle board and case design files are provided under a Creative Commons *Attribution-NonCommercial-ShareAlike 4.0 International*[23,24] license.

[23] https://creativecommons.org/licenses/by-nc-sa/4.0/
[24] https://creativecommons.org/licenses/by-nc-sa/4.0/legalcode.en

How it Works – The CRT

The purpose of the cathode ray oscilloscope is to permit visual observation of the behaviour of alternating voltages and currents. This requires a conversion of electric current, or electrons in motion, into light. To do this, a cathode ray tube, CRT, is used. Figure 1 illustrates such a tube. The cathode ray tube can be divided into three major units: the electron gun, the deflection system and the fluorescent screen.

This description, by its very nature, is overly simplified. In practice the arrangement of the electrodes can vary considerably.

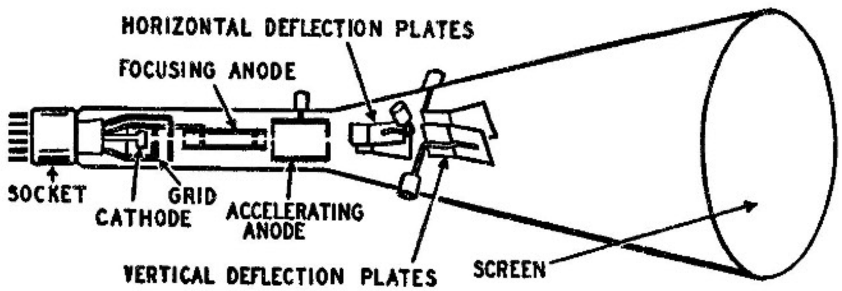


Figure 1. Sketch of a typical cathode ray tube showing the location of the gun, deflection plate system and fluorescent screen

<u>The Electron Gun</u>

This is the structure and arrangement of elements or electrodes in the cathode ray tube which produces a sharp beam of electrons moving at high velocity in the direction of the screen. The elements of the electron gun are:

Heater

The heater resembles, both in structure and function, the filament of the familiar vacuum valve.[25,26] Its job is to bring the cathode to normal operating temperature. Most cathode ray tubes used in oscilloscopes have heaters designed to operate on 6.3 volts AC (although there are CRTs that operate on 4V, 2.5V and other voltages).

Cathode

The purpose of the cathode, as in any vacuum valve, is to emit electrons. However, the physical structure of the cathode is not the same as that in an ordinary vacuum valve because of the difference in requirements. In most vacuum valves, the anode is in the form of a cylinder around the cathode (the various grids, located between the cathode and the anode, are also cylindrical in shape), and the electrons flow to the anode in the pattern of spokes from the hub to the rim of a wheel. In the cathode ray tube, however, the electrons do not go to such an "anode". Instead, they form a narrow stream which travels straight ahead, somewhat like a thread pulled through a hollow tube or pipe. Therefore, the cathode is constructed like a pillbox or cylinder, covering the heater, and having a small circular area of oxide-coated electron-emitting material on the surface facing the tube screen. Thus, the stream of electrons from this cathode is almost entirely forward. An enlarged view of the filament and cathode structure is shown in Figure 2.

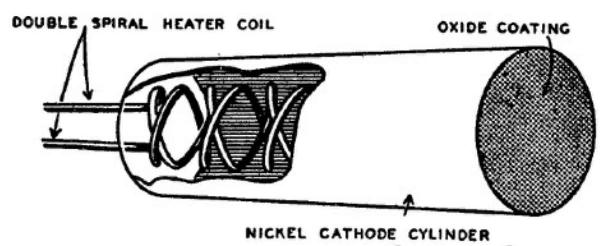


Figure 2. The cathode is a nickel cylinder surrounding the spiral-wound filament. The oxide coating is the electron source

[25] Tube to our transatlantic cousins….
[26] https://en.wikipedia.org/wiki/Vacuum_tube

Control Grid

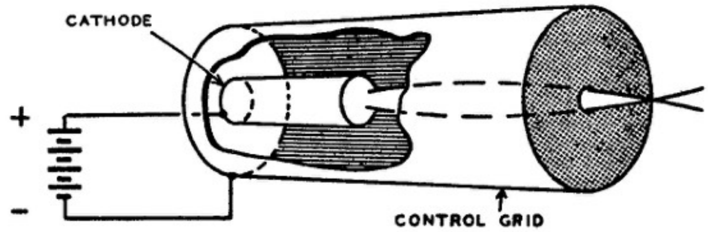


Figure 3. The CRT control grid serves two purposes; it regulates electron emission and helps focus the beam

The control grid functions in a manner similar to the ordinary vacuum-valve grid, but it is modified in structure to meet the particular requirements of the cathode ray tube. The grid (always negative with respect to its cathode) controls the intensity (brightness or brilliance) of the electron beam. In some oscilloscopes, and in almost all television receivers[27], the control varying the grid bias is called the brightness control because the effect of varying the bias on the grid actually varies the brightness of the trace on the cathode ray screen. On many oscilloscopes it is called the intensity control. In most cathode ray tubes, the bias voltage varies between 0 and -150V. Since the electrons are to move in a narrow stream, the grid consists of a metal sleeve or cylinder open at the cathode end and closed, except for a very small, almost pin-point aperture, on the end facing the screen.

Figure 3 shows the cathode and the control grid. Visualise these elements as a small cylinder enclosed by a larger one. It is in the cathode and grid structure that we have the beginning of the formation of the cathode ray beam. Electrons emitted by the heated oxide-coating on the cathode can escape only by moving through the small hole in the centre of the grid cylinder. The entire grid cylinder is negative with respect to the cathode. This means that any electrons directed toward the inside wall of the grid cylinder will be repelled. The motion of these electrons is such that they rejoin the main electron stream. The control grid actually does three jobs, by controlling the amount of emission from the cathode it determines the brightness of the spot on the screen, it acts as a lens, concentrating the electrons into the shape of a beam and finally, the grid can be modulated (intensity modulation).

Focusing Anode

This element has as its function the concentrating or focusing of the electron stream so that it ends in a fine point at the surface of the screen. The first narrowing or focusing of the electron beam is done by the control grid. Since the focusing action of the control grid is rather weak, the electrons come to a point (point of focus) only a short distance after the grid; beyond that they diverge or spread out. The focusing anode, located forward of the control grid, is also shaped like a cylinder, but with small openings at both ends. It is operated at a positive potential with respect to the cathode, and focus is achieved by varying this potential. The actual voltage varies with the type and diameter of the tube, being as low as 50 volts in the case of a 25mm diameter tube and increasing to thousands of volts for special purpose tubes. At first, it might seem that the focusing anode, being positive, would merely attract electrons in a manner similar to the plate of an ordinary tube. However, since the anode is cylindrical and exerts an equal pull all around, the net effect is to force the beam as close to the centre line, or axis, as possible.

Accelerating Anode

The principal function of the second anode is to impart a high velocity to the electron beam. In addition, this anode combines with the focusing anode to determine the focusing characteristics of the cathode ray tube. The second anode is located closer to the screen than the focusing anode, and is generally

[27] Not any more alas…

similar to it, except that it is larger. It is operated at a fixed positive potential, usually three to four times higher than the focusing-anode potential. In addition to the actual cylinder, there is often a conductive coating called "aquadag"[28] (colloidal graphite) on the inner surface of the glass. It extends almost all the way to the screen and it is internally connected to the accelerating-anode terminal and serves as part of the accelerating anode.

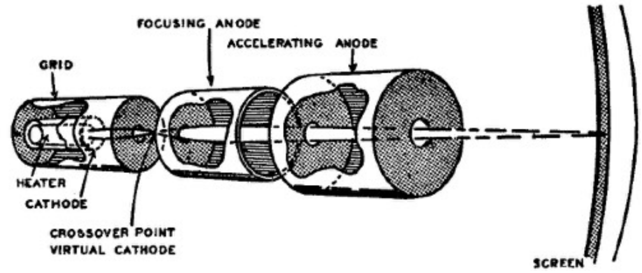


Figure 4: The control grid focuses the beam on the crossover point. The beam then diverges, but is re-focused on the screen by the focusing anode

Figure 4 illustrates the manner in which the electron gun produces a sharp or focused spot on the cathode ray screen. For the sake of clarity, the deflection plates have been omitted. The electrons leave the cathode in a rather wide stream. Since the control-grid aperture is very small, and since the potential on the grid produces a negative charge all around the aperture, the electrons begin to converge and actually come together in a small area near the focusing anode. This area is commonly referred to as the virtual cathode (as distinguished from the physical cathode) since the electrons are concentrated at this point and continue forward as from a cathode. As a matter of fact, this point acts as the electron source, except that the area is much smaller than the original cathode surface. Continuing past the crossover point, the electrons begin to spread apart just as light rays would in passing through a small opening. Now both the focus and accelerating anodes combine to do the focusing. While the detailed discussion of the nature of the electric field produced by the two anodes is beyond the scope of this document, a simplified statement of the functioning at this portion of the gun can easily be described.

Since both the anodes are positive with respect to the cathode and are cylindrical in shape, they exert a uniform pull on the electron beam. However, because of the structural and potential differences between the two anodes, the electrostatic (or charge) field within the region of the anodes is such that the farther from the centre line (or axis) of the tube an electron is, the greater the force on the electron toward the axis. The strength of the field along the axis is greatest in the vicinity between the anodes; therefore, it is here that most of the bending of the beam toward the axis takes place. Further on, the beam is less and less affected, hence it travels generally in the forward direction under the influence of the high accelerating potential. As shown in Figure 4, the beam converges rather gradually as it leaves the region of the focusing anode, the amount of convergence being just enough to make the beam come to a point at the surface of the cathode ray screen. Too high a focusing potential would make the convergence so great that the beam would come to a point before reaching the screen, then start spreading out again and be out of focus when finally reaching the screen. Conversely, too weak a bending force, because of too low a focusing potential, would allow the beam to reach the screen before it had time to converge to a point. If allowed to continue past the cathode ray screen, the beam would focus somewhere beyond the front surface of the screen.

[28] https://en.wikipedia.org/wiki/Aquadag

Figure 5 illustrates the effects of too little or too great a focusing potential. The exact function of the focusing control should now be clear. The focusing anode is made sufficiently positive so that the bending of the electron beam toward the axis is just enough to make the electrons reach the axis at the screen.

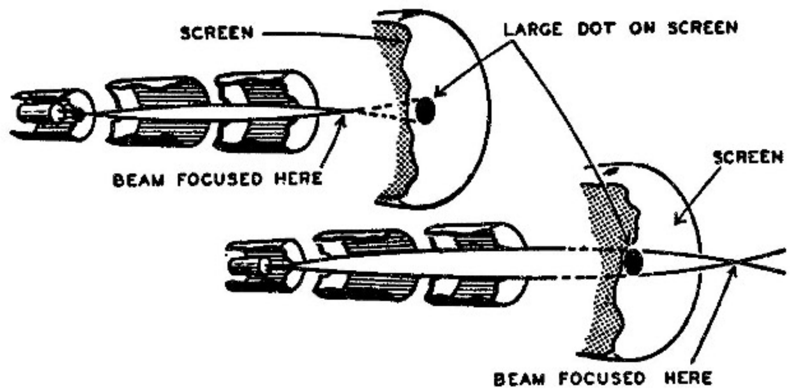


Figure 5: Improper focusing caused by too little or too great focus potential results in a large dot on the screen

How Fast?

Exactly how fast are the electrons travelling? The velocity of the electrons leaving the final anode will depend on the voltage applied to the final anode, i.e. the greater the voltage the higher the velocity. The energy of an electron, due to the final anode voltage V_a, will be eV_a joules where e is the charge on the electron. The kinetic energy of the electron will be ½mv^2 joules, where m is the electron mass and v is the velocity. So equating these….

$$\frac{1}{2} \times m \times v^2 = e \times V_a$$

Therefore

$$\sqrt{2 \times \frac{e}{m} \times V_a}\ m/s$$

Since e/m is 1.759×10^{11} coulomb/kg, for an anode voltage of 2kV this gives;

$$v = \sqrt{2 \times 1.759 \times 10^{11} \times 2000} = 26 \times 10^6\ m/s$$

…or about 10% the speed of light[29]!

The Deflection System

The electron gun is designed to produce a sharp spot on the cathode ray screen. For this spot to trace various patterns of voltage or current, it is necessary to move it to any required point on the screen. This is the function of the deflection system. Two main systems of beam deflection are in use today.[30] These are:

1. Electrostatic, used almost exclusively in oscilloscopes, radar sets, spectrum analysers and similar commercial applications; and
2. Electromagnetic, found in television receivers.

The electrostatic deflection method is based on the law of magnetic poles; like charges repel each other and unlike charges attract each other. A simple illustration of this is the behaviour of a capacitor. In its

[29] Not too shabby…..
[30] Well, not really 'today' as CRT's aren't that common any more…..but you get the gist….

simplest form, a capacitor consists of two metallic surfaces or plates insulated from each other; i.e. separated by a dielectric. When a capacitor is in a neutral or uncharged state, both plates have the same number of electrons. No force exists between the plates. However, when a charge is placed on the capacitor, one plate has more electrons than the other plate. In other words, one plate is negative with respect to the other. Notice that this is only a relatively polarity, since both plates may be negative with respect to a common point, such as a chassis or ground.

Relative to each other, one plate is called positive, the other negative. In such a charged capacitor, a force of attraction exists between the plates. Not only does this force tend to pull the plates toward each other, but it also acts on any electron between the plates in the dielectric. This effect of a charged capacitor on the electrons in the dielectric is utilised in electrostatic deflection. There are two such pairs of plates or capacitors in the electrostatic cathode ray tube, see Figure 1.

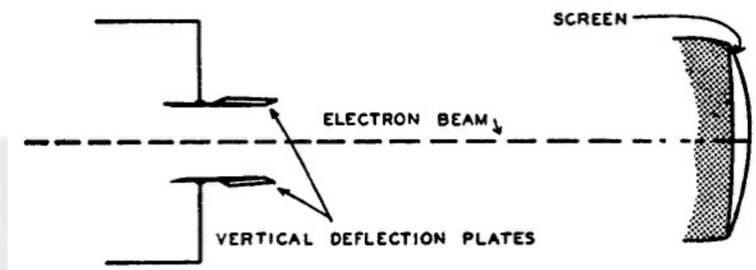


Figure 6: With zero potential difference between the vertical deflection plates, the beam is unaffected

One pair are called the horizontal plates, the other, the vertical plates. The horizontal deflection plates are positioned like two opposite walls of a room; the vertical deflection plates resemble the position of the ceiling and the floor. As shown in Figure 1, the plates of each pair are not quite parallel, but diverge or flare somewhat toward the front of the tube. The first pair of plates can deflect the electron beam to the left or right, hence the name horizontal plates, although physically they are in a vertical position. The second pair, actually in the horizontal position, are called the vertical plates, because they deflect the beam up or down. In addition, the deflection plates are used to centre the beam or, for that matter, position it anywhere on the screen. To illustrate the functions of the deflection plates, let us begin by examining Figure 6.

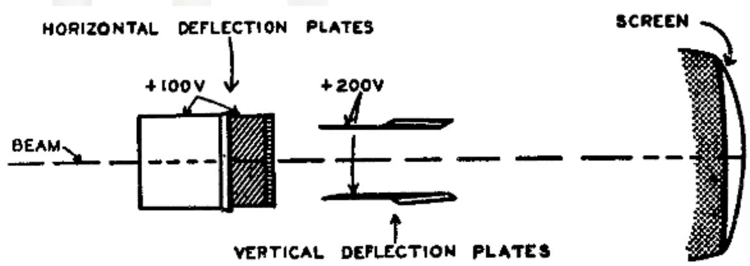


Figure 7: A voltage difference must exist between the vertical and horizontal plates for beam deflection to occur.

This illustration shows one set of plates with no potential between them, hence with no force on the travelling electron beam. Theoretically, the electron beam will strike along the centre line of the screen. Figure 7, showing both sets of plates, assumes a high DC potential from each of the plates to ground but, and this is important, there is no difference of potential between the plates.

The net force on the direction of the electron beam is still zero, hence the beam will continue undeflected. In other words, the beam will be centred. While centring the beam involves adjusting the potentials on the deflection plates so that the beam remains undeflected and proceeds on course, in actual practice this does not necessarily mean that the voltage between the plates is exactly zero. Quite often, due to minor structural and circuit variations, the beam would originally be off centre, and a certain amount of force on the beam is required to bring it to the central axis. Furthermore, in many applications it may be desirable to have the beam at some point other than the exact centre. In such cases, a definite force across the horizontal, vertical, or both sets of plates may be required. In addition to the need for centring, it is necessary for purposes of acceleration to have a high potential on the deflection plates, regardless of the desired initial position of the beam.

For either purpose, centring or deflection, an adjustment of the potential across the two pairs of deflection plates is required. For initial positioning, whether exactly on centre or at any other point on the screen, a DC potential, adjustable at will, is required. In cathode ray oscilloscopes, these adjustments may be made by potentiometers in the high-voltage system, varying the difference between each of the plates to the extent of a few hundred volts, while at the same time maintaining the deflection plates at a potential high enough to allow acceleration of the beam.

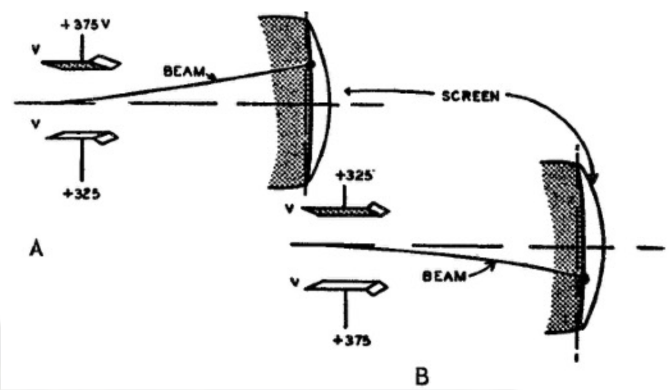


Figure 8: The beam always moves in the direction of the plate having the higher positive voltage

Figure 8 depicts the effects of a difference of potential between a pair of plates. In Figure 8 (A) the upper plate is positive with respect to the lower. The electron beam, being negative, is attracted toward the upper, more positive plate. Since the voltage on the upper plate also acts to pull the beam forward, the net result is that the beam strikes the screen above the mid-point. In Figure 8 (B) the polarity is reversed, causing the beam to strike the screen below the mid-point. The same situation applies to the horizontal deflection plates. If the left plate is made negative with respect to the right plate, the beam will move to the right and vice versa.

Why bend the deflection plates?

The answer is purely mechanical - if the plates are parallel, then the beam can be intercepted by the plate limiting the angle that can be deflected as illustrated in Figure 9.

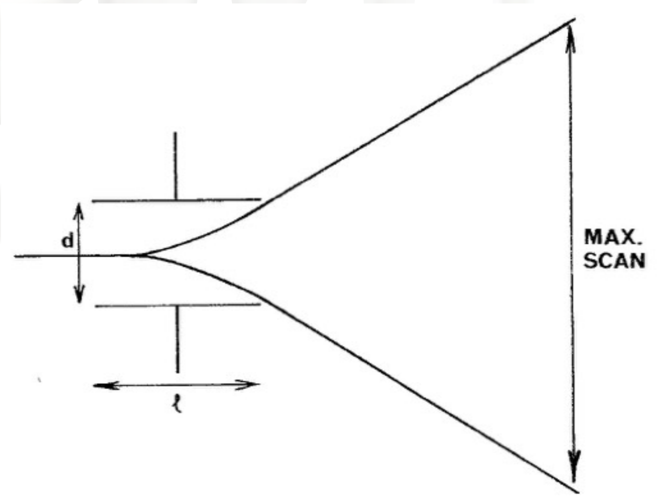


Figure 9: Plates can cause limited beam deflection unless flared

Linear Deflection

In addition to the general direction of deflection of the beam, the amount of deflection (and hence distance moved on the screen), also depends on the voltage across the plates. Thus, if a 50-volt difference between a pair of plates will deflect the beam 25mm from the centre, 100 volts will deflect the beam 50mm, and so on. This is known as linear deflection.

Figure 8 (A) shows the position of the spot on the screen under the force of a 50-volt difference in potential across the plates.

An example of the effect of deflection potentials on both sets of plates is shown in Figure 10. Here, a potential difference of 50 volts exists across the vertical plates, and 125 volts across the horizontal plates. As shown, the spot deflects in each direction in proportion to the particular force in that direction, 64mm to the left of centre, and 25mm above the centre line.

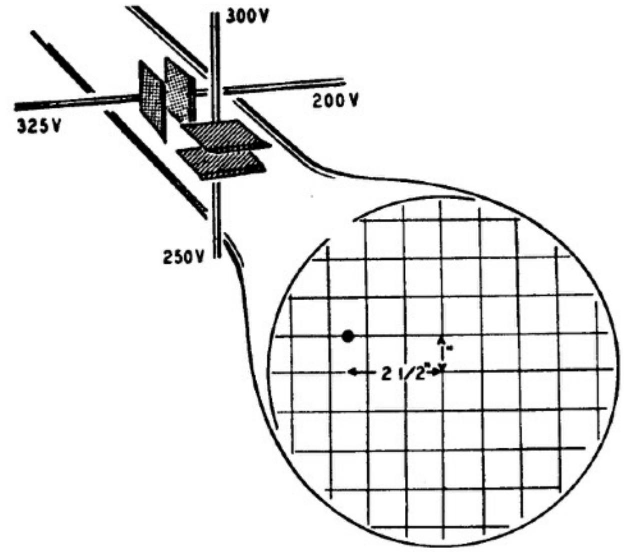


Figure 10: Applying deflection potentials on both sets of plates

Up to this point, examples of deflection under fixed potentials have only been considered. If, instead, a gradually varying potential is applied to one set of plates, while the other set has a DC potential not fixed but increasing at a uniform rate, the spot, while moving across the screen at an even speed (due to the DC potential just mentioned) would also move up and down, in step with the varying potential on the other sets of plates. Figure 11 illustrates such a case. A sine wave (AC) is applied to the vertical plates, while a DC voltage, starting with a high negative value and gradually and uniformly (linearly) "Increasing" to zero and continuing to increase in the positive direction, is applied to the horizontal plates. As the spot is moved at an even pace from left to right across the screen by the horizontal voltage, the sine wave applied to the vertical plates is also moving the spot, but in an up-and-down direction in step with the changes of the voltage of the sine wave. Thus, the actual wave-shape of a signal is traced on the screen.

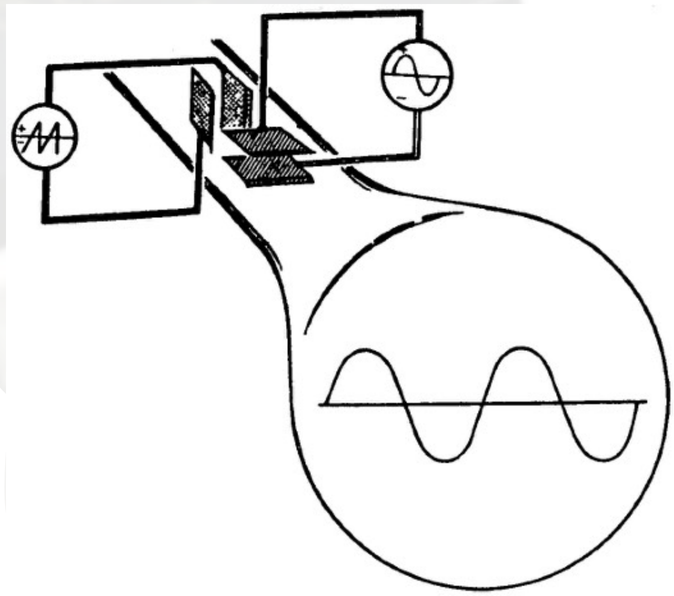


Figure 11: The signal under observation is applied to the vertical plates, while the sweep voltage is fed to the horizontal plates

The Fluorescent Screen

The conversion of electron energy into light is accomplished by impact of the electron beam on the fluorescent screen. This screen, or rather the coating on the inner surface of the faceplate of the cathode ray tube, has two important characteristics. The first of these is fluorescence[31], a form of luminescence[32]; i.e. the property of converting the kinetic energy of the electron beam into light (energy at relatively low temperatures). The second characteristic is that of phosphorescence[33]. This is the property of continuing to glow after the actual impact of the high-speed electron beam. This persistence varies with the type of chemical coating according to the application for which the cathode ray tube was intended. The coatings, or phosphors, as they are commonly called, may be zinc silicates for many normal oscillographic applications, or various zinc sulfides in the case of television picture tubes. The persistence, too, varies with usage requirements and is identified by the letter P followed by a numeral. For example, P1

[31] https://en.wikipedia.org/wiki/Fluorescence
[32] https://en.wikipedia.org/wiki/Luminescence
[33] https://en.wikipedia.org/wiki/Phosphorescence

designates a green, medium-short persistence screen, commonly found in oscilloscope tubes. Black and White television tubes have a white medium persistence and are identified as P4, while P7 is an example of a very long yellow persistence, found in radar as well as oscilloscopes, where it may be necessary to see the trace, or its slow motion on the screen, for quite a while after the first instance of observation. Table 1 gives the characteristics of a range of commonly found phosphors.[34]

US Number	EU Number	Fluorescence	Colour	Phosphorescence	Colour	Notes
P1	GJ	Green		Green 20 mS		Very Common Oscilloscope
P2	GL	Green		Green Long		
P3		Yellow		Yellow Long		
P4	W	White		White < 33 mS		B&W TV Screens
	WA	White		White < 33 mS		B&W TV Screens
P5		Blue		Blue <1 mS		Photography
P7	GM	Blue (0.5 S)		Yellow-Green 7 S		Radar
P11	BE	Blue (40 µS)		Blue <1 mS		Photography
P12		Orange		Orange Long		Radar
P19		Orange		Orange Long		Radar
P31	GH	Yellow-Green		Yellow-Green < 1 mS		Oscilloscopes

Table 1: Examples of common phosphor types and their applications

Further information on the persistence of these and other phosphors is detailed in Figures 11 and 12.

[34] An exceptional list of phosphor characteristics can be found here http://www.bunkerofdoom.com/tubes/crt/crt_phosphor_research.pdf

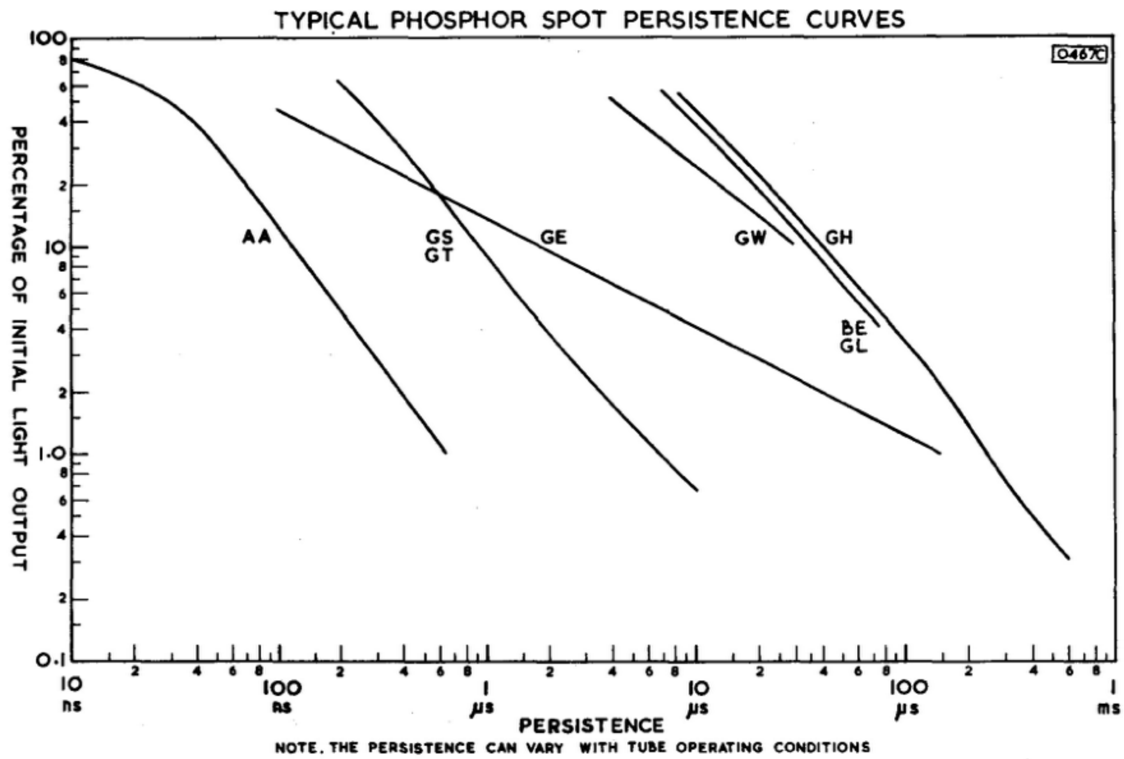


Figure 11: Typical spot persistence for various CRT phosphors

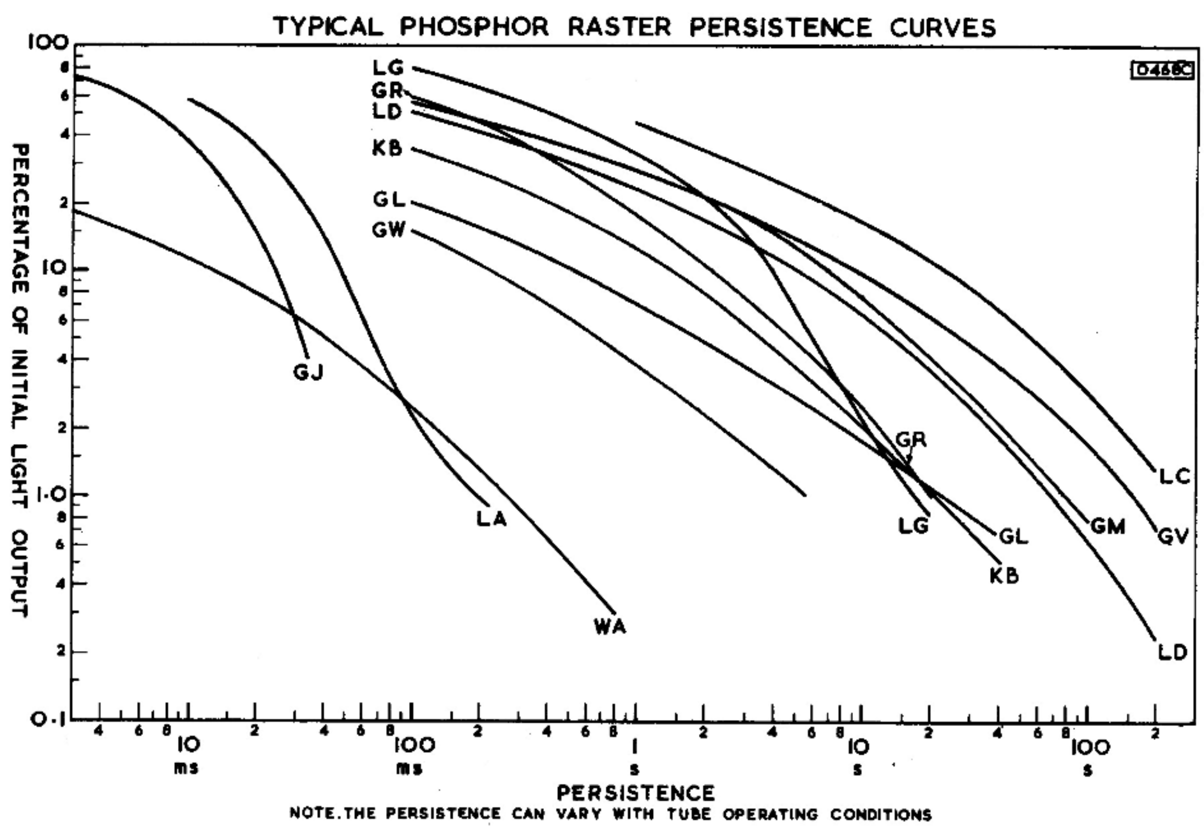


Figure 12: Typical raster persistence for various CRT phosphors

Phosphor Burning

When phosphor is excited by an electron beam having an excessively high current density, a permanent loss of phosphor efficiency may occur. The light output of the damaged phosphor will be reduced and in extreme cases complete destruction of the phosphor may result. Darkening or burning occurs when the heat developed by electron bombardment cannot be dissipated rapidly enough by the phosphor.

The two most important and controllable factors affecting the occurrence of burning are beam current density (controllable with the brightness, focus and astigmatism controls) and the length of time the beam excites a given section of the phosphor. Under normal conditions in CRTs with grid unblanking, the ambient voltage on the control grid will hold the tube in cut-off and no spot will be present on the screen.

The brightness control can be adjusted to override the normal cut-off condition of the gun in the absence of an unblanking pulse in a CRT using grid unblanking. If this is done, a spot of reasonable intensity will be seen on the face of the CRT.

Remember, burning is a function of intensity and time. Keeping intensity down or the time short will save the screen. The typical phosphor is about 10% efficient. This means that of the total energy from the beam, 90% is converted to heat and 10% to light. A phosphor must radiate the light and dissipate the heat; or as any other substance, it will burn.

More Electrodes

The prior explanation has covered the basics of the construction and operation of the cathode ray tube. However, it should be noted that various CRTs can contain a wide variety of other electrodes.

Pre-Acceleration Anode (very common)

The first and most common configuration is an anode between the grid and the focus anode. This anode is sometimes call the pre-acceleration anode. As shown in Figure 13, the three anodes act together to form the electrostatic lens.

Although the beam passing through the hole of the first anode is of small cross-section it tends to spread out due to mutual repulsion between electrons. Thus a 'lens' is required to focus the electrons so that they arrive at the screen in a spot that is as small as possible. The electrostatic lens acts in a way very similar to an optical lens and forms an image of the cathode (or, more correctly, the crossover point near to the cathode) on the screen. The electrostatic lines between the anodes are shown in the figure, and it can be seen that they are in such a direction as to tend to bend the electrons round so that they are all focused to the same point. This obviously is a very simple explanation of a complex electrostatic lens system. The second anode commonly has a potential about one-fifth of that of the first and third anodes, which usually are at the same or about the same potential, as in the figure. By varying the potential

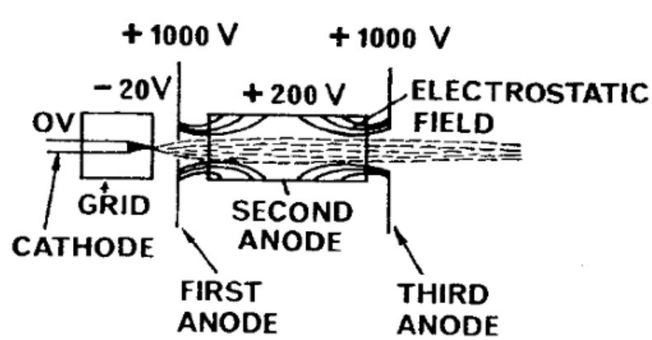


Figure 13: The electrostatic lens formed by the three anodes

of the second anode the effective focal length of the electrostatic lens is varied, hence this forms the focus control. This is known as a mono-accelerator tube because all the electron acceleration is done in one stage in the electron gun. Further on we will cover CRTs that have a second stage of acceleration after the deflection plates.

Deflection Plate Screen

Distortion is liable to occur when the beam is deflected, and some shaping of the plates may be made to reduce this. Usually, a shield or screen is placed between the plane of the plates, as shown in Figure 14, preventing a distorting field being set up between them.

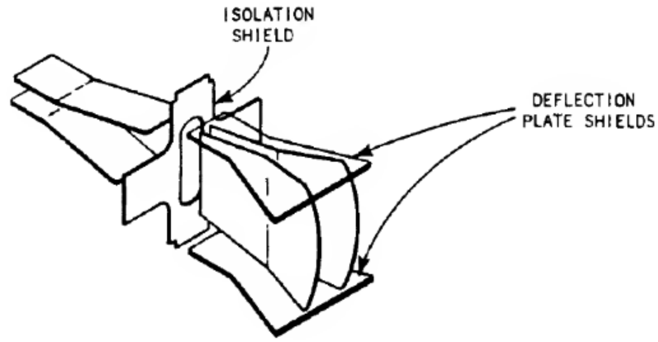


Figure 14: X and Y deflection plates and intermediate shield or screen

Although the potential of this shield should be approximately the same as that at final acceleration anode A3, some control over the geometry (barrel or pincushion distortion) can be made by varying its voltage slightly relative to A3, Another electrode after the X-plates may also be used for the same purpose. Sometimes shield plates are placed at the side of the deflecting plates to reduce distortion and unwanted stray fields. Some defocusing of the spot will occur when it is deflected because the distance from the plate to the screen is increased, but this effect is usually small compared with others. It is very important that the deflecting plates are fed in push-pull so that their mean voltage does not vary in relation to A3, otherwise serious distortion occurs. The spot on the screen may not be round but may be oval in shape which is known as 'astigmatism'. It's usual to include a control to reduce this, either on the front panel or as a preset control. This control varies the mean voltage of the Y-plates relative to A3 and forms a variable cylindrical lens between the plates and the final anode A3.

Post Deflection Acceleration (PDA)

As the frequency of operation is increased, especially where fast transients are to be seen or photographed, the trace has to be brighter. This can be accomplished by increasing the beam current so that more electrons reach the phosphor. However, increasing the beam current means a larger spot size, therefore the beam current must be limited in value. The only other way of obtaining more brightness is to increase the velocity of each electron by raising the accelerating voltage. However, the deflection sensitivity is inversely proportional to the accelerating voltage applied before the deflecting plates. This is a serious disadvantage, as it is difficult to get a large deflecting voltage at high frequencies, particularly when transistors are used. The actual sensitivity will depend on the deflecting plate size and spacing; an older mono-accelerator tube with a final anode voltage of 4 kV may have a deflection factor of 50 volts/cm. Thus, to get a 3 cm peak deflection (i.e. a total of 6 cm peak-to-peak) requires a deflecting voltage of 3 x 50 = 150 volts peak (or 300 V p-p). If the accelerating voltage becomes 8 kV then the required deflecting voltage is 300 volts peak or 600 V p-p).

To overcome this limitation, post deflection acceleration (PDA) was used. The general idea is that if the final anode of the gun is given a voltage of, say, only 1 kV, the electron beam will have a relatively low velocity when passing through the deflecting plates, and the deflection sensitivity will be high. If the electrons are accelerated *after*[35] deflection it will have little or no effect on the deflection sensitivity. There are several methods of doing this. One is to use a high resistance helix (e.g. 500 MΩ) deposited on the inside of the tube. The screen end of this helix is connected to a high voltage, and the other end to a potential at or near that of the final anode. The PDA acceleration voltage required was commonly 5 to 10 kV, but may go as high as 20 kV.

From the point of view of a scope clock builder, viewing fast transients and photography are not our goals. However there are many fine CRTs available that have PDA. If incorrect voltages are applied to such a CRT it can result in a dim trace, poor focus or variable focus over the CRT face. PDA cannot therefore be ignored.

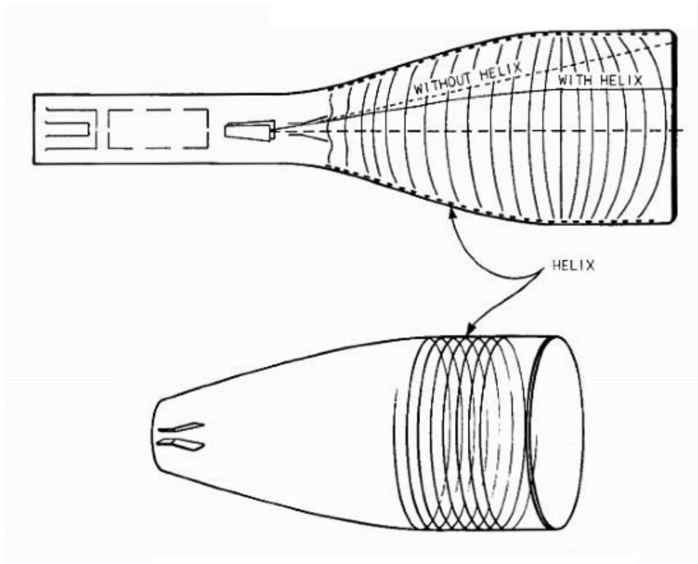


Figure 15: A helical PDA

[35] After is a synonym for post - get it? (try harder… Ed.)

The Building Blocks of a Scope Clock

The question now is how do we make a cathode ray tube into a clock? The prior lengthy description of the cathode ray tube gives us a short list of requirements:

- A power supply for the heater,
- A power supply for the grid which can be used to control the brightness of the beam, and if made sufficiently negative (with respect to the cathode) turn off, or blank, the beam entirely,
- An adjustable power supply for the focus anodes,
- A power supply for the acceleration anodes,
- Two deflection amplifiers, one for the X plates and one for the Y plates,
- If the tube requires one, a power supply for the PDA.

The current version of the clock meets the first five requirements and a future version will meet the sixth as well. The simple block diagram (Figure 16) depicts five elements listed here connected to a CRT. Also shown is some *gizmo*[36,37] connected to the deflection amplifiers and the grid power supply. The *gizmo* can position the beam on the CRT face and turn the beam on and off…

Not surprisingly a small microcontroller is often used for the *gizmo* but the design of this clock does not use one! Additional circuits allow it to send an analogue signal to each of the deflection amplifiers and a digital signal to switch the beam. Being able to position the beam and make a glow at any point on the face of the CRT allows objects to be drawn.

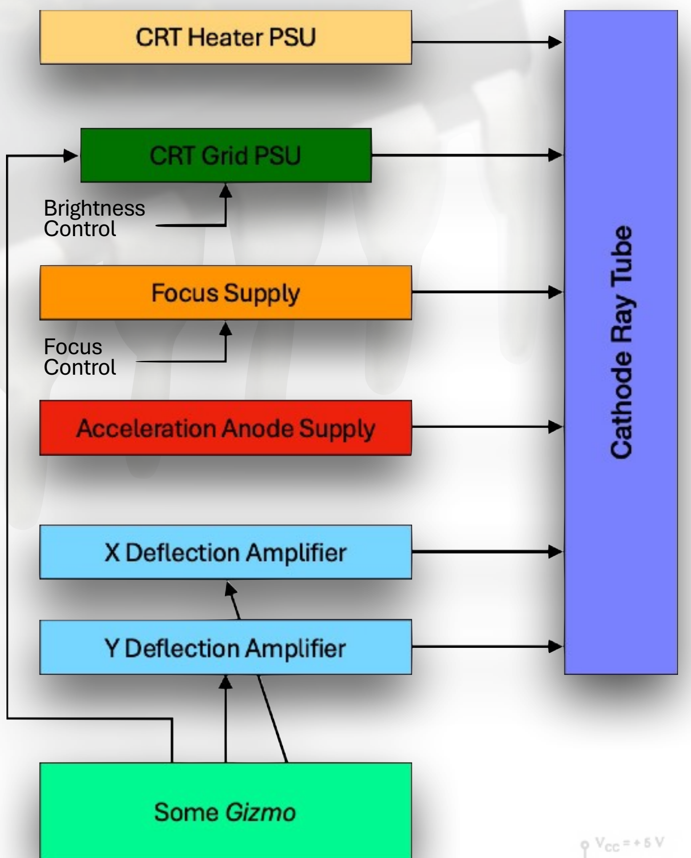


Figure 16: Block diagram of a Scope Clock

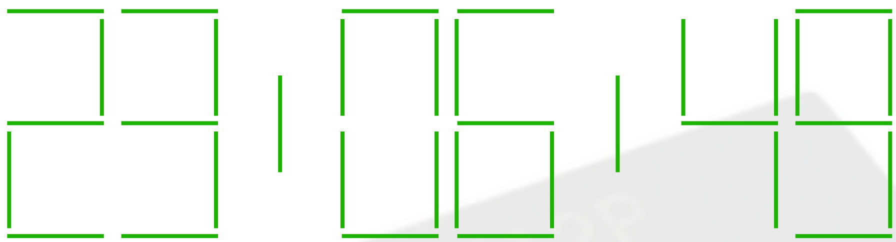
[36] A technical term obviously…
[37] https://en.wikipedia.org/wiki/Gizmo

TTL Scope Clock – How it works - A Simplified Overview

This is a basic description of how the clock works – a detailed description based on the clock's schematics follows in the next section.

The Intent!

The clock aims to display the time as six 7-segment characters, separated by some form of colons, like this on a cathode ray tube screen:



..and in practice this is what results...

To achieve what looks like a rather simple objective[38], the electronics are divided into three major sections.

- Time keeping
- Display logic, analogue line generator, font generator
- CRT drivers
  - Power supplies
  - Deflection amplifiers
  - Unblanking amplifier

[38] Deceptively simple….but there's a lot that goes into this as you will soon see…

Accurate Time Keeping

To keep accurate[39] time a 32.768kHz temperature compensated crystal oscillator (TCXO[40]) is used. The oscillator is divided by 2^{15} times to generate a 1Hz signal. In the clock this divider chain is called the Master Clock. The 1Hz signal is then divided further to generate signals that represent the time encoded into six Binary Coded Decimal (BCD[41]) signals:

- The 1Hz signal is counted to produce the units BCD seconds number (4 bits)
- The 1Hz signal is divided by 10 and counted to produce the 10s BCD hours number (3 bits)
- The 10s seconds are counted and divided by 6 to produce the units BCD minutes number (4 bits)
- The minutes are counted and divided by 6 to produce the 10s BCD minutes number (3 bits)
- The 10s minutes are counted and divided by 10 to produce the BCD hours number (4 bits)
- The BCD hours are counted to produce the BCD 10s hours number (2 bits)

The hours counter can be set to divide by 12 or 24 to enable the time to be displayed as 01 to 12 for a 12 hour clock or 00 to 23 for a 24 hour clock. The whole time is therefore available in the clock as a 20 bit BCD number. The TCXO performs a second function in the clock – it provides the signals to control the display of the lines on the CRT face that make up the 8 characters.

Drawing the Face for a Particular Time

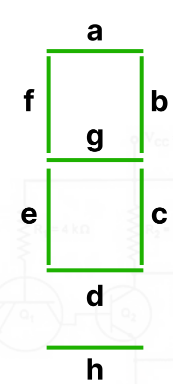
Drawing a time on the CRT face is broken into several tasks:

- Drawing all the lines is based on signals from the Master Clock divider chain
  - Timing signals to draw the 8 lines that make up each character
  - Timing signals to draw 8 characters across the face
  - A driver signal to a triangular wave[42] generator that will draw individual lines
- Converting digital position information into analogue voltages that can be sent to the CRT's deflection amplifiers
- Drawing only the lines that are required for a given number based on the time by converting a character number using data stored in a memory chip into a signal that is applied to the CRT's grid to turn the beam on/off to draw lines as required

Let's look at how this is all done.

A Word about 7 Segment Naming

The convention used in this clock for naming the 7 + 1 elements of a displayed character in this clock is:



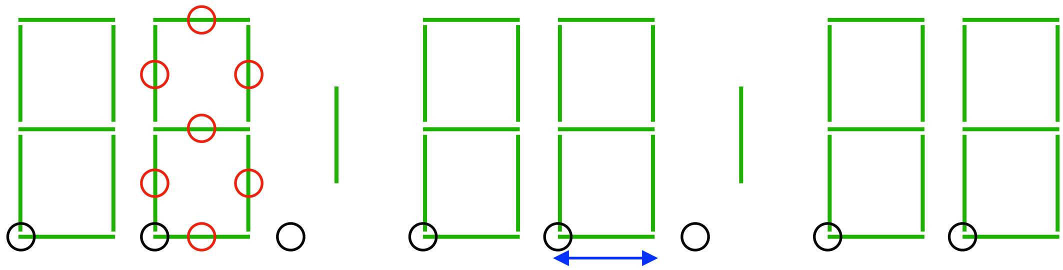
Not all part manufacturers use this naming convention.

---

[39] Better than 1 minute a year…good enough for us!
[40] https://en.wikipedia.org/wiki/Crystal_oscillator
[41] https://en.wikipedia.org/wiki/Binary-coded_decimal
[42] https://en.wikipedia.org/wiki/Triangle_wave

Line Drawing

The Master Clock divider produces 3 bits of data that are used to position each character on the tube face:



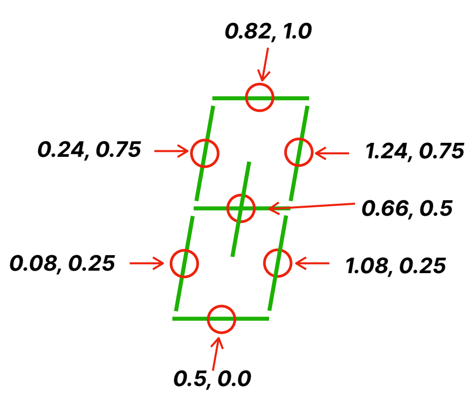
These are the **black** circles at the lower left corner of each of the characters above. The Master Clock divider also produces a further 3 bits of data at a faster rate that are used to position the lines to be drawn relative to the lower left corner. These are shown in **red** circles. The vertical line used as a colon has the same relative position as the 7 segment centre horizontal bar. Therefore there are 8 centre points in total. The positioning information is 6 bits in total giving 64 unique centre point locations. These locations are generated by three 3 bit DACs (Digital to Analogue Converters[43]), their analogue signal outputs are summed to give the required X and Y positions.

The X position is produced by summing the output of the character position X DAC (**black** circles) with the X component of the line centres (**red** circles). The Y position is simply the Y component of the line centres. With only one row of characters there is no Y character position (all the **black** circles have Y = 0). If the display had multiple lines of characters then there would be a Y direction character DAC to sum the output with.

DAC input - bits	DAC output - volts
0	0
1	0.5
10	1
11	1.5
100	2
101	2.5
110	3
111	3.5

Note that the DAC output voltages are not necessarily linear over the 3 bit range. The output voltage is set to give the required voltage to position the beam. The default X character position DAC output which is obviously linear (**black** circles) are given in this table (right).

The default X and Y line centre DAC outputs (**red** circles) used are based on the character below.



[43] https://en.wikipedia.org/wiki/Digital-to-analog_converter

Here a further twist[44] to the design is introduced, namely the intent to have the number leaning slightly to the right to give the character more errr.... character.[45] This line arrangement was made by drawing the character on graph paper and measuring the X, Y coordinates;

DAC input bits	X DAC output volts	Y DAC output volts	Line drawn
0	0.82	1.0	a
1	1.24	0.75	b
10	1.08	0.25	c
11	0.5	0.0	d
100	0.08	0.25	e
101	0.24	0.75	f
110	0.66	0.5	g
111	0.66	0.5	h

A separate manual covers the topic of clock customisation, where the 7 + 1 segment display can be altered (within reason). A spreadsheet in the project documents folder on the Dropbox presents the calculation of the resistor values in the DACs based on these required character positions and line centre DAC output voltages. You can use this spreadsheet to recalculate resistor values to change the presentation of the characters.

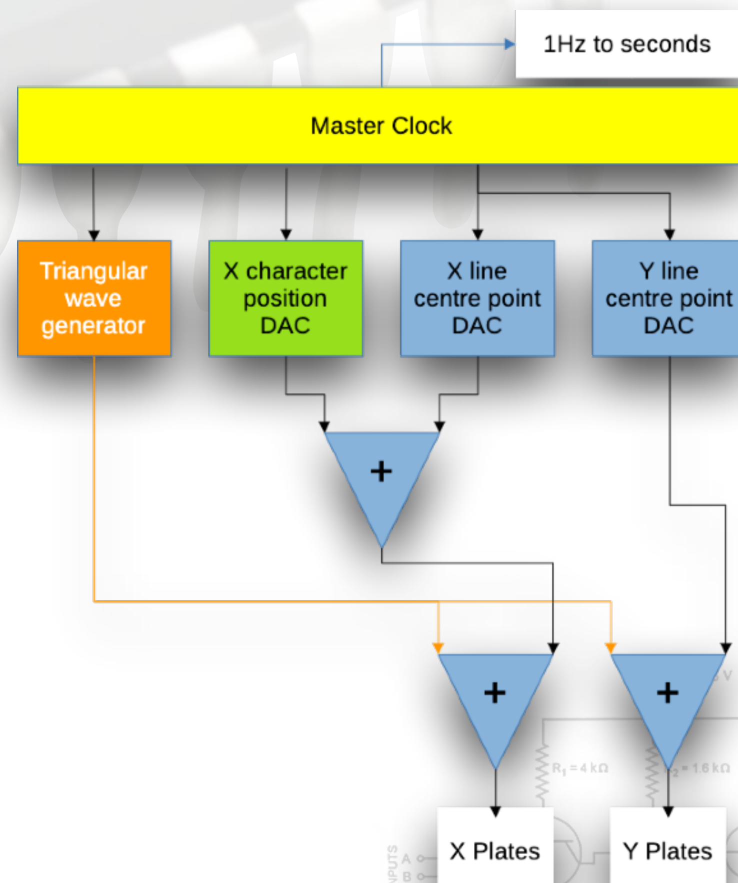
Up to this point, we can now position the CRT beam to the centre points of the 8 lines making up a character and for 8 characters in a row. We now need to draw the lines themselves. This is done using a triangular waveform. The amplitude of the triangular wave must produce the required length. This length is shown as the **blue** double arrow line in the diagram at the start of this section. All lines will have this same length.

The Master Clock divider sends a square wave signal to an analogue section where it is converted into an analogue triangular wave. If this triangular wave is also summed into the summed position data from the DACs then the signal when sent to the CRT deflection amplifiers will produce a line.

If the signal is sent to

- The X deflection plates only then a horizontal line will result,
- The Y deflection plates then a vertical line will result,
- Both deflection plates then a line with a positive slope will be produced, the angle of the line will depend on the relative applied voltages.

In summary the 64 lines that can make up the clock's display are formed by a combination of position setting DACs and a triangular wave generator to draw the lines.



[44] *Slant* maybe?

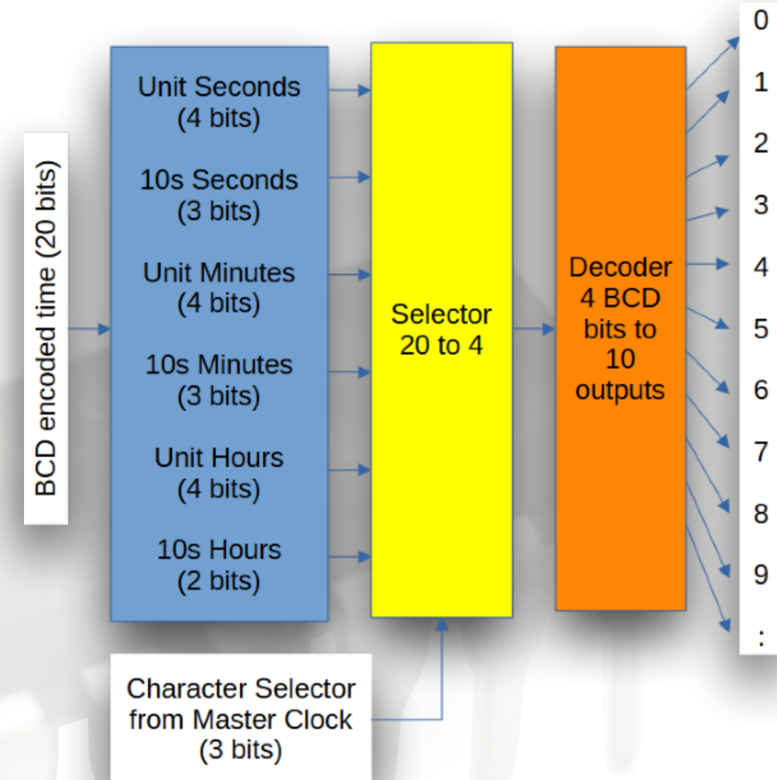
[45] Please leave the jokes to me..... Ed.

Font, Character Selection and Line Blanking

At this point the hardware displays all of the 64 lines, so now we need to display only the lines that make up a particular character. A separate section does this. The characters to display must be the ones required by the time keeping section as HH:MM:SS.

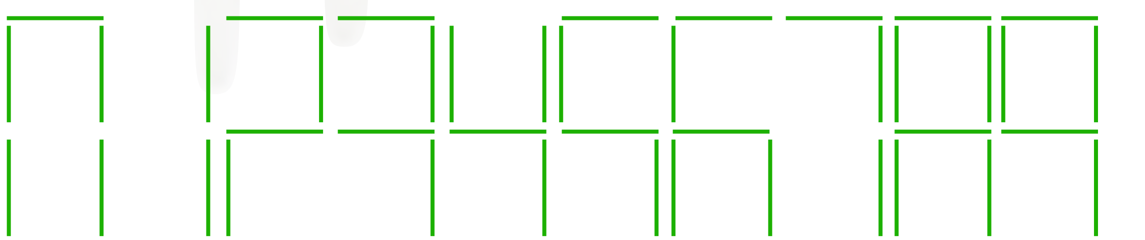
Character Selection

The section above has shown that the Master Clock produces 3 bits of data that are used to draw the 8 characters across the tube face. The same 3 bits of data are used to select the BCD time element (unit seconds, 10s of seconds, unit minutes etc.) that correspond to the tube position. This is done by a selector that extracts the required 4 bits of data from the BCD encoded time (unused bits are set to 0). The extracted 4 bits of data are passed to a decoder that converts the BCD number (4 bits) to a single signal that is logical high (1). Character 10 is interpreted as a colon character and is used between the hours and minutes, and the minutes and seconds. Character 11 is interpreted as the alternative colon character to show when the colon is being flashed on and off.



The Font

The clock needs to be able to display 11 characters: the numbers '0' to '9' and a colon character to act as a separator between the hour, minutes and second digits. The default font[46] in the clock (without the slight *lean*) is; (there is a deliberate space at the end…)



The font is defined in the hardware in a non-volatile memory chip called an electrically erasable programmable read-only memory (EEPROM[47]). Each bit in the EEPROM will define if a line is to be drawn for a given selected character. In reality the colon character selection is slightly more complex. Colon character selection is described in the kit building section. The customisation manual deals with changing the colon character entirely.

[46] Before any customisation is carried out…
[47] https://en.wikipedia.org/wiki/EEPROM

A Few Words About Customisation[48]

There is some latitude to customise the clock faces. Simple changes you can make include:

- The colon character shape. The default is a vertical bar '|' but others such as a small box '☐' or horizontal bar '-' are easy to create. You can have no colon character at all!
- The angle of the 'lean to the right' of the characters, including no lean at all.
- The inter-character spacing. You can tighten or space out the character in a linear or non linear fashion.
- There is the opportunity to create and entirely new or 'secret' face that only you can read the time from.

This is a complex subject so it has its own manual.

CRT Stuff and the Rest of the Clock

The rest of the clock is completely conventional for a CRT clock!

- An external 12V DC supply to the clock.
- 3.3V and 5V DC for logic operations.
- -5V DC and +5V for analogue operations.
- +5V pulsed using Pulse Width Modulation[49] (PWM) to control LED[50] brightness.
- $6.3V_{RMS}$ AC for the CRT heater supply.
- +300V DC for deflection amplifier and final acceleration anode.
- -1.5kV DC for the CRT cathode and focus resistor chain.
- +90V DC for the CRT grid.
- X and Y deflection amplifiers.
- Unblinking amplifier.
- Astigmatism control.
- Trace rotation control.
- A Passive Infrared (PIR[51]) motion sensor to detect room occupancy and shut down the clock display if the room is left unoccupied for a while.
- Switches to set the hours, minutes and zero the seconds.

Epilogue

A microcontroller makes things so much simpler but perhaps not much of a challenge or dare I say it, fun?

[48] Customization to our American friends…
[49] https://en.wikipedia.org/wiki/Pulse-width_modulation
[50] https://en.wikipedia.org/wiki/Light-emitting_diode
[51] https://en.wikipedia.org/wiki/Passive_infrared_sensor

How it works – In Some Detail[52]

The standard clock uses two PCBs and this section will describe each board in turn. It is assumed that you have read the simpler how it works section as it won't necessarily be repeated here.

The schematics of the two boards are provided in a separate manual. It is suggested you print them out so you can refer to them while reading this section or have them open in a separate PDF should you be reading this on a computer. This will (hopefully) make it easier to follow along.[53]

This section provides, it is hoped, sufficient information to assist with troubleshooting. In this regard, there are several images from an oscilloscope[54] illustrating the signals you should expect to have in various places.

Power Supply and CRT Board

This PCB carries a raft of support functions like power supplies and CRT drive circuits, including

- +12V DC input with over voltage, over current and reverse voltage protection.
- +5V regulated supply for digital circuits.
- +5V PWM supply to LEDs.
- +5V and -5V power supply for analogue circuits.
- +300V supply for CRT acceleration anodes and deflection amplifiers.
- -1.5kV for CRT grid and cathode.
- +90V power supply for the unblanking amplifiers.
- 6.3V AC_{RMS} power supply for the CRT heater.
- CRT grid, cathode and focus voltage divider chain.
- Unblanking[55] amplifiers.
- X and Y CRT deflection amplifiers.
- Trace rotation coil power supply (optional).
- Board inter-connections.

A word about power supplies

Voltages are normally measured with reference to ground which is the negative lead of the 12V supply to the whole clock. Ground connections on the schematics are normally called GND. Therefore, a measured voltage described as, say, 90V means +90V with respect to clock ground. However, if a voltage is described as [250V][56] then the voltage is referenced to the CRT cathode. CRT datasheets list normal operating condition voltages for the CRT with respect to the cathode. You will only see the […] nomenclature used in the sections that deal with powering the CRT.

---

[52] Strap in, this is going to get interesting..
[53] Avoids all the back and forth etc…
[54] A Rigol MSO5104 adequate for both the task and my bank balance….
[55] It is common to have a "blanking" amplifier that turns the CRT electron beam off when not required. In this design, the beam is normally held off and the amplifier unblanks the beam when required so is an *unblanking* amplifier.
[56] Note the square brackets […]..this is quite **important**

The clock Eagle schematics refer to the following voltage supplies:

Eagle Schematic Reference	Voltage	Function
+12V	+12V DC	Main power supply to the clock. Supplies to, *inter alia*, 5V supply, CRT heater power supply, CRT HT/-EHT power supply, first stage of the unblanking amplifier.
+5V	+5V DC	Main digital electronics power supply and power supply to the analogue power supply
+5V/1	+5V DC	Clock timekeeping digital electronics power supply. This power supply can be from a back up battery that will keep the timekeeping function running when the main 12V power is switched off (i.e. the clock will maintain the correct time). If the back up battery is not available then +5V/1 is connected to +5V.
+5V/2	+5V PWM variable pulse width	Supply to the LEDs on the clock digital and analogue board by varying the PWM pulse width the brightness of the LEDs can be varied.
+5VA	+5V DC	Supply to the analogue sections of the clock – line positioning and line creation section and CRT deflection amplifiers. Also supplies the trace rotation power supply if used.
-5VA	-5V DC	
+3V3	+3.3V	Supply to the PIR sensor only
+90V	+90VDC	Supply to the second stage of the "beam -on" amplifier
+300V	+300V	Supply to the CRT deflection amplifiers and CRT acceleration anodes via the astigmatism control
-300V, -900V …	Corresponding negative voltages	Intermediate stages in the -EHT multiplier chain
-1.5kV	-1.5kV	-EHT supply to the CRT grid, cathode, focus controls
H1 & H2	6.3V_{RMS} AC	CRT heater supply

+12V DC input with over voltage, over current and reverse voltage protection[57]

There are two +12V DC input connectors, one at right angle and one perpendicular to the board to facilitate different case designs.

F1 and D2 provide simple over current and over voltage protection and P-Channel MOSFET[58] Q1 provides reverse voltage protection.[59]

+5V DC digital power supply[60]

The 5V digital power supply uses a LM2576-5[61] monolithic integrated circuit with a +5V fixed output. It is a step-down (buck) switching regulator[62] and just uses the typical application note circuit. It is required to deliver up to approximately 1A. This power supply is called +5V. J2 is normally fitted but it can be lifted to measure the +5V digital supply current to the clock.

[57] Eagle PSU/CRT Schematic Page 1/6
[58] https://en.wikipedia.org/wiki/MOSFET
[59] https://components101.com/articles/design-guide-pmos-mosfet-for-reverse-voltage-polarity-protection
[60] Eagle PSU/CRT Schematic Page 1/7
[61] https://www.ti.com/lit/ds/symlink/lm2576hv.pdf
[62] https://en.wikipedia.org/wiki/Buck_converter

Optional +5V DC digital battery back up power supply connection[63]

An option for the clock is a battery backup for the time keeping section. If the battery backup is used then J1 is not fitted and the battery board is connected to X3. The power supply to the timekeeping logic is called +5V/1. The battery board and X3 are not part of the standard kit nor are the standard case designs to house the battery board. This manual will not discuss the battery backup any further.

Normally J1 is fitted.

CRT Deflection Amplifiers[64]

The design is a slightly modified version of the deflection amplifier used by David Forbes in his SC200 clock.[65] The amplifier was modeled in LTSpice[66] and the values tweaked a little with a constant current source added using IC2 and IC3 as LM234Zs[67] in an application note design with D20 and D21 providing temperature compensation.

The OPAMP IC4A and IC4B input stages are simple summing amplifiers[68]. Two independent inputs are brought in from the digital and analogue board, a position trim pot is provided and the gain adjustable. These controls allow the clock image to be nicely centred and presented on the CRT face.

The deflection amplifiers are differential input and output totem-pole amplifiers. The input stage is a differential amplifier circuit (Q10, Q11 etc.) referred to as a long-tail pair. The voltage from the X or Y signal presented to one transistor is developed across the emitter-coupling resistor to generate a current difference which causes a varying voltage to be generated across the high-voltage pull-up resistor. The gain is controlled by the emitter coupling resistor values.

The output stage has a pair of high-voltage amplifiers (Q1, Q3, Q6, Q7 etc.) which serve to speed up the operation by actively pulling the output high or low as needed. The two diodes (D4, D5 etc.) on the emitter of the upper transistor (D4 etc.) direct current into the base of one transistor or the other depending on whether the output needs to be driven higher or lower. This allows the output voltage to be driven high faster than the RC[69] time constant of the CRT capacitance and the load resistor. The result is a slew rate of about 150 V/μS.

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[63] Eagle PSU/CRT Schematic Page 1/6
[64] Eagle PSU/CRT Schematic Page 2/6
[65] http://www.cathodecorner.com/sc200/SC200CBoardManual.pdf
[66] https://en.wikipedia.org/wiki/LTspice
[67] https://www.ti.com/product/LM234/part-details/LM234Z-6/NOPB
[68] https://www.electronics-tutorials.ws/opamp/opamp_4.html
[69] resistance × capacitance

+300V HT[70,71] Flyback Power Supply[72]

The +300V PSU for the deflection amplifiers, acceleration anodes and, if the CRT has one, the shape/geometry/screen electrode uses a LM2588-ADJ[73] flyback regulator[74] IC6. The flyback also generates the +90V and -1.5kV voltages described below. The LM2588 series of regulators are monolithic integrated circuits specifically designed for flyback, step-up (boost), and forward converter application. There is an exceptionally good description of how flyback converters work here[75]. This reference contains this diagram:

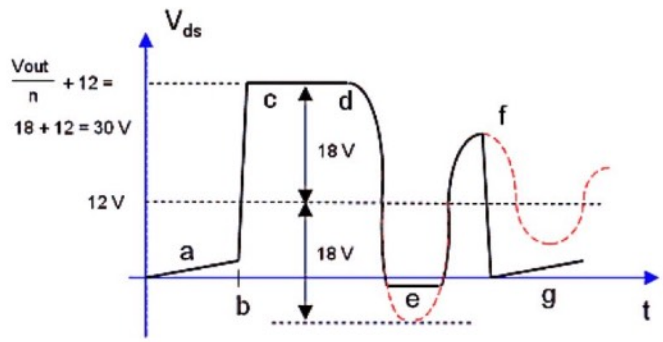
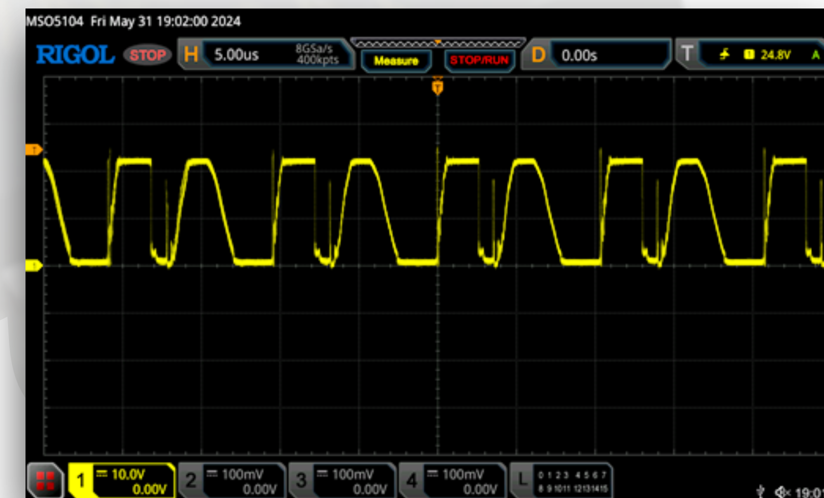


Figure 13 Voltage over the switch during all three phases

This shows the voltage on the the lower side of the flyback transformer primary. It is interesting to compare this with what my oscilloscope measures.[76] Not exactly the same but similar, enough to convince me that the flyback is functioning.



Clicking on these oscilloscope images will take you to a full screen version at the end of this manual

D33 and D36 protect the output transistor in the IC.

Q15 is used to turn on the flyback. Normally the flyback is not running as the ON pin is held high by R49 and D37. When a +5V digital signal is applied to the gate of Q15 it conducts pulling the high signal from R49 to ground.

The flyback transformer, TR1, is a custom wound part with a +12V primary and two secondaries, +150V (when rectified) and +90V (when rectified). The +150V secondary is rectified and voltage doubled with a Cockcroft-Walton voltage multiplier[77]. This transformer is used in many Sgitheach/StocksClocks kits and clocks, included Scope Clock Due, the CRT Tester[78], the Harwell Dekatron Clock[79] and the Fortress E1T Clock[80].

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[70] https://en.wikipedia.org/wiki/High_voltage
[71] High Tension – what constitutes a high voltage or high tension is over 1.5kV by official definition. I tend to use a lower, more informal approach from vacuum valve circuits, that anything over 50V is high tension, HT, and anything over 500V is EHT, Extra High Tension.
[72] Eagle PSU/CRT Schematic Page 3/6
[73] https://www.ti.com/lit/ds/symlink/lm2588.pdf?ts=1717113337043
[74] https://en.wikipedia.org/wiki/Flyback_converter
[75] https://www.dos4ever.com/flyback/flyback.html
[76] Throughout the manual, if you click on the scope images you can see higher-resolution images in Annex A of the manual, with a very handy click back to where you came from.. neat huh?
[77] https://en.wikipedia.org/wiki/Cockcroft–Walton_generator
[78] http://www.sgitheach.org.uk/crttester1.html; https://stocksclocks.com/index.php/cathode-ray-tube-tester/
[79] http://www.sgitheach.org.uk/harwell.html; https://stocksclocks.com/index.php/harwell-a-dekatron-clock/
[80] http://www.sgitheach.org.uk/fortress.html; https://stocksclocks.com/index.php/fortress-an-e1t-clock/

+90V DC unblanking power supply[81]

The CRT operates with the beam normally blanked, the CRT grid is held at a negative voltage whereby the spot is extinguished. This 90V positive power supply is used to turn the beam on when required. The operation of the unblanking amplifier is described below. The +90V supply consists of, after rectification and smoothing, a LR8 regulator[82] with a pass transistor Q14. The output voltage can be adjusted over a wide range using R50. This trim pot is the “Light Level” control. The use of this is described below.

-1.5kV EHT power supply[83]

The -EHT voltage for the CRT grid, cathode and focus anode (described next) is generated by harvesting pulses from the flyback convertor and a 5 stage Cockcroft-Walton voltage multiplier. Each stage increases the output by -300V so -1.5kV is available.

CRT astigmatism control and optional CRT screen supply[84]

Q16 is an emitter-follower that supplies the acceleration anodes with an adjustable voltage of about 150V. This adjustment is called the astigmatism control. The deflection plates have the secondary effect of acting as focusing lenses, first on one axis and then on the other. The magnitude of this effect depends on the voltage of the final acceleration anode relative to the average DC voltage on the deflection plates. If not adjusted correctly the dot on the face will be oval rather than round. Some CRTs have a screen between the pairs of X and Y deflection plates. This screen electrode is held near the average DC voltage on the deflection plates. A Telefunken D9-10 CRT[85] is one example of a CRT with a screen electrode, in which case R55, R61 and X8-1 are fitted.

CRT grid, cathode, focus potential divider[86]

The -1.5kV supply is taken to a resistor voltage divider to ground. The resistor values are arranged to present the correct voltages depending on the CRT. At the most negative position is a trim pot, R80, that adjusts the grid voltage. When sufficiently negative to the cathode the CRT beam is extinguished. This trim pot is the “dark level” control.

Then there is the fixed cathode voltage tap and also a trim pot, R70, that adjusts the voltage on the CRT focus anode.

For example, the 3ASP1 CRT requires:

- Grid to be about [-32V] to [-56V]
- Focus anode to be [320V] to [560V]
- Acceleration anodes at [1500V]

More details on adjusting the voltage divider to suit a particular CRT is in the customisation manual together with resistor values for a range of CRTs.

[81] Eagle PSU/CRT Schematic Page 3/6
[82] https://ww1.microchip.com/downloads/en/DeviceDoc/20005399B.pdf and what a fantastic part this is!!
[83] Eagle PSU/CRT Schematic Page 3/6
[84] Eagle PSU/CRT Schematic Page 4/6
[85] See information on the D9-10 in the clock customisation manual.
[86] Eagle PSU/CRT Schematic Page 4/6

Unblanking amplifier and CRT grid capacitive coupling[87]

When the digital section of the clock decides that the beam needs to be switched on it sends a 5V signal to the unblanking amplifier. This amplifier consists of two stages made up of MOSFETs Q17 and Q18. Normally when the beam is off, Q18 is non-conducting as it has a 0V signal on its gate. Q18 drain will be at 12V and this holds Q17 in a conducting state so its drain will be near ground. When Q18 is turned on by the unblanking signal, Q17 is turned off and its drain rises to the “light level” voltage from the unblanking PSU previously described. The voltage on the drain of Q17 is capacitively coupled to the grid of the CRT by C34. This capacitor provides the DC isolation between the -EHT voltage on the grid.

CRT heater power supply[88]

The CRT heater typically requires $6.3V_{RMS}$ at 300mA to 600mA. The heater power supply is a Royer oscillator[89] hand wound on a small ferrite core. The design is by Mike Moorees[90].

There is normally a limitation on the maximum heater-cathode voltage, typically around [100V]. The heater must be isolated or connected to the cathode. The isolation, remembering that the cathode is at -EHT voltage, is accomplished by winding the secondary with EHT rated wire providing a working isolation of 3kV. Q19 and Q21 provide a simple high-side switch so that the Royer oscillator can be turned on only when it is required.

Optional CRT trace rotation power supply[91]

A simple arrangement of two emitter-followers Q20 (NPN) and Q24 (PNP) can provide a trace rotation coil on the CRT neck to be used. With both a positive and negative supply the image on the CRT can be rotated in both directions. At the time of writing this no development work has been made. On smaller rectangular CRTs, such as the 3SP1, the trace appears to be well aligned and a rotation coil does not seem essential. Other CRTs are yet untested. Please get in touch if you need to use this feature.

LED brightness control[92]

The digital clock has arrays of LEDs that tell the time using BCD. Rather than select the current limiting resistor with each LED to give a fixed brightness, the clock uses the venerable 555[93] timer, IC7, as a variable mark-space PWM signal to switch the P-Channel MOSFET Q25. The drain of this supplies power to all of the LEDs using the power supply called +5V/2. The trim pot R95 can adjust the mark-space ratio from about 0.5% to 95% giving almost complete control of the LED brightness.

Adjust according to taste.[94]

[87] Eagle PSU/CRT Schematic Page 4/6
[88] Eagle PSU/CRT Schematic Page 5/6
[89] https://en.wikipedia.org/wiki/Royer_oscillator
[90] Near the bottom of the page - https://threeneurons.wordpress.com/miscellaneous-projects/
[91] Eagle PSU/CRT Schematic Page 5/6
[92] Eagle PSU/CRT Schematic Page 6/6
[93] https://en.wikipedia.org/wiki/555_timer_IC
[94] I like them quiet dim – the main event is the CRT?

Analogue power supply[95]

The deflection amplifiers and trace rotation on this board both require a clean ±5V power supply, these are called +5VA and -5VA (A for analogue). There is also GNDA which is the analogue ground. An isolated DC-DC convertor, Z1, is used as a simple way to provide these supplies. The digital and analogue board also uses the +5VA and -5VA supply to the analogue OPAMP section.

Board Inter-connectors[96]

Two 2 x 10 female headers provide connections to the digital and analogue board. Header X4 carries the digital connections:

- Power outputs:
  - +5V/2
  - +5V/1
  - +5V
  - Ground

- Digital signal inputs:
  - Unblanking
  - Flyback and Royer On

Header X5 carries the analogue connections:

- Power outputs:
  - +5VA
  - -5VA
  - Analogue ground

- Analogue signal inputs:
  - X direction – channel 1
  - X direction – channel 2
  - Y direction – channel 1
  - Y direction – channel 2

The different analogue channels are described below in the OPAMP analogue sections.

[95] Eagle PSU/CRT Schematic Page 6/6
[96] Eagle PSU/CRT Schematic Page 1/6

Clock Digital and Analogue Board

This PCB carries the time keeping functions, including;

- 32.768 kHz TCXO that all timing signals are based on.
- Four divide by 16 counters to produce clock timing signals down to 0.5Hz, these:
  - Feed a 32.768kZ signal to the triangle wave generator.
  - A 16.384kHz signal that starts drawing a line on the CRT.
  - A 3 bit signal that defines which line segment to draw and a DAC to convert the 3 bit signal into X and Y deflection analogue voltages.
  - A second 3 bit signal that defines which character to draw and a DAC to convert the 3 bit signal into a X deflection analogue voltage.
  - Signals at 4, 2, 1 and 0.5Hz used to flash the “colon” character on the CRT display.
  - Signal at 1Hz used by the clock to count seconds.
- Divide by 60 counter with a 7 bit seconds BCD output.
- Divide by 60 counter with a 7 bit minutes BCD output.
- Divide by 12 or 24 with a 6 bit hours BCD output.
- BCD time LED indicators.
- Triangle wave generator.
- Logic to specify if a given line is vertical or horizontal.
- Logic to determine which character number to draw given the time BCD signals.
- Font logic to convert the character number into blanking/unblanking signal depending on the character to draw.
- Blanking logic to suppress spurious lines on the CRT when the beam is moved between drawing locations.
- PIR sensor to turn the clock display on when the room is occupied.
- Controls to set the time.
- Board inter-connectors.

Master 32.768kHz TCXO[97]

The Master Clock oscillator IC1 from which all the clock timing signals are derived is a DS32KHZ[98] IC. This is a temperature compensated crystal oscillator (TCXO). The output is accurate to ±2ppm (±1 min/yr) from 0 °C to +40 °C.

It has an output frequency of 32.768kHz and has many uses in the SCTTL:

- Timekeeping (after division to 1Hz).
- The display timing.
- Analogue line drawing – see Triangle Wave Generator.
- Anti-phosphor burn measure.

The TCXO can be powered by the optional timekeeping +5V/1 battery backed up supply.

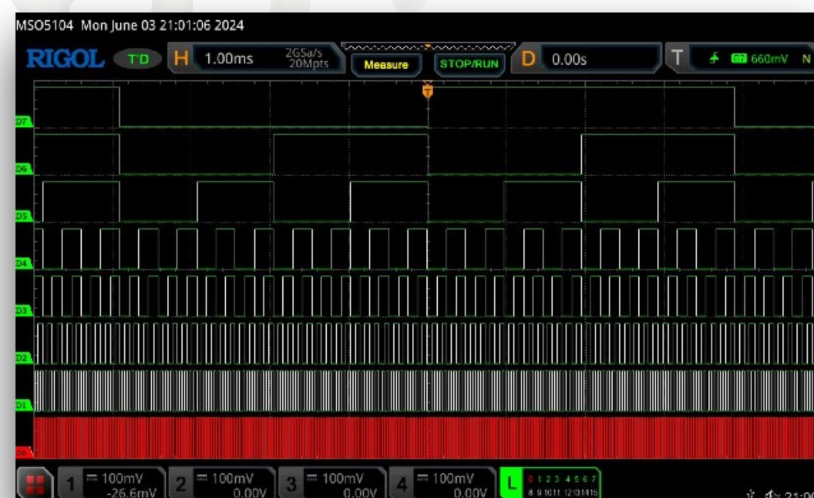
[97] Eagle Digital/Analogue Schematic Page 1/11
[98] https://www.analog.com/media/en/technical-documentation/data-sheets/DS32KHZ.pdf

Master clock dividers[99]

Two 74LS393[100] dual 4-bit binary counters, IC2 and IC3, take the 32.768kHz signal from IC1 and divide it by two 16 times. The final output is 0.5Hz. The divider outputs are used as follows:

IC	Output	Frequency (Hz)	Use
IC2A	QA	16384	Falling edge indicates that a new line (segment) is about to be drawn
IC2A	QB	8192	BCD value of the line (segment) that is being draw. Three bits give a value from 0 to 7. LSB (least significant bit) is QB and MSB (most significant bit) is QD.
IC2A	QC	4096	
IC2A	QD	2048	
IC2B	QA	1024	BCD value of the character that is being drawn. Three bits give a value from 0 to 7. LSB is QA and MSB is QC.
IC2B	QB	512	
IC2B	QC	256	
IC2B	QD	128	Unused (other than they are intermediate values on the way down)
IC3A	QA	64	
IC3A	QB	32	
IC3A	QC	16	
IC3A	QD	8	
IC3B	QA	4	Bling LED flash
IC3B	QB	2	Bling LED flash; Colon flash
IC3B	QC	1	Bling LED flash; Colon flash; 1Hz signal to seconds divider
IC3B	QD	0.5	Bling LED flash; Colon flash

Here are the first 8 signals from the Master Clock:



D0 (lowest trace in red) is the 32.768kHz output of the TCXO. D1 to D7 (ascending up the screenshot) are the successive divide by 2 outputs from IC2. The remainder of the Master Clock outputs are identical with each successive divide by 2 down to 0.5Hz.

The 'bling LED flash' are 4 LEDs that show the state of the outputs from IC3B. The outputs are buffered by 4 gates from a 74LS05[101] IC4A, IC4B,

[99] Eagle Digital/Analogue Schematic Page 1/11
[100] https://www.ti.com/lit/ds/symlink/sn54ls393.pdf
[101] https://www.ti.com/lit/ds/symlink/sn74ls05.pdf

IC4C and IC4D. These are inverters with open-collector outputs. The LEDs are powered by the PWM +5V/2 supply.

The colon flash output is selected by X1 and buffered by a gate from a 74LS14[102] IC5B. This output alternates the colon character being shown. Finally, the 1Hz output from IC3B Q_C is taken to the seconds divider.

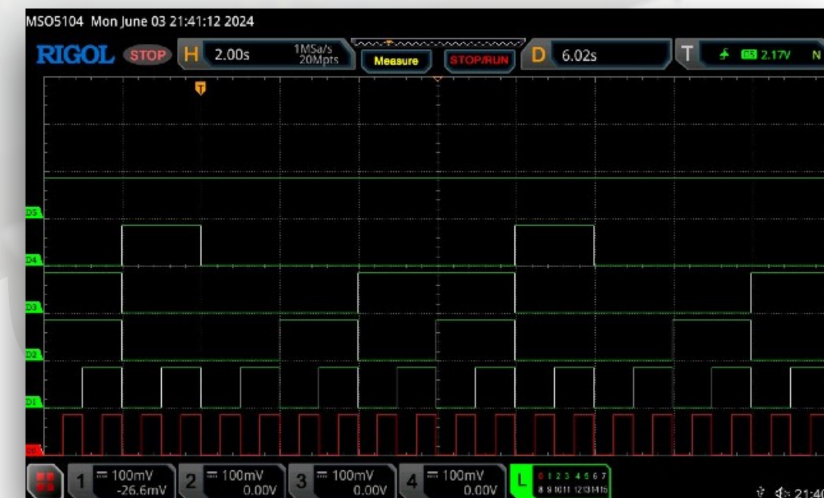
Unit Seconds Divider[103]

The unit seconds divider comprises 4 negative-edge triggered flip-flops[104] in two 74LS112[105], IC7 and IC8. The Q outputs on each flip-flop give the seconds time as a BCD number. The LSB[106] from IC7A Q and the MSB from IC8B Q. IC6A is a 74LS00[107] NAND[108] gate that detects the *illegal* count of 10 (1010 in BCD). The output from this gate goes low when this count is detected causing IC7 and IC8 to be cleared to zero. Therefore the BCD value proceeds from 0 to 9 and the output comprises the 4 bit signal SEC_A, SEC_B, SEC_C and SEC_D. There is an output from the last stage to the Tens of Seconds Divider.

IC7 and IC8 $\bar{Q}$ outputs run 4 bling LEDs which will show the seconds count at any time as a BCD number. These LEDs are powered by the PWM +5V/2 supply. Resistor R1 and the SEC_HOLD signal are part of the time-setting logic and will be discussed later.

In the image to the right:

- D0 (in red) – 1Hz input from the Master Clock, Pin 1 of IC7A
- D1–SEC_A signal, Pin 5 of IC7A
- D2–SEC_B signal ,Pin 9 of IC7A
- D3–SEC_C signal, Pin 5 of IC8A
- D4–SEC_D signal, Pin 9 of IC8A
- D5–Clear to zero signal, Pin 3 of IC6A



The trigger is on D5 but the output pulse is too short (see below) to be visible on this scan speed of 2S/div. After the first trigger shown by the "T" icon you can see that all 4 SEC_ data lines are zero. If you then count 10 falling edges on the 1Hz (D0) you reach the second clear point as the data lines are set to zero, This illustrates the seconds counting and the 'clear' operating as they should.

102 https://www.ti.com/lit/ds/symlink/sn74ls14.pdf
103 Eagle Digital/Analogue Schematic Page 2/11
104 https://en.wikipedia.org/wiki/Flip-flop_(electronics)
105 https://www.silicon-ark.co.uk/datasheets/sn74ls112a-datasheet-texas-instruments.pdf
106 https://en.wikipedia.org/wiki/Bit_numbering
107 https://www.ti.com/lit/ds/symlink/sn74ls00.pdf
108 https://en.wikipedia.org/wiki/NAND_gate

With the same data line attached, the scan speed is now 100nS/div. The clear signal (D5) is now visible and it is about 60nS wide. You can also see the short delays between each action:

- On the left hand side, the data lines are binary 1001 decimal 9.
- On the falling edge of the 1Hz input (D0), after a short delay SEC_A (D1) changes from 1 to 0, so the data is now binary 1000 decimal 8[109].
- After a further short delay SEC_B (D2) changes from 0 to 1, so the data is now binary 1010 decimal 10 – the illegal state!
- This condition is detected by the NAND gate IC6A and its output (D5) now falls to zero.
- After a slightly longer delay, the SEC_B (D2) and SEC_D (D4) data lines fall to zero; so now all four data lines are zero and the divider has been cleared.
- The illegal state is no longer present so the output of IC6A returns to 1.
- Job done!

This illustrates the operation of the units of second divider. There are some odd states, like a count of 8 after 9 existing for a few nS, and the count of 10 existing for about 60nS. However, the whole clear operation is over in about 100nS so nothing is visible on the CRT. The operation of all of the other dividers is roughly the same; just the BCD number can change and the operation is a *lot* slower.

Tens of Seconds Divider[110]

The tens of seconds divider comprises three 74LS112 flip-flops. Gate IC6B, another 74LS00 NAND gate, detects the illegal count of 6 (110 in BCD) which clears IC9A, IC9B and IC10A to zero. Therefore the BCD value proceeds 0 to 5 and the output comprises the 3 bits SEC10_A, SEC10_B and SEC10_C. The SEC10_C signal is taken forward to the unit minutes divider.

IC9A, IC9B and IC10 $\bar{Q}$ outputs run 3 bling LEDs which will show the tens of seconds count at any time as a BCD number. These LEDs are powered by the PWM +5V/2 supply. Resistor R2 and the SEC10_HOLD signal are part of the time-setting logic and will be discussed later.

Unit Minutes Divider[111]

The unit minutes divider is a repeat of the unit seconds divider with flip-flops IC10B, IC11A, IC11B and IC12A dividing and NAND gate IC6C detecting the illegal 1010 state and clearing the divider to zero. The output comprises the 4 bit signal SEC10_A, SEC10_B, SEC10_C and SEC10_D. The output from the last stage goes to the Tens of Minutes Divider.

[109] We have gone backwards!
[110] Eagle Digital/Analogue Schematic Page 2/11
[111] Eagle Digital/Analogue Schematic Page 3/11

Again the flip-flop $\bar{Q}$ outputs run 4 bling LEDs which will show the minutes count at any time as a BCD number. The MIN_A and MIN_B signals are also used in the provision of a phosphor anti-burn measure (see below under Character Position DAC).

Tens of Minutes Divider[112]

The tens of minutes divider is a repeat of the 10's seconds divider with flip-flops IC12B, IC13A and IC13B dividing and NAND gate IC6D detecting the illegal 110 state and clearing the divider to zero. The output comprises the 3 bit signal MIN10_A, MIN10_B, and MIN10_C. The output from the last stage goes to the Tens of Minutes Divider. Again the flip-flop $\bar{Q}$ outputs run 3 bling LEDs which will show the minutes count at any time as a BCD number.

Unit and Tens Hours Divider[113]

This is more complex than the seconds and minutes dividers as two cases must be dealt with:

- 12 Hour clock that counts 01 to 12 and set to 01 on the illegal count of 13
- 24 Hour clock that counts 00 to 23 and set to 00 on the illegal count of 24

The units of hours divider comprises the flip-flops IC15A, IC15B, IC16A and IC16B. They have a 4 bit output HR_A, HR_B, HR_C and HR_D. Again, their $\bar{Q}$ outputs run 4 bling LEDs to show the hour count. The tens of hours divider comprises the flip-flops IC18A and IC18B. They have a 2 bit output HR10_A and HR10_B. Again, their $\bar{Q}$ outputs run 2 bling LEDs to show the tens of hours count.

The selection of 12 or 24 hour operation is made by jumper X2.

12 Hour Clock: NAND gate IC14A detects the illegal state of binary 1010 in the units divider and clears the units flip-flops to zero. This means that decimal 09 changes to decimal 10. NAND gate IC17A detects the illegal state of binary 010011 (2 BCD bits from the tens counter and 4 BCD bits from the units counter) and this means that decimal 12 changes to 01. IC14C and IC14B combine the two clear signals to clear the hours flip-flops. Note that IC15A (BCD bit A) is not cleared as it is always in the required state. It is 0 when the flip-flops are cleared from decimal 09 to decimal 0 and is 1 when the they are set to decimal 01.

24 Hour Clock: The units of hours counter operates as before ensuring that decimal 09 changes to decimal 10 and decimal 19 changes to decimal 20. IC17B detects the illegal state of binary 100100, decimal 24 and clears decimal 23 to decimal 00 as IC15A is in the correct state.

R3 and C16 were found to be necessary as the glitches did cause unwanted flip-flop clearing.

Time Keeping Completed!

At this point we have BCD numbers for seconds (4 bits), tens seconds (3 bits), minutes (4 bits), tens of minutes (3 bits), hours (4 bits) and tens of hours (2 bits). Twenty bits of time data.

This BCD data is used to select the character to draw – see later under Font Selection.

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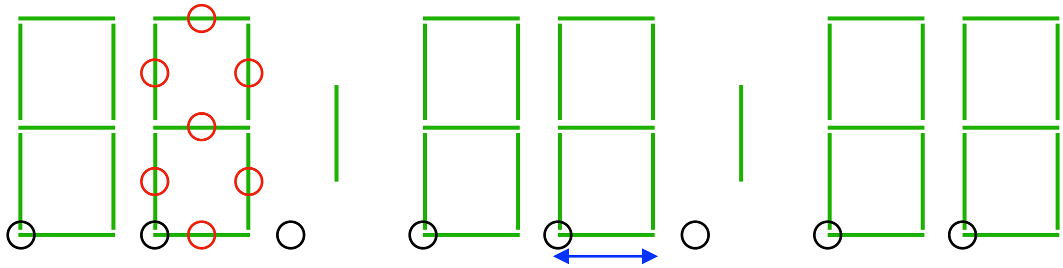
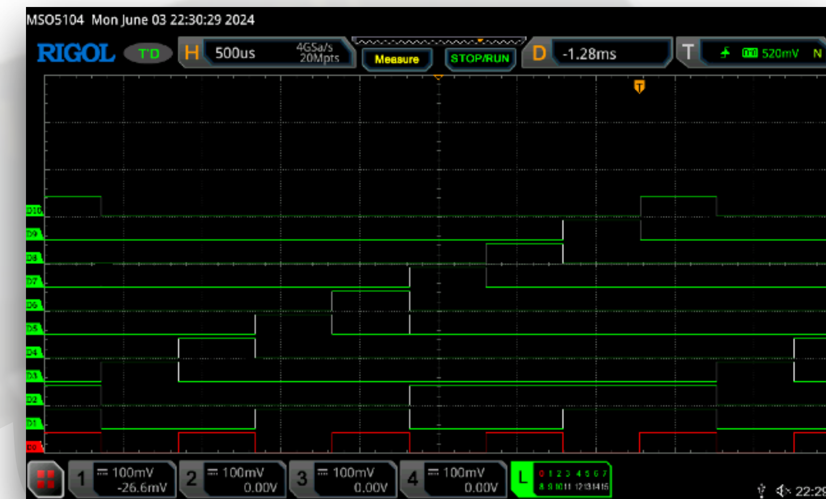
112 Eagle Digital/Analogue Schematic Page 3/11
113 Eagle Digital/Analogue Schematic Page 4/11

Character Position DAC[114]

The simplified description of how the clock works presented this diagram:



Now is the time to start positioning the beam to draw the characters. In this case we need to position the beam to the lower left point of each character in turn, shown by the **black** circles above.



IC20 is a 3-to-8 line decoder/ demultiplexer 74HCT238[115] IC. It takes the 3 bit CHR_CLK signals from the Master Clock, uses them as inputs (A0, A1 and A2) and decodes them into 8 mutually exclusive outputs (Y0 to Y7). As the Master Clock counts the CHR_CLK signals, one Y output goes high at a time.

Here, the CHR_CLK input bits are D0, D1 and D2. You can see them counting BCD 0 to 7. The outputs from IC20 are D3 for Y0 through to D10 for Y7. You can see each Y output going high in turn.

These high (+5V) signals are passed to a simple resistive DAC[116] with OPAMP IC19A acting as a summing amplifier. The resistor values are selected to produce linear steps of +0.5V at the OPAMP output.

DAC input bits	DAC output volts
0	0
1	+0.5
10	+1.0
11	+1.5
100	+2.0
101	+2.5
110	+3.0
111	+3.5

Resistor R4 provides negative bias so that the OPAMP output is ±1.75V.

C20 suppresses excessive overshoot or ringing[117] due to the input stray capacitance on the inverting input. These capacitors exist across many of the OPAMPs and have the same function – with one important exception which is looked at in the next section.

[114] Eagle Digital/Analogue Schematic Page 5/11
[115] https://assets.nexperia.com/documents/data-sheet/74HC_HCT238.pdf
[116] Digital to Analogue Converter - https://en.wikipedia.org/wiki/Digital-to-analog_converter
[117] https://e2e.ti.com/blogs_/archives/b/thesignal/posts/taming-the-oscillating-op-amp

IC19B inverts the output from IC19A so that a positive voltage will move the beam to the right on the CRT. Here D0, D1 and D2 again show the CHR_CLK data. The yellow analogue line shows the output from IC19B and shows the X character position staircase waveform.

IC19B is also a summing amplifier as it adds the MIN_B signal from the unit minutes divider. The summing input R10 has a high value selected so the beam only moves a small amount. The upshot is that every two minutes the whole image on the CRT will move slightly in the X direction – this is a phosphor anti-burn measure.[118]

The MIN_A signal is output directly (there is no Y DAC) via R16 (again a high value resistor) to the Y output so that every minute the whole image will move slightly in the Y direction. Over a 4 minute cycle the whole image will move through 4 directions, starting with the Left and Down position:

- Right (and remain Down)
- Left and Up
- Right (and remain Up)
- Left and Down

Lastly, a provision for X=0 is made by R7 even though it is not required. This is to allow for customisation of the clock.

[118] And a cunning one at that…

Triangle Wave Generator[119]

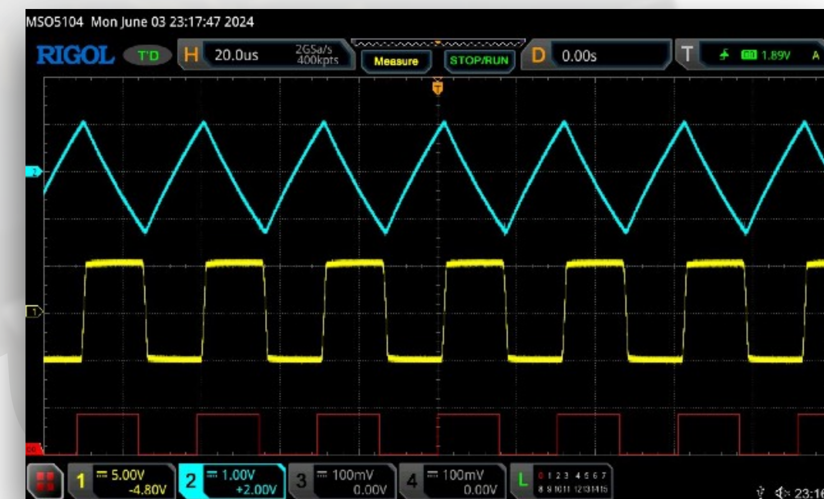
The prior simplified description said that a triangular wave was used to draw the individual lines making up a character. The 32768Hz signal from the Master Clock is a 0 to +5V square wave and this is converted into a triangle wave in two steps.

IC25B is a comparator[120], it compares the 0 – +5V signal with roughly +2.5V from the R47 and R51 potential divider. R48 provides some hysteresis.[121] The output from IC25B swings between the supply voltages, so has a square wave output of about ±5V.

The comparator square wave is passed to the OPAMP integrator[122] IC25A. R53 provides a consistent load. R46 is a feedback resistor to set the overall gain of the OPAMP. C44 is the integration capacitor. The output from IC25A is our required triangular wave.

Here[123] is an illustration of a self oscillating triangle wave generator. The Master Clock is used rather than a free-running oscillator so that the triangle wave remains in perfect synchronisation with the other Master Clock functions.

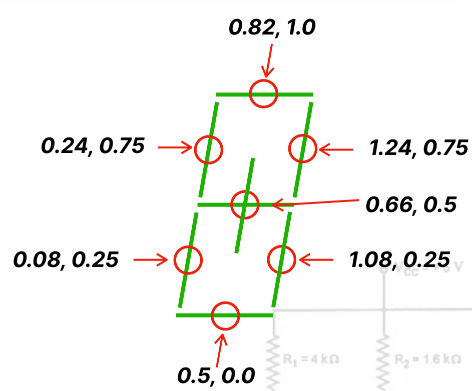
The red D0 is the 32.768kHz TRIANGLE_CLK signal from the Master Clock. Being a digital signal it varies 0 to 5V. The yellow analogue trace 1 is the output from the comparator IC25B. It varies -5V to +5V. Finally, the cyan analogue trace 2 is the output of the integrator IC25A. Not a perfect triangle wave but good enough for our purposes.



The triangle wave output is passed via C43 to remove any DC bias to two analogue switches IC24A and IC24D. How these operate is discussed below under Horizontal/Vertical line Selection.

Line Position X/Y DACs[124]

The simplified description of where the clock draws the lines is presented in this diagram:



It shows the X and Y voltages needed to position the beam at the centre point of each line. The character is drawn leaning slightly to the right..(also presented in the table on the next page).

[119] Eagle Digital/Analogue Schematic Page 6/11
[120] https://www.electronics-tutorials.ws/opamp/op-amp-comparator.html
[121] https://en.wikipedia.org/wiki/Hysteresis
[122] https://www.electronics-tutorials.ws/opamp/opamp_6.html https://en.wikipedia.org/wiki/Op_amp_integrator
[123] https://www.falstad.com/circuit/e-triangle.html
[124] Eagle Digital/Analogue Schematic Page 6/11

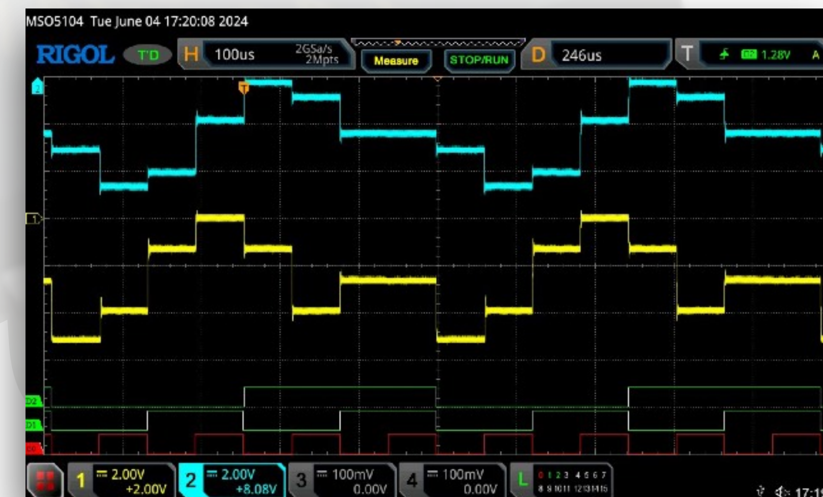
IC23 is another 74HCT238 3-to-8 decoder which decodes the BCD number from the Master Clock (3 bit SEGCLK signal). It is used in three ways:

- Y DAC
- X DAC
- Line orientation (horizontal or vertical)

DAC input bits	X DAC output volts	Y DAC output volts	Line drawn
0	0.82	1.00	a
1	1.24	0.75	b
10	1.08	0.25	c
11	0.50	0.00	d
100	0.08	0.25	e
101	0.24	0.75	f
110	0.66	0.50	g
111	0.66	0.50	h

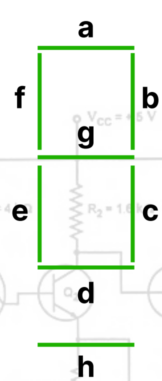
The Y DAC works in the same way as the character position DAC previously described. Each output Y0 to Y7 passes to a summing OPAMP IC22 via resistors selected to give the required DAC output voltages. This OPAMP output voltage will be the Y voltage (inverted). The gain of this OPAMP can be adjusted by R20 so that nice alignment of the lines can be achieved on the CRT face.

The X DAC uses summing amplifier IC21B with resistors selected to give the required DAC output voltages. This OPAMP output voltage will be the X voltage (inverted). The gain is adjusted by R33.



Two complete cycles of the line drawing DAC outputs are shown here. The red D0 signal is the Master Clock SEGCLK_A, D1 is SEGCLK_B and D2 is SEGCLK_C. You can see these 3 signals counting from 0 to 7 twice. The cyan analogue trace is the output from IC21B. This is the inverted X line drawing DAC output. The yellow analogue trace is the output from IC22A. This is the inverted Y line drawing DAC output. If you follow each trace you will see how the voltages change relatively (not forgetting that the signals are inverted). The table above was calculated for a +1.0V maximum DAC output. In practice the output is about +5V as shown by these traces. At this point we have positioned the CRT beam to the centre of each line. As described before, we sum the triangle wave to draw the line.

Horizontal/Vertical Line Selection and final Summation[125]



Line orientation is set using the diode matrix D25 to D32. A diode is fitted when the line to be drawn is horizontal i.e. lines ‘a’, ‘d’ and ‘g’ on a the 8 segment character (7 segment + 1):

Only Y0 ‘a’ (D32), Y3 ‘d’ (D29) Y6 ‘g’ (D26) are fitted normally. The output from these diodes is taken to the control pin of the analogue switch IC24D and inverted by Q1 to the control pin of switch IC24A. Therefore when the line is deemed (i.e. the diode is fitted) to

[125] Eagle Digital/Analogue Schematic Page 6/11

be horizontal IC24D switch is closed and when vertical, IC24A is closed. These two analogue switches forward the triangle wave to the summing OPAMPs IC21A and IC22B.

IC22B is the X line summing OPAMP. It sums the line X position from IC21B, the triangle wave from IC24D (when the line is horizontal) and from IC24A (when the line is vertical, to produce a sloping line, noting that R41 is a higher value than the other summing resistors). The output from IC22B is the line X waveform – a triangle wave with a DC offset.

IC21A is the Y line summing OPAMP. It sums the line Y position from IC22A, the triangle wave from IC24A (when the line is vertical). R27 is not fitted as horizontal lines have no slope. The output from IC21A is the line Y waveform – a triangle wave when the line is vertical with a DC offset.

The D0 to D2 traces still show the SEGCLK signals from the Master Clock. The cyan analogue trace now shows the X line DAC output (normal, not inverted) combined with the triangle wave to draw horizontal lines as needed. The yellow analogue trace now shows the Y DAC output combined with the triangle wave to draw vertical lines as needed.

To give one example, at the screen centre, the SEGCLK has a value of binary 000. This is the first line to draw, i.e. line ‘a’ on the 7 segment. You can see that the X voltage (cyan trace) is an offset triangle wave (incidentally, you can see two complete cycles of the triangle wave meaning that the line is actually drawn 4 times). The corresponding period for the Y voltage (yellow trace) is an offset line with no triangle wave component – this is because the line is horizontal.

One exercise is to work through each SEGCLK state from binary 000 to binary 111 and check that the X and Y signals are as expected for the 7 segment line to be drawn.[126]

Number and Colon Selector[127]

This schematic may look a bit daunting but it really is quite simple. It is the start of the line blanking process so that lines on an individual character are turned on or off as required.

The selection of a BCD number to draw is made using four 74LS251[128] data selectors/multiplexers IC26 to IC29. They select a 1-of-8 data inputs using a decoded 3 bit binary address. The binary address is the character clock (CHRCLK 3 bits) from the Master Clock. When this has a value of binary 000 the left most character, tens of hours is to be drawn, a value of binary 001 then units of hours is to be drawn, and so on to binary value 111 when units of seconds is required.

[126] Hint: they are… 😀

[127] Eagle Digital/Analogue Schematic Page 7/11

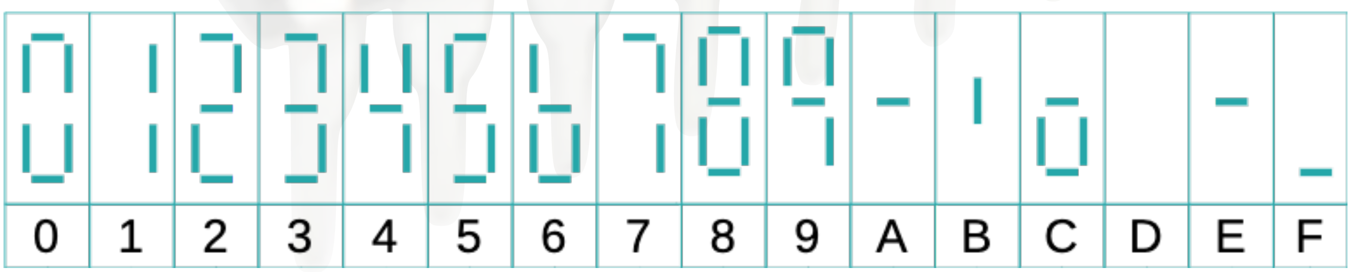
[128] https://www.ti.com/lit/ds/symlink/sn74ls251.pdf

IC29 is used to select the binary LSB A data from the timekeeping dividers. Six of its inputs (D0, D1, D3, D4, D6 and D7) select from HR10_A, HR_A, MIN_A, MIN10_A, MIN_A, SEC10_A and SEC_A. The other two data inputs (D2 and D5) are the colon characters and their use is discussed later. IC28 selects the B data from the clock sources in the same way. Then IC27 selects the C data noting that there is no HR10_C data from the timekeeping dividers so input D0 is grounded. Finally, IC26 selects the MSB D data. There is only HR_D, MIN_D and SEC_D data so the other timekeeping data inputs are again grounded.

The outputs from IC26 to IC29 are the BCD numbers from a timekeeping divider when the character clock (CHRCLK) is D0, D1, D3, D4, D6 and D7. The other two data inputs, D2 and D5 are for colon characters. The BCD numbers are decimal 0 (binary 0000) to decimal 9 (binary 1001). The next section shows how this BCD number is converted into a character image (a font) using a lookup table in an EEPROM. The BCD number has values decimal 10 (binary 1010, hexadecimal 0xA) to decimal 15 (binary 1111, hexadecimal 0xF) available. These output values are used to select colon characters from the font EEPROM.

IC26 has the D2 and D5 inputs tied high as the MSB D is always 1. IC27, C, and IC28, B have their D2 and D5 inputs selectable high or low using X3. This allows the selection of values decimal 8 (binary 1000), decimal 10 (binary 1010, hexadecimal 0xA), decimal 12 (binary 1100, hexadecimal 0xC) and decimal 14 (binary 1110, hexadecimal 0xE). This brings us back to the selection of colon characters using the BCD LSB A, IC29. The two data inputs D2 and D5 receive the signal from X1 (on the first schematic, the Master Clock). This jumper can select logic 0, logic 1 or 2Hz, 1Hz and 0.5Hz square waves. The local 0 or 1 are fixed values. The square waves alternate the BCD values, depending on the settings of X3, between decimal 8 and 9, decimal 10 and 11, decimal 12 and 13 or decimal 14 and 15. Having a colon that alternates between character 8 and character 9 is a *bit weird* and is deemed an *illegal* setting. The other number value pairs allow 3 different colon character pairs to be associated with each 0 to 9 font.

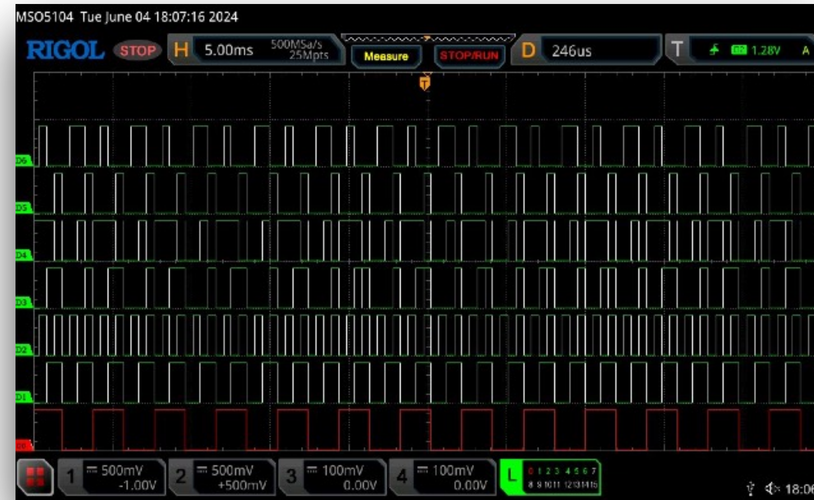
For example, the 16 font character might look like this;



Characters 0 to 9 are then numbers 0 to 9 as expected. The colons are A/B formed by alternating – and │, C/D formed by alternating ☐ and <blank>, and E/F formed by alternating – and _.

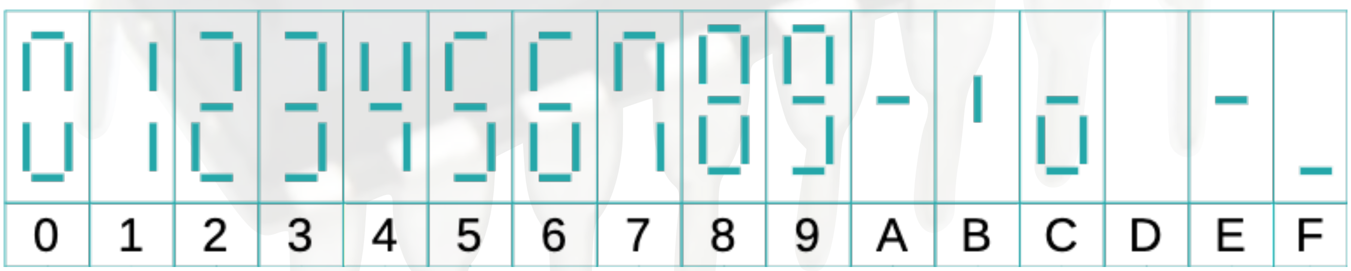
Designing and implementing fonts and colon characters is described in the customisation manual.

Shown here are the CHRCLK signals from the Master Clock on D0, D1 and D2. They select the character to be taken from the clock's time dividers by IC26 to IC29. D3 to D6 show the 4 bit binary data (ABCD) from these ICs. Because the time is changing and the colons are flashing this data is changing, so this image is just a static snapshot.

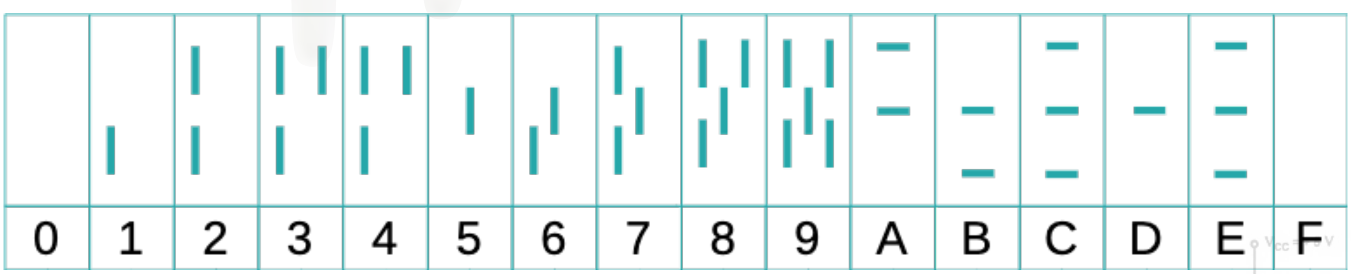


Font Storage and Line Drawing Selection[129]

The output from the number and colon selector is a 4 bit BCD value that represents the character number to display. This is converted into the lines needed to draw the character by EEPROM IC30. This EEPROM is typically a 28C64[130] although others can be used. These types of EEPROM come in 24 and 28 pin packages and both types can be accommodated by setting jumper X6. The font data in the EEPROM is accessed by setting address input A0 to A3 using the 4 bit BCD select value. Additional address lines (A4 to A9) can be used to select a different font. Comparing this font:



with the one above and you can see that number 6, 7 and 9 are embellished. Fonts can be quite obscure as well. This one uses a base 5 counting scheme[131] :



The jumper X4 selects the font to use and its 6 jumpers allow 64 fonts to be devised and stored[132]. Even so, this only uses a fraction of the storage in the EEPROM, most of which remains unused.

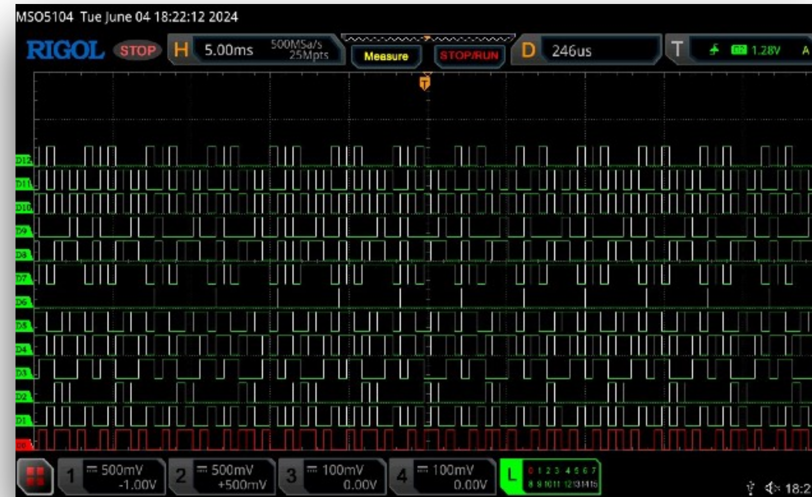
129 Eagle Digital/Analogue Schematic Page 8/11

130 https://ww1.microchip.com/downloads/en/DeviceDoc/doc0270.pdf

131 without explanation!

132 and by using an awful lot of imagination!

The data outputs from IC30 (D0 to D7) each correspond to a single line in the current character to be displayed. D0 is a 7 segment line ‘a’, D1 is line ‘b’ and so on. Logical 1 means the line should be shown and logical 0 means it should not be shown.



As described, the 4 bit binary from IC26 to 29 is then used to look up a character in the EEPROM. Here the ABCD select signals are shown on D0 to D3. The output from the EEPROM for a given input address is shown on D4 to D12. If you were to take the value of select address, take into account the font that has been selected on X4 then you will see the character entry present on the EEPROM data outputs. This is probably an exercise too far!

Again as the characters being shown are changing, this oscilloscope view is changing as well and again is just a snapshot.

The line to be shown is selected using IC31, another 74LS251 1-of-8 data selector using the decoded address from the Master Clock line segment clock (SEGCLK). The single data bit is buffered by IC5A. A logical 1 means unblank the beam. X5 allows the polarity of the signal to be reversed if alternative blanking/unblanking hardware requires it. Finally, an unblanking signal can only be sent when IC31 G input is high. This is discussed below under artifact suppression.

Spurious CRT Artifact Suppression[133]

The falling edge on the output Q_A of IC2A in the Master Clock, SEGMENT_START, signals that a new line should be drawn. The Master Clock SEGCLK and CHRCLK outputs select the line and character to draw, the outputs from the X and Y DACs must be set correctly and finally, the deflection amplifiers must move the beam to its new start location. All of these actions take time. If the beam is unblanked too quickly then the movement of the beam can become visible as a faint line on the CRT[134].

The $\bar{Q}$ output of IC32B, a 74LS123[135] re-triggerable monostable multivibrator, is normally low which means that the unblanking signal from the line selector IC31 is set to unblanked. The falling edge on the Q_A output of IC2A is fed to the A input of IC32A triggering the timing operation. After about 3μS the $\bar{Q}$ output rises triggering the timer IC32B. This delay period allows the DAC outputs to settle and the beam to slew to its new position. The $\bar{Q}$ output of IC32B goes high allowing the beam to be unblanked if the line is to be drawn according to the font selected. After another 57μS the $\bar{Q}$ output of IC32B again goes low. This period allows the line to appear but the beam is then turned off ahead of the next falling edge on the Q_A output of IC2A. These two timers suppress any CRT drawing artifacts.

133 Eagle Digital/Analogue Schematic Page 8/11
134 Some people like these artifacts but I don’t and so the clock contains hardware to suppress them.
135 https://www.ti.com/lit/ds/symlink/sn74ls122.pdf; https://www.ti.com/lit/an/sdla006a/sdla006a.pdf

Here D0 shows the SEGMENT_START signal from the Master Clock. About ¼ of the way across this image, this signal falls to zero which is the signal for a new line to be drawn and is the trigger for the artifact suppression timers. D1 is the $\bar{Q}$ output of the first timer, IC32A. At this time the $\bar{Q}$ output of IC32B is high meaning the beam should not be unblanked.

When triggered by the input falling edge, the output of IC32A rises to 1 and the timer period is started. After about 3µS the output falls back to 0. This falling edge triggers the second timer IC32B and its $\bar{Q}$ output, shown by D2, falls to 0. This low signal means the beam can be unblanked. It remains low for about 57µS to about 1µS before the next falling edge on SEGMENT_START is expected. The upshot of this is that the $\bar{Q}$ output remains high, meaning that the beam should be kept blanked during the period when artifacts can appear.

PIR Sensor and Clock Shutdown Timer[136]

The clock uses a PIR (Z1)[137] to monitor room occupancy and a timer to shut down the CRT after an elapsed period of inactivity. The PIR is a 3.3V part so a small linear regulator[138] is provided to supply it. When the PIR senses movement its output pin voltage rises. This has two effects, the first is to turn on a LED to show that the PIR has been "hit"; the LED is buffered by IC4F. The second effect is to turn on the MOSFET Q4. This brings the base of the PNP transistor Q2 down to ground which turns it on. C59 is charged via Q2, R69 and D33. When the PIR is not sensing movement, C59 is slowly discharged[139] through Q3 and R71. When C59 is charged and the voltage on the input of the 555 timer is high, the 555 timer's output is low. The output is inverted by gate IC5D; the output from this gate has two effects, the first is to turn on a LED to show that the CRT is "on"; the LED is buffered by IC4E. The second effect is to send a power supply on signal to the PSU & CRT board to turn on the HT/-EHT and heater power supplies. When the voltage on the inputs of the 555 fall to ⅓ of the supply voltage, about 1.7V, the 555 output goes high. This turns off the LED, the HT/-EHT PSU and the heater PSU. The clock stays in this condition until the PIR is hit and the cycle starts again.

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136 Eagle Digital/Analogue Schematic Page 9/11
137 https://industrial.panasonic.com/sa/products/pt/papirs/models/EKMC1601112
138 https://en.wikipedia.org/wiki/Linear_regulator
139 with values shown the timer runs for about 25 minutes..

D0 is connected to the output of the PIR, D1 is connected to the output of gate IC5D which is the flyback and Royer power supply 'on' signal. The analogue trace is the voltage on the timing capacitor C59. Note that the sweep time is 200S/div.

At the start of the experiment C59 is fully discharged and so the output from IC5D on D1 is low meaning that power supplies are off. A few hand-waves in front of the PIR and things change. The PIR output on D0 shows a few lines as the PIR sees the waving hand, C59 is charged and the analogue signal goes up. The output of IC5D on D1 goes high and the power supplies will have now started. The voltage across the C59 now starts to decay (the PIR was covered to prevent accidental triggering simulating an unoccupied room). The 555 follows this decaying voltage and then, as set by its design, the output from it changes state. The output from IC5D on D1 goes low, turning off the power supplies.

<u>Clock Time Adjustment</u>[140]

The clock has three buttons to set the time. Button S1 advances the hours at the rate of 1 hour per second when pressed. Normal operation is when switch S1 is open, C64 is charged via R73 and D36. The output of the Schmitt-trigger inverter 74LS14[141] IC5E is low. The low signal enables the bus buffer 74LS125[142] IC35A MIN10_C output from the minutes divider to pass forward to the hours divider. Q5 inverts the output of IC5E and the high signal disables the bus buffer IC35B. When the button S1 is pressed C64 is discharged via R74. The discharge period acts to debounce any jitter as the contacts of S1 close. The Schmitt-trigger provides a sharp output transition from low to high. Now IC35A is disabled and IC35B is enabled. This allows a 1Hz signal to pass from the Master Clock to the hour divider.

Button S2 operates in the same way as S1, using IC5F, Q6, IC35C and IC35D to pass the SEC10_C output from the seconds divider or the 1Hz signal to pass from the Master Clock to the minutes divider.

Button S3 operates differently, when closed it turns on Q7 and Q8 and these clear the tens of seconds and units of seconds dividers[143]. Resistors R1 and R2 prevent excess current flow out of IC6A and IC6B.

How to set the time on the clock is described in the clock testing section.

[140] Eagle Digital/Analogue Schematic Page 10/11
[141] https://www.ti.com/lit/ds/symlink/sn54ls14-sp.pdf
[142] https://www.ti.com/lit/ds/symlink/sn74ls125a.pdf
[143] Eagle Digital/Analogue Schematic Page 2/11

Board Inter-connectors[144]

The inter-board connectors mirror the ones on the PSU & CRT board:

Two 2 x 10 male headers provide connections to the PSU & CRT board. Header X7 carries the digital connections:

- Power inputs:
  - +5V/2
  - +5V/1
  - +5V
  - Ground

- Digital signals outputs:
  - Unblanking
  - Flyback and Royer On

Header X8 carries the analogue connections:

- Power inputs:
  - +5VA
  - -5VA
  - Analogue ground

- Analogue signal outputs:
  - X direction – channel 1
  - X direction – channel 2
  - Y direction – channel 1
  - Y direction – channel 2

[144] Eagle Digital/Analogue Schematic Page 11/11

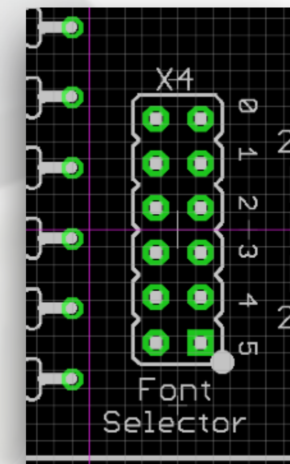
Scope Clock TTL – Setting The Jumpers

The clock display can be customised in a number of ways by changing jumpers on the digital and analogue board:

- The character font selected.
- The colon shape selected.
- Colon "flash" speed.
- 12/24 hour operation.

If you have bought a built and tested clock then these jumpers allow you to select what you want. You can experiment with the various jumper settings to operate the clock as you wish. If you are building the kit then you will need to set these jumper positions, again to select what you want.

Character Font Selection



The character font selection is made using the jumper header X4 on the Digital & Analogue Board:

The default font is Font Number 0 selected by fitting all 6 jumpers.

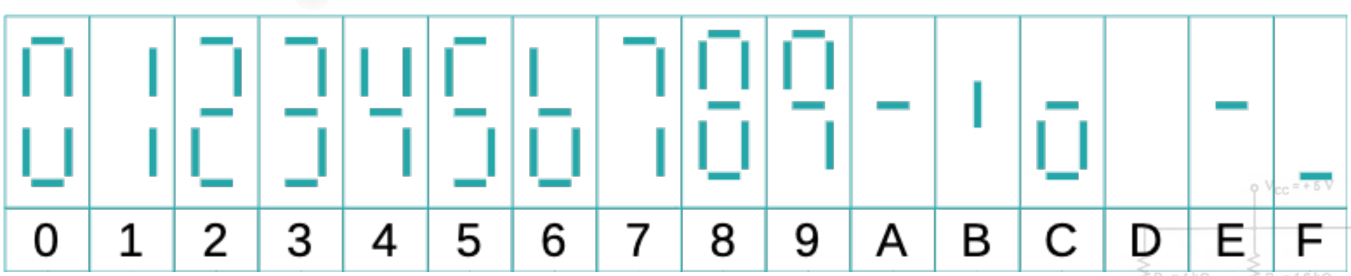
Note: At this time only fonts numbers 0..15 are available and therefore Jumpers 4 and 5 are unused. However, they must be fitted for correct operation i.e. always fit jumpers 4 and 5.

The available lines in the standard kit are as follows.[145]

In the standard kit font, the vertical centred line, which is not part of an ordinary 7 segment character is used to generate colon characters and is used in some of the more *unusual* fonts.

Font 0 – Ordinary 7 segment display with no embellishments

The colons are A/B formed by alternating – and │, C/D formed by alternating ☐ and <blank>, and E/F formed by alternating – and __

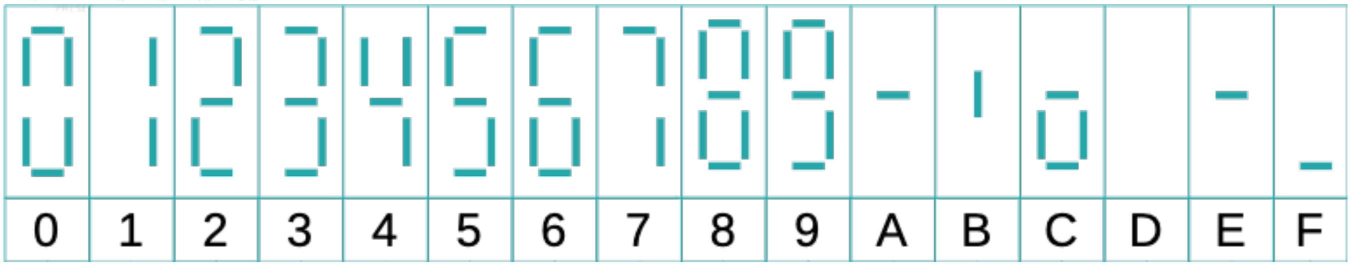


From this example you can see how the numerical characters 0 to 9 are formed and then the 3 pairs making up the colon selection for use with these numerical characters.

[145] ..and the vertical lines *lean* to the right

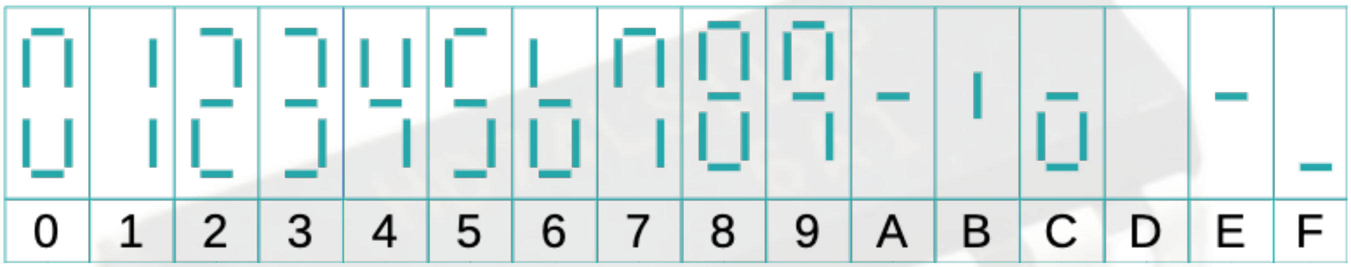
Font 1 – Ordinary display with 6 and 9 embellished

Additional lines are added to the number 6 and 9. Colons unchanged.



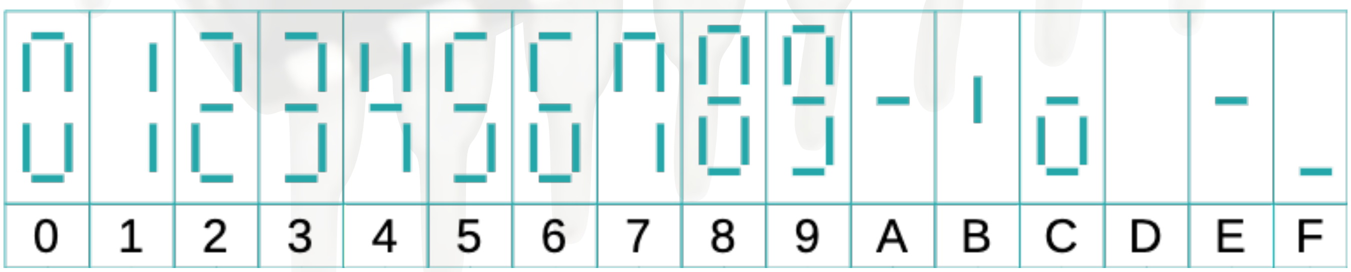
Font 2 – Ordinary display with 7 embellished

Additional line added to 7. Colons unchanged.



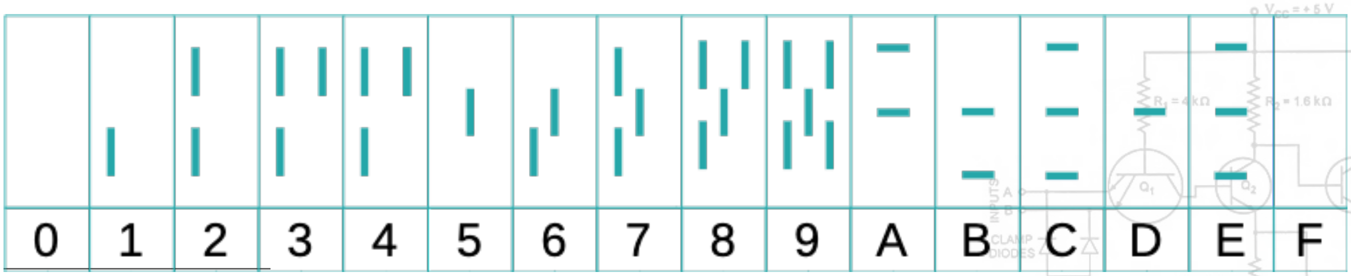
Font 3 – Embellishments added to 6, 7 and 9[146]

Fonts 1 and 2 combined. Colons unchanged.



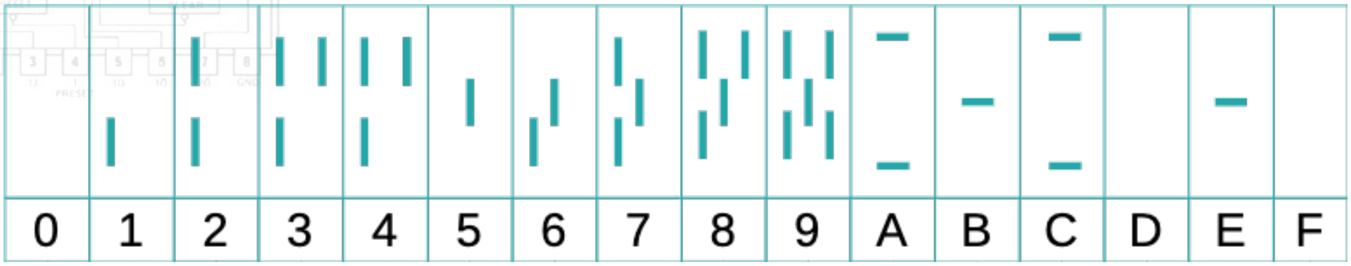
Font 4 – Base 5 Counting

The outer 4 vertical lines are worth 1 each, the centre vertical line is worth 10 in base 5 (decimal 5). Therefore, adding the values together gives 0 to 14 in base 5 (decimal 0 to 9). The colon characters use the horizontal lines.



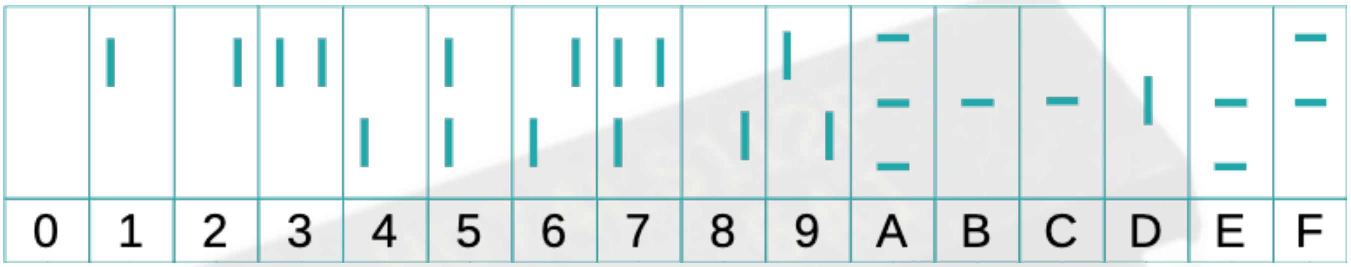
[146] ..my favourite.

Font 5 – As Font 4 but with different colons

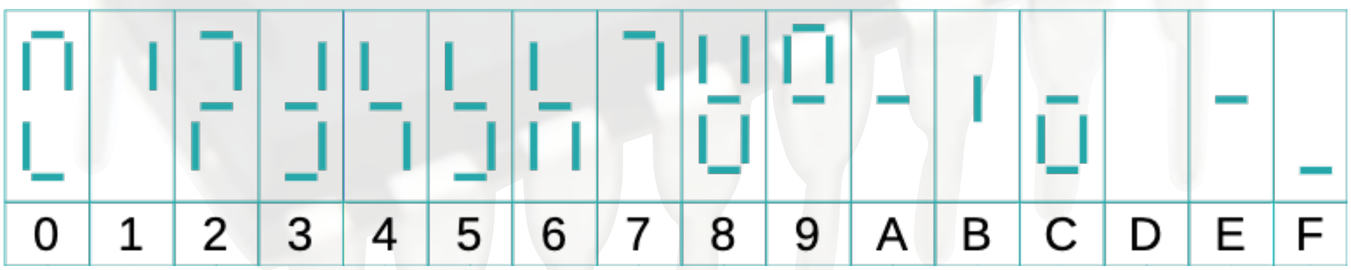


Font 6 – Binary Counting

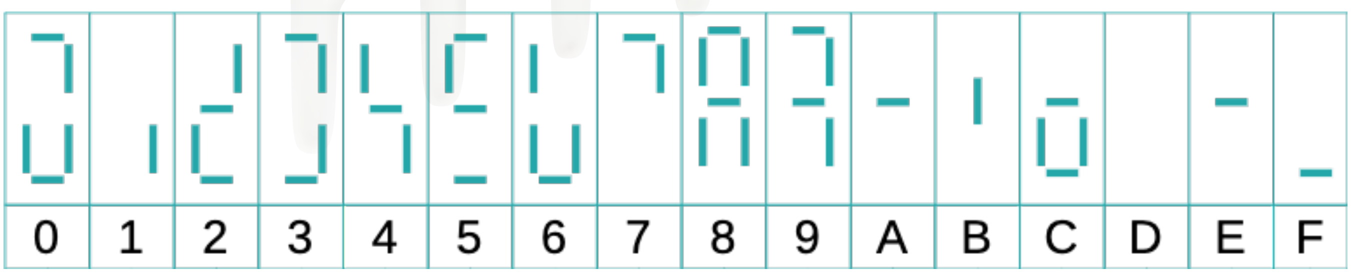
The top left vertical bar is worth 1, the lower left 2, the upper right 4 and the lower right 8. For example, number 7 is made up of 1, 2 and 4. The colon characters use the horizontal lines (same as font 4).



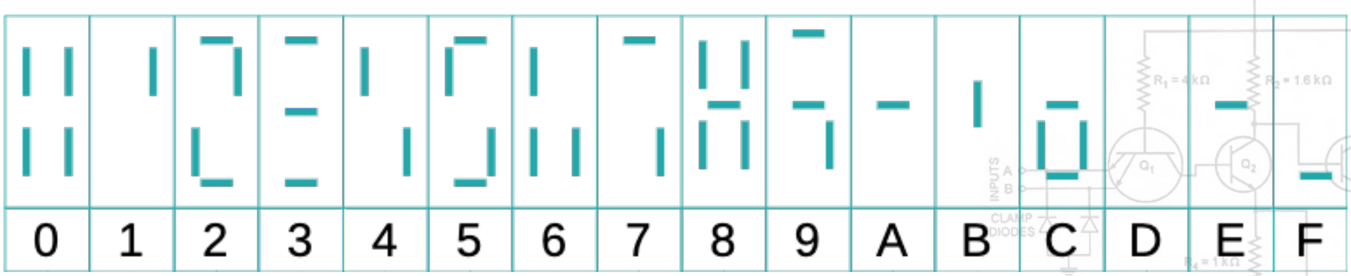
Font 7 – As font 0 but with 1 line removed in each characters



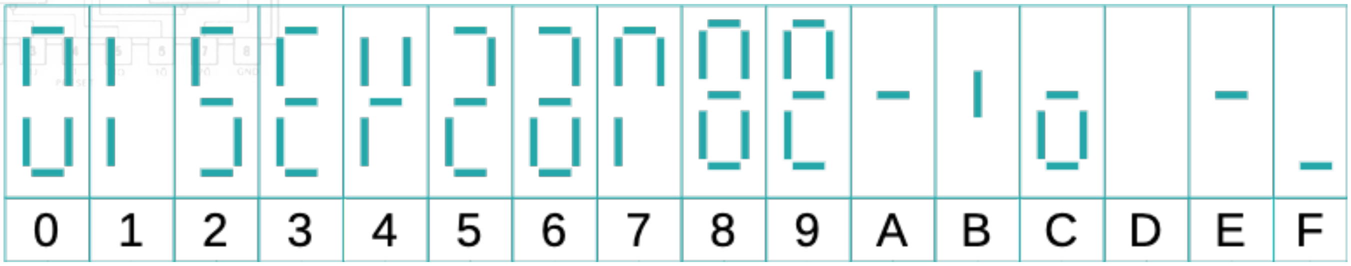
Font 8 – Another missing line font



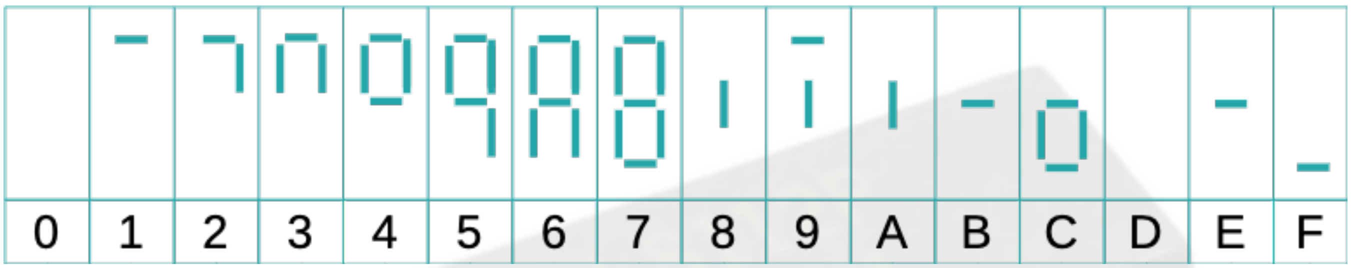
Font 9 – More missing lines



Font 10 – Font 3 Mirrored horizontally

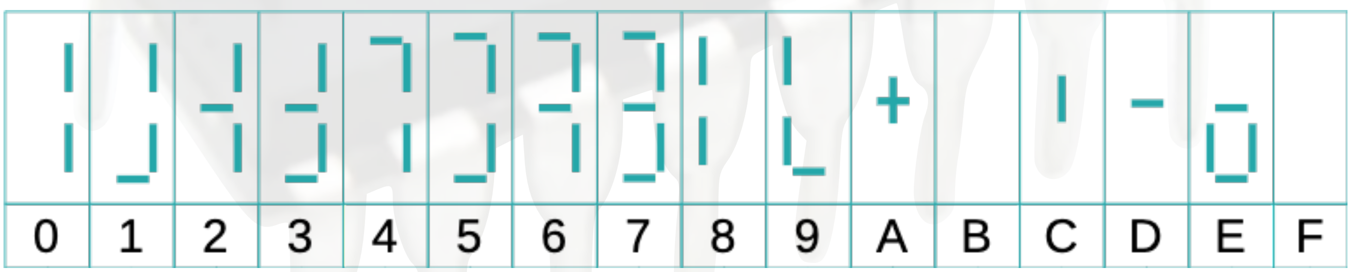


Font 11 – Octal Base 8 Counting

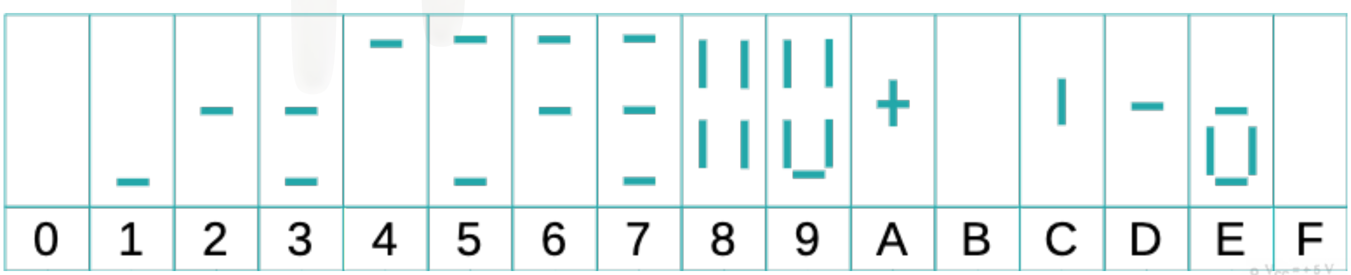


Font 12 – Hexadecimal Counting

I'm not going to even try to explain how these fonts work… Instead read this (http://ijcset.com/docs/IJCSET17-08-06-027.pdf).



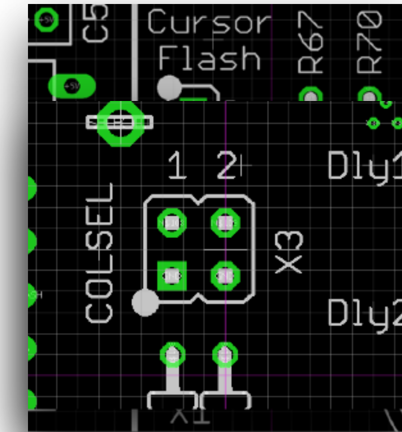
Font 13 – Another Hexadecimal Font



Font 14 – Slot Unused

Font 15 – Slot Unused

Colon Shape Selection



Each font (see jumper X4 below) has three cursor on/off pairs of characters, six characters (0x0a to 0x0f) in total. You can select the character pair to use using these jumpers. It is a 2x2 male header with 2 removable jumpers. The default state is to leave both jumpers open.

Jumper 1	Jumper 2	Cursor ON Character	Cursor OFF Character
Fit	Fit	An illegal state	
Open	Fit	0x0a	0x0b
Fit	Open	0x0c	0x0d
Open	Open	0x0e	0x0f

Note

1. No harm will occur to the clock if both jumpers are fitted but the colons will become the characters 8 and 9 which is probably not what you would want, but we're not judging…

Colon Flash Speed

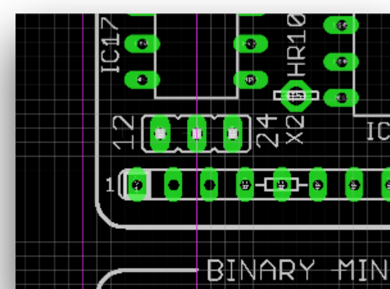
The colon shape selected consists of three pairs of characters in the EEPROM selected using jumper X3 (see above). These characters are alternated. The character pairs are called A/B, C/D and E/F. Characters A, C and E are the "on" characters and B, D and F are the "off" characters.

Jumper X1 selects the speed with which the colon separators on the display will alternate or "flash":

- On – the colons are "on" but don't flash.
- Off – the colons remain "off".
- 2Hz – the colons flash on-off-on-off each second.[147]
- 1Hz – the colons flash on-off each second.
- 0.5Hz – it takes 2 seconds to complete the on-off cycle.

The flashing colons have a 50:50 duty cycle. What character is "on" and what character, if any, is "off" is set in the font data in IC30. If unsure set to 1Hz.

12/24 Hour Clock Operation



Jumper X2 is used to select between a 12 hour display (hours show as 01 to 12) and a 24 hour display (hours show as 00 to 23):

- Linking 12 – Centre pin will select 12 hour operation.
- Linking 24 – Centre pin will select 24 hour operation.

Fit according to taste.

147 The designer's personal favourite…

Scope Clock TTL – Board Assembly and Testing

The clock has two PCBs to assemble, in order:

- Power Supply & CRT Driver Board
- Digital & Analogue Board

There is an optional battery backup board available. This requires a slightly taller horizontal case (or deeper vertical case) to make room for the board, so two case designs are available for each CRT orientation. The battery backup board has its own manual.

There are no SMD parts to fit![148]

As a general rule of thumb, it is preferable to solder components in the order of smallest to largest, unless otherwise noted in the instructions. This is by no means a beginners electronics kit!! There are also high voltages involved, so if you are not comfortable following these instructions please contact us to either return the kit for a full refund (minus shipping costs), or discuss purchasing a fully built unit. If you have any questions, then please don't hesitate to contact us.[149]

This clock construction guide includes staged testing instructions. It is not a good idea just to build the whole clock, and with no intermediate testing, just plug it in and hope that it works. To carry out staged testing you will **need a reasonable quality multimeter**. To carry out fault finding on the digital and analogue board you will **need a reasonable quality oscilloscope**.

Tools and Hardware Required

- Flat blade screw driver
- Soldering iron
- Pliers
- Side cutters
- Wire strippers
- Hot air gun (for heat shrink tubing)
- Heat shrink tubing, cable ties[150]
- Solder
- Glue (UV cured, two part epoxy or superglue)
- Connecting wire[151]
- A multimeter for construction, testing and fault finding
- Patience[152]

Optionally

- An (aforementioned) oscilloscope for fault finding
- A 2-channel function generator for advanced testing (really, optional)

---

[148] Yippee!
[149] http://www.sgitheach.org.uk/contact.html or stocksclocks@gmail.com
[150] A selection is included in the case kit
[151] A selection of appropriate wire is included in the case kit
[152] Alas, in short supply these days…

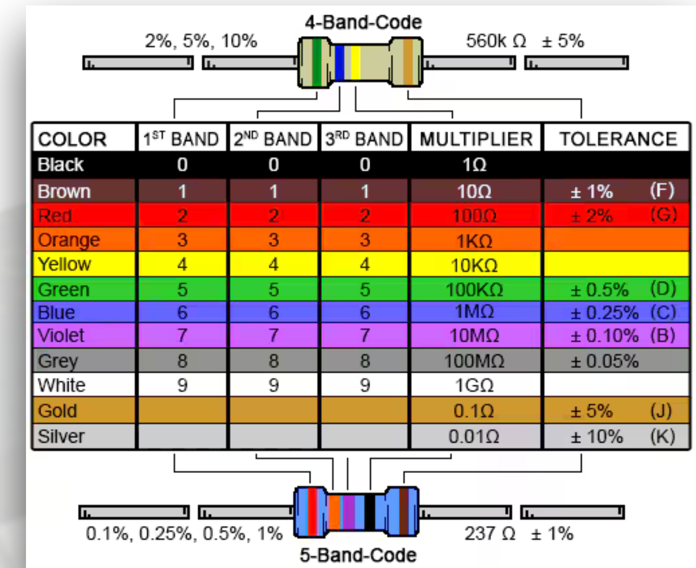
A Word about the Inter-Board Connectors

The two boards are designed to mount back-to-back and connect using two 2x10 way connectors on each board. These connectors MUST be mounted on the reverse, non-component side of the boards.[153]

A Word about Resistor Colour Codes

The clock uses a large number of metal film 1% tolerance resistors from the E96 series[154]. These resistors have 5 colour code bands. Here's a quick reminder about resistor colour codes for the 4 band 5% and the 5 band 1% resistors used.[155]

If in doubt about a resistor value then use a multimeter to check the value. In fact, even if you can read the resistor code, *measure it with a multimeter anyway*. Needless to say, if you fit an incorrect value resistor then the clock will not operate correctly and damage to the clock may occur. Tracking any incorrect resistor is RRPITA.[156]



COLOR	1ST BAND	2ND BAND	3RD BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8	100MΩ	± 0.05%
White	9	9	9	1GΩ	
Gold				0.1Ω	± 5% (J)
Silver				0.01Ω	± 10% (K)

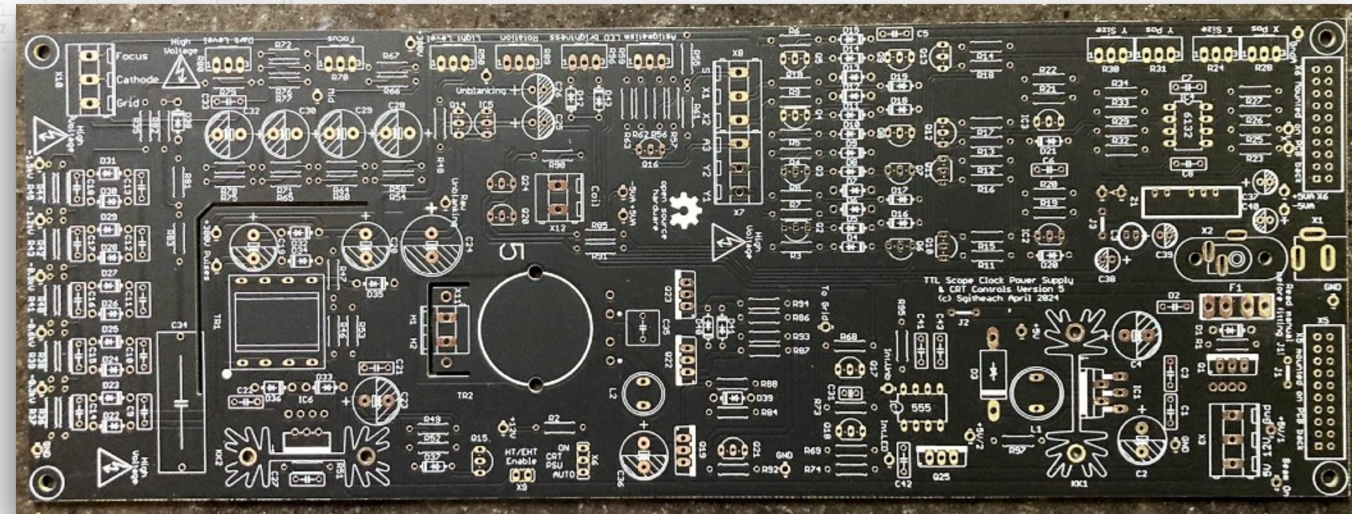
A Word about Parts Lists/Supplied Components

Whilst the parts list specifies LS parts and one HCT part, many other TTL ICs will operate fine in the SC-TTL. A packing note with the kit will tell you if a substitution has been made. All substitutions will have been fully tested and have generally been made due to the unavailability of the LS part or on cost grounds. Similarly the voltage rating of electrolytic capacitors may be different to the parts list. For example, the part rating might be for a 10V capacitor but a 16V capacitor is supplied.

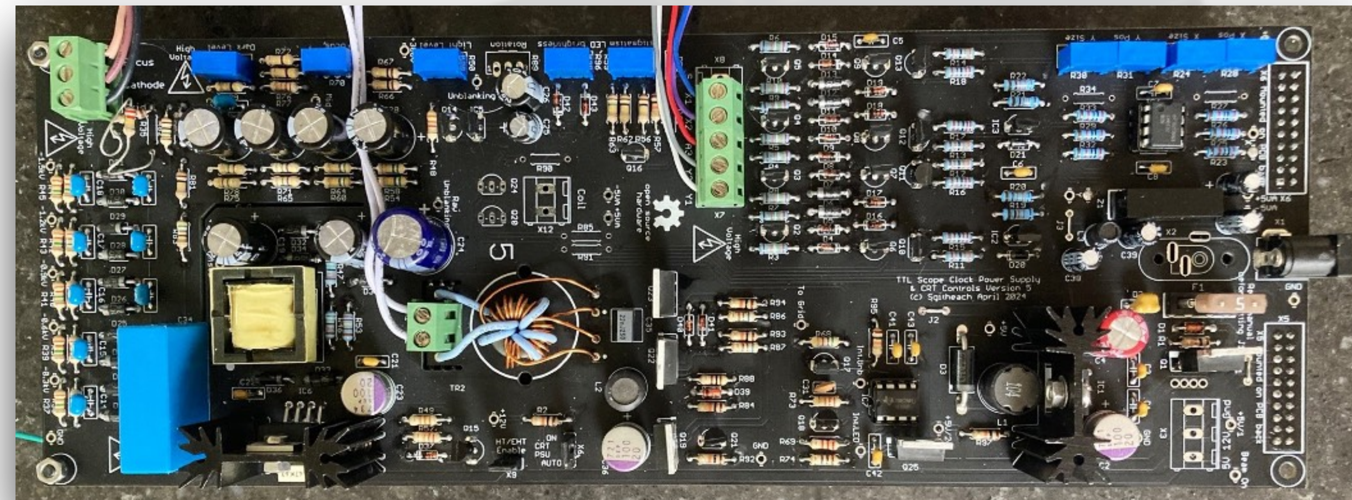
Right ladies and gentlemen, fire up your soldering irons please!

[153] They are a nightmare to remove and resolder, so get it right first time!
[154] https://www.electronicsplanet.ch/en/resistor/e96-series.php
[155] https://www.digikey.com/en/resources/conversion-calculators/conversion-calculator-resistor-color-code
[156] Right royal pain in the….

Power Supply & CRT Board Assembly



The unpopulated PSU PCB



A completed PSU PCB - Note DC power socket for horizontal case

Errata[157]

On the reverse and component sides of the board the silkscreen references to component number “X5” should be “X4” and “X6” should be “X5”. Both are 2x10 female headers mounted on the reverse side of the board.

[157] It doesn’t matter how much checking and re-checking is done, there’s always *something*….

Parts List[158]

Check that these parts are present in the Power Supply kit bag and tick them off. If there are any missing components then please notify us so they can be supplied. You should also do the same for the CRT board kit too (see here in the manual).[159] An alternative parts list organized in component size order can be found at the end of the document here.

Tick	Quantity	Part Number	Value	Component
☐	11	C1, C3, C5, C6, C7, C8, C21, C22, C41, C42, C43	100n	ceramic
☐	3	C2, C23, C36	100μ 20V	electrolytic (Al polymer)
☐	1	C4	1000μ 10V	electrolytic
☐	11	C9, C10, C11, C12, C13, C14, C15, C16, C17, C18, C33	47n 500V	ceramic
☐	2	C19, C20	4μ7 400V	electrolytic
☐	1	C24	220μ 100V	electrolytic
☐	1	C25	1μ 100V	electrolytic
☐	1	C26	10μ 100V	electrolytic
☐	1	C27	470n	ceramic
☐	4	C28, C29, C30, C32	4μ7 450V	electrolytic
☐	1	C31	47p	ceramic
☐	1	C34	47n 1.6kV	film
☐	1	C35	22n 250V	low DF film
☐	4	C37, C38, C39, C40	4μ7 16V	electrolytic
☐	2	D1, D39	1N4742	12V 1W Zener
☐	1	D2	CG21AS26F105MR	TVS
☐	1	D3	1N5822	diode
☐	17	D4, D5, D8, D9, D10, D11, D14, D15, D16, D17, D18, D19, D37, D40, D41, D42, D43	1N4148	diode
☐	19	D6, D7, D12, D13, D22, D23, D24, D25, D26, D27, D28, D29, D30, D31, D32, D34, D35, D36, D38	UF4007	diode
☐	2	D20, D21	1N457	diode
☐	1	D33	P6KE18A	TVS
☐	1	F1	5A	fuse
☐	1	F1	Mini blade holder	fuse holder
☐	1	IC1	LM2576-5	IC
☐	2	IC2, IC3	LM234Z	IC
☐	1	IC4	LM6132	IC

[158] This Parts List is also available as a spreadsheet to assist component ordering if you are not using a kit
[159] We try to accurately make up the kits but sadly errors do occur

Tick	Quantity	Part Number	Value	Component
☐	2	IC4, IC7	DIL08 socket	IC
☐	1	IC5	LR8	IC
☐	1	IC6	LM2588-ADJ	IC
☐	1	IC7	NE555	IC
☐	2	KK1, KK2	SK104 25mm	heat sink
☐	2	M3 bolt, washer, nut		hardware
☐	1	L1	100µH 2.1A	inductor
☐	1	L2	47µH 1.5A	inductor
☐	1	L3	6µ8H 0.1A	inductor
☐	1	Q1, Q19, Q25	IRF9540	P MOSFET
☐	10	Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q14, Q16	ZTX658	NPN BJT
☐	4	Q10, Q11, Q12, Q13	MPSA06	NPN BJT
☐	3	Q15, Q18, Q21	2N7000	N MOSFET
☐	1	Q17	BS107P	N MOSFET
☐	2	Q22, Q23	IRFZ24	N MOSFET
☐	10	R1, R2, R35, R57, R84, R92, R93, R94, R95, R97	10k	5% carbon film
☐	8	R3, R4, R5, R6, R7, R8, R9, R10	249k	1% metal film
☐	4	R11, R12, R13, R14	330k	1% metal film
☐	4	R15, R16, R17, R18	2k20	1% metal film
☐	2	R19, R21	133R	1% metal film
☐	2	R20, R22	1k33	1% metal film
☐	6	R23, R25, R26, R29, R32, R33	20k0	1% metal film
☐	4	R24, R28, R30, R31	10k	trim pot
☐	10	R36, R37, R38, R39, R40, R41, R42, R43, R44, R45	3M3	5% carbon film
☐	2	R46, R47	150k	1% metal film
☐	1	R48	3k9	5% carbon film
☐	1	R49	33k	5% carbon film
☐	1	R50	200k	trim pot
☐	1	R51	3k3	5% carbon film
☐	2	R52, R73	22k	5% carbon film
☐	1	R53	1k24	1% metal film
☐	3	R56, R62, R81	100k	5% carbon film
☐	1	R59	500k	trim pot
☐	1	R63	150k	5% carbon film

Tick	Quantity	Part Number	Value	Component
☐	1	R68	5k6	5% carbon film
☐	1	R69	2k2	5% carbon film
☐	1	R74	10R	5% carbon film
☐	1	R82	1M	5% carbon film
☐	1	R83	560R	5% carbon film
☐	2	R86, R87	680R	5% carbon film
☐	1	R88	100R	5% carbon film
☐	1	R96	100k	trim pot
☐	1	TR1	Flyback Transformer	CC7306
☐	1	TR2	Royer Transformer	Ferrite Core
☐	1	TR2	Primary	0.7mm enamelled wire
☐	1	TR2	Secondary	EHT wire
☐	2	X7, X10	3 way screw terminal	
☐	2	X4, X5	Female 2x10 Header	
☐	1	X6	Male 1x3 pin header	
☐	1	X9	Male 1x2 pin header	
☐	2	X6, X9	Jumpers	
☐	2	X11, X12	2 way screw terminal	
☐	1	Z1	DC DC Converter	

Notes

1. Only one of X1 or X2 is normally fitted. Which is supplied depend on the case orientation – see below
2. X4 and X5 mount on the back of the board
3. The board has many test points. Optionally you can fit test point loops which give a good connection point for oscilloscope leads etc. Typically these look like this[160] and come in several colours so you can colour code the test point functions. They are not supplied in the standard kit but can be bought from component stockists, ebay etc.

The components not fitted by default are:

- R27, R34, R55, R61, R85, R89, R90, R91
- Q20, Q24
- X12
- Test point loops

[160] https://cpc.farnell.com/multicomp/test-1-r/test-pin-pcb-red/dp/PC02379

Horizontal Case Board Components

If you intend to use a horizontal case then the following are supplied

Tick	Quantity	Part Number	Component
☐	1	X1	Power jack

Vertical Case Board Components

If you intend to use a vertical case then the following are supplied

Tick	Quantity	Part Number	Component
☐	1	X2	Power jack
☐	2	M2x10mm screw, washer and nut	

Standard Kit Components for a 3SP1[161] CRT

This list is the parts used specifically by a 3SP1 CRT:

Tick	Quantity	Part Number	Value	Component
☐	4	R54, R58, R60, R64	560k	5% carbon film
☐	4	R65, R71, R75, R78	4M7	5% carbon film
☐	2	R66, R67	100k	5% carbon film
☐	1	R70	1M	trim pot
☐	3	R72, R76, R79	470k	5% carbon film
☐	1	R80	500k	trim pot
☐	1	V1	3SP1 CRT	
☐			CRT socket	B12-43
☐			HT & EHT wire	
☐	1	X8	2 way screw terminal	

X8 is mounted so that the X1 and X2 CRT connections can be made and the S connection is left empty. R55 and R61 are not fitted. Board to socket wiring is described below. The 3SP1 CRT data sheet is in Annex A.

[161] A separate manual covers other CRTs that can be used with the clock

5V Back Up Battery Board[162]

The backup battery board is not part of a standard kit and has its own manual. If used then the following parts are required on the Power Supply and CRT Board:

Tick	Quantity	Part Number	Component
☐	1	X3	3 way screw terminal

Trace Rotation Coil

If the CRT you are using has a trace rotation coil then fit the following components (not included in a standard kit):

Tick	Quantity	Part Number	Value	Component
☐	1	Q20	MPSA06	NPN BJT
☐	1	Q24	MPSA56	PNP BJT
☐	2	R85, R91	100R	5% carbon film
☐	1	R89	10k	trim pot
☐	1	R90	330R	5% carbon film
☐	1	X12	2 way screw terminal	

CRTs that have a Screen Electrode connection

X8 is a 2 way screw connector in the standard kit as the 3SP1 CRT does not have a screen electrode connection. Additionally, R55 and R61 are omitted. If the CRT in use has a screen connection then the following parts are used:

Tick	Quantity	Part Number	Value	Component
☐	2	R55, R61	CRT dependent	5% carbon film
☐	1	X8	3 way screw terminal	

TR1 Orientation

The flyback transformer, TR1, is fitted so the part number writing on one side is on the same side as the flyback IC.

[162] http://www.sgitheach.org.uk/batterybu.html

Winding TR2 (Royer)

The Royer oscillator transformer is very easy to wind so don't be daunted by it. This is the list of parts used to wind the transformer.

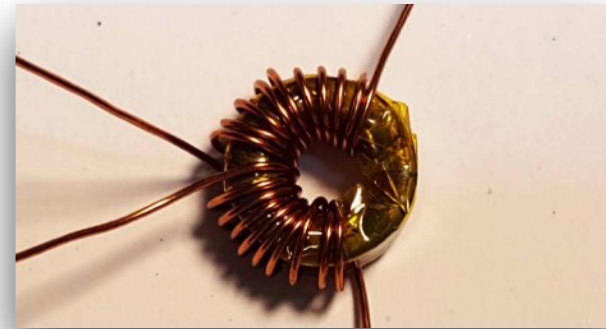
Tick	Quantity	Part Number	Component
☐	2	TR2	250mm length 0.7mm enamelled copper wire
☐	1		250mm EHT insulated wire
☐	1		Amidon FT-50-77 ferrite toroid core
☐	1		Small cable tie

- *Optional* - wind a layer of Kapton[163] tape over the core. If you do not use tape then take care to not wind tightly or allow the enamel to be scratched by the core. This can create a short between the winding and the core.
- Take a 250mm length of enamelled copper wire and wind 10 turns on to the core.
- Keep a mental note of the winding starting wire.
- Try to keep the windings neat, they don't have to be super tight.
- Do not allow the wire to kink as you wind the turns.
- The wire should be nearly all used after completing 10 turns.
- Using a multimeter, check for continuity between the core (which is conductive) and the winding. If there is continuity then go back to the first step above.

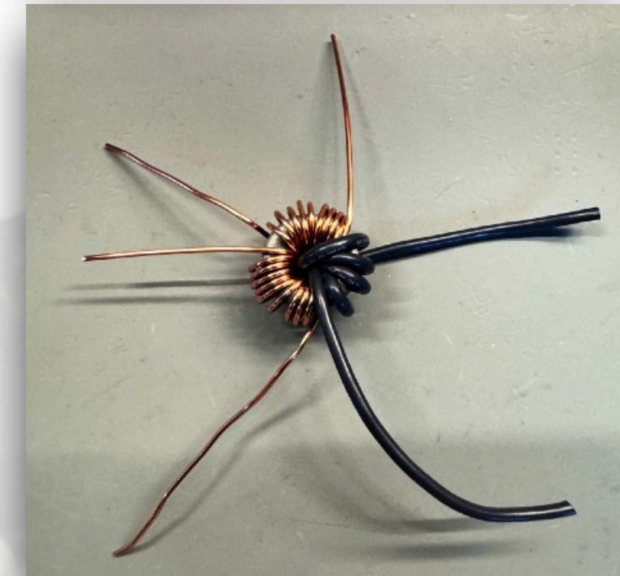
- Take the second length of enamelled copper wire and, winding in the same direction, wind on a further 10 turns.
- Again, keep a mental note of the starting wire and keep in next to the ending wire of the first winding.
- Using the multimeter again, check for continuity between the core and the second winding. If there is continuity then go back to the first step above.

[163] https://en.wikipedia.org/wiki/Kapton - not provided in the kit, but available on ebay etc...

- An optionally Kapton taped wound core should look like this:



- Take the EHT insulated wire and wind on 5 turns. The last turn is tight as there is not much room in the centre of the core now. However, it will go through…
- Offer the transformer up to the PCB and trim the wires to the required length.
- You can be slightly generous as the wires do not have to be taught.
- Scrape off about 5mm of the enamel at the wire ends and tin the bare copper with solder.
- Strip back the EHT insulation by a similar amount.



- Fit the transformer to the PCB, bowing the wires as needed and soldering the noted starting leads to the holes marked with a dot on the PCB.
- Finally use a cable tie to anchor the transformer to the PCB.

A Royer transformer with a Kapton tape covered core.

Jumpers J1, J2 & J3

- **J1** is only fitted if the additional back up battery is **<u>not</u>** used.
- **J2 & J3** are always fitted.

3SP1 CRT Socket B12-43 Board to Socket Wiring

Socket Pin	Function	Board Connection	Wire	Wire Colour	
1	Heater	H1 on X11	EHT	Greyish Lilac	
2	Grid	Grid on X10	EHT	Black	
3	Cathode	Cathode on X10	EHT	Brown	
4	Focus Anode	Focus on X10	EHT	Pink	
5	N/C				
6	D3	Y2 on X7	HT	Grey	
7	D4	Y1 on X7	HT	White	
8	Acceleration Anodes	A3 on X7	HT	Red	
9	D2	X1 on X8	HT	Blue	
10	D1	X2 on X8	HT	Purple	
11	N/C				
12	Heater	H2 on X11	EHT	Greyish Lilac	

Notes:
1. When using the vertical case, the Y connections (pins 6 and 7) should be reversed.
2. Standard wire colours supplied in the kit

Power Supply & CRT Board Testing

Before starting to test the board ensure that

- The jumpers for X6 and X9 are not fitted.
- The CRT is disconnected.
- All trim pots are roughly centred.

Ideally the board should be tested using a 12V 5A bench power supply with an adjustable current trip. As a minimum a multimeter is required to test the board. If an oscilloscope is available it may help with fault finding. A function generator can be used for advanced testing. The voltages and currents listed below are nominal and none are expected to be super accurate. Your knowledge and experience is needed to interpret if a reading is correct.

<u>Step 1</u>

Set the 12V bench PSU to 1A trip current. Connect the power supply to the board and switch the power supply on. There should be no obvious issues! Nothing gets warm or smokes! The fuse doesn't blow.

Current demand will be around 20mA. If OK, then proceed.

Step 2

Check the following test points:[164]

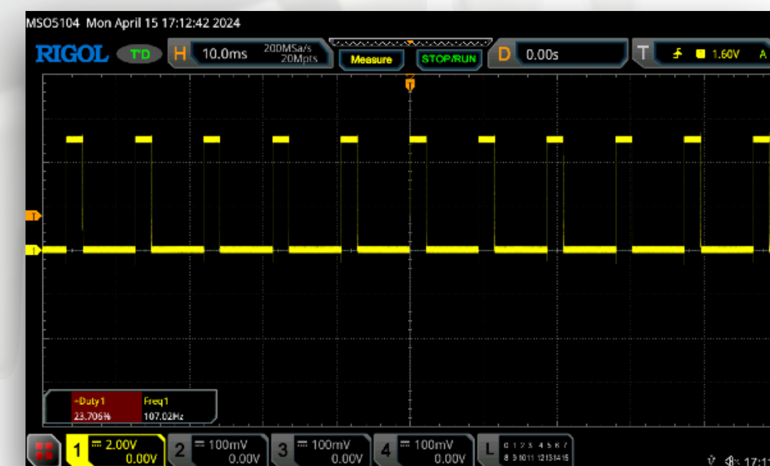
Schematic Name	PCB silkscreen	Expect reading about
TP1	+12V	12V
TP2	+5V	5V
TP3	+5V/1	5V
TP8	+5VA	5V
TP9	-5VA	-5V
TP27	+5VA	5V
TP30	-5VA	-5V

If all these test correctly, then this demonstrates that the various low voltage DC supplies are working correctly and power is being distributed.

If OK then proceed.

Step 3 - Optional

If you have an oscilloscope then you can test the +5V/2 which is available on TP29. This is not DC but a PWM supply to the LEDs on the Digital and Analogue Board. This is what you should typically find:



The frequency is around 100Hz. Using the “LED Brightness” trim pot R96 the duty cycle should be variable from about 1% to 95%. The peak voltage is 5V. If OK then proceed.

Step 4

Switch off the 12V bench power supply.

To test the 6.3V AC heater supply[165]:

- Fit jumper X6 between the centre, CRT PSU, and the ON pin.
- Connect a small 600mA (or 300mA) incandescent filament bulb across the heater output connections on screw terminal X11.

[164] It is a bit of an Easter egg hunt to find them all and there are multiple (GND) test points to aid in these measurements.

[165] If you come back to this test, ensure that jumper X9 is removed.

Adjust the current limit on the 12V bench power supply to 3A and turn it on. The filament bulb should light merrily, no smoke and nothing gets hot. If the bulb fails to light then recheck the phasing of the primary windings of transformer TR2. The 12V bench PSU current draw should be around 0.6A (with a 600mA bulb).

If you have a true RMS meter[166] then read the secondary winding voltage – it should be between 6V and 6.6V.[167] An ordinary multimeter won't cut the mustard.[168]

Leave the board running and check that the Royer MOSFETs Q22 and Q23, the tuning capacitor C35 and the transformer TR2 do not get hot, just fairly warm, and certainly no more than 50 °C.

If OK then proceed. Switch off the 12V bench power supply.

Step 5

To test the HT and EHT flyback convertor fit jumper X9, HT/EHT Enable.

Warning
During this test there will be +300V HT and up to -1.5kV EHT on the board
Take Care!

Increase the current trip on the bench 12V power supply to 5A[169] and switch the power supply on. You should see the switch on current rise to well over 2A but fall back very quickly to about 0.5A. The filament bulb on the heater supply should light again. No smoke! Nothing gets hot! Carefully test the following test points to ground:

Schematic Name	PCB silkscreen	Expected reading
TP14	-0.3kV	-300V
TP15	-0.6kV	-600V
TP16	-0.9kV	-900V
TP17	-1.2kV	see text
TP18	-1.5kV	see text
TP20	+300V	300V
TP23	Unblanking	10V - 80V
TP24	Mid	see text

Most common multimeters do not read above 1kV so are unable to check the -1.2kV and -1.5kV test points directly. However, you can carefully check the voltage between the -0.9kV test point and the

[166] My Rigol oscilloscope does, so there...
[167] The actual voltage should be at the low end of the range as I am to extend tube life with a slightly low heater voltage.
[168] https://www.collinsdictionary.com/us/dictionary/english/to-cut-the-mustard
[169] The flyback converter draws considerable current when it is switched on. The switcher IC limits the current to 5A so it is possible the a sensitive bench power supply may trip at a 3A setting. My *cheap* bench power supply does not trip at 3A. You may need a bench PSU with a higher current trip to test carefully. My *expensive* bench PSU delivers up to 30V at 6A and I find I need to set the trip current high enough not to trip, typically 5A.

-1.2kV test point when you should get a reading of -300V and then with the -1.5kV test point when you should get a reading of -600V.

The “Unblanking” test point is dependent on the position of the “Light Level” trim pot R50. Therefore, swing the trim pot between extremes and check the voltage range. The “Mid” test point TP24 measures the voltage across the -EHT filter capacitors C28 and C29. This voltage is dependent on the CRT in use and the voltage here is for a 3SP1 configuration. The measurement should not exceed -900V which is the series voltage rating of the two capacitors.

On screw connector X10 measure the voltage between the “Cathode” connection and the “Focus” connection. Do this **carefully** as the cathode connection will be at around -1.4kV to ground. The focus-cathode voltage is dependent on the position of the “Focus” trim pot R70. Therefore, swing the trim pot between extremes and you should see a voltage range of about [260V] to [510V]. This voltage range is dependent on the CRT that the board is configured for and the range here is for a 3SP1 CRT.

On screw connector X10 measure the voltage between the “Cathode” connection and the “Grid” connection. Do this **carefully** as the cathode connection will be at around -1.4kV to ground. The grid-cathode voltage is dependent on the position of the “Dark Level” trim pot R80. Swing the trim pot between extremes and you should see a voltage range of about [-90V] to [-6V]. This voltage range is dependent on the CRT that the board is configured for and the range here is for a 3SP1 CRT.

On screw connector X8 measure the voltage between the “A3” connection and ground. This will be about 150V but is dependent on the position of the “Astigmatism” trim pot R96. The voltage range should be about 70V to 230V.

Switch off the bench power supply and wait a few minutes for the capacitors to discharge. Check over the board for any hot components again. In particular, the Royer and Flyback power supplies.

Move all the trim pots back to their centre positions.

<u>Step 6 – Optional but recommended</u>

At this stage there are only limited tests that can be performed on the deflection amplifier. However, if you wish, connect a multimeter set to measure the voltage between the “X1” and “X2” connections on X8. Switch the power supply on. By rotating the “X Pos” trim pot R28 you should find that the voltage can be varied from a negative voltage through to a positive voltage. If you do this step then leave the trim pot so the voltage is near zero as this will help with the Step 7.
Repeat the test using the “Y1” and “Y2” connections on X7 and rotating the “Y Pos” trim pot R31. Again, leave the voltage near zero when you are finished.

<u>Step 7</u>

Switch off the bench power supply and wait several minutes for the capacitors to discharge. If in doubt use your multimeter to check the +300V and -900V test points to ground and only continue when they have both fallen to a low voltage, say, <10V.

Remove the incandescent bulb you used to test the heater power supply.

Now it is time to test the board with a CRT! A table above shows how the 3SP1[170] CRT socket should be wired to the board.

Switch on the bench power supply. After a few moments the heater should start to glow. You may see a green dot on the CRT face. The "Dark Level"[171] trim pot when set roughly centred should allow a cathode ray beam. If you did not carry out Step 6 you may need to go hunting for the beam by rotating the beam position trim pots R28 and R31 (or go back to Step 6).

Turn the Dark Level trim pot down to leave just a dim spot. Try rotating the "Focus" trim pot R70 and a sharp well defined dot should be possible. If the dot looks slightly oblate[172] then try adjusting the "Astigmatism" trim pot R59. The cycle of adjusting Astigmatism, Dark Level and Focus may need to be repeated to get the best dot possible.[173]

Warning

Do not leave the CRT lit for a long with a bright dot only as you may burn the tube[174]

Although this warning sounds dire, you won't burn the tube in a short space of time. It should actually take days to damage the phosphor but why chance it? If at this stage you cannot get a "perfect" dot, do not be overly concerned. At the moment the inputs to the deflection amplifier are floating and might be picking up noise. Additionally, external AC magnetic fields – bench PSU? – soldering iron transformer? – can disturb the focus into a small blob or circle.

Check:

- The Dark Level trim pot brightens the dot when rotated clockwise.
- The Dark Level trim pot dims the dot and can completely extinguish it when rotated anti-clockwise.
- The X Pos trim pot should move the dot to the right when rotated clockwise.
- The Y Pos trim pot should move the dot upwards when rotated clockwise.[175]

Switch off the bench power supply when finished..

Step 8 - Optional[176]

If you have a two channel function generator[177] then you can connect it to the deflection amplifier inputs to create some Lissajous curves[178]. There are test points in the deflection amplifier area that can be used to inject signals into the amplifier.

- X inputs are near to the X6 inter-board connectors.
- Y inputs are near to the analogue power supply module Z1.

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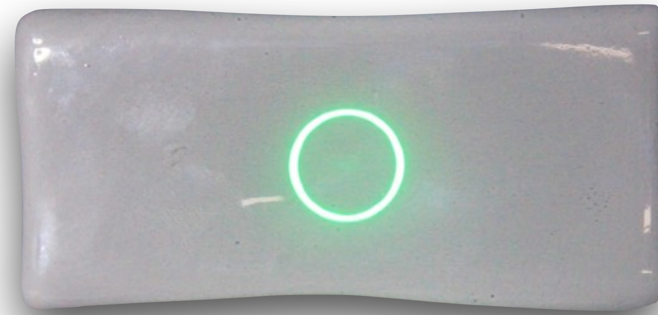
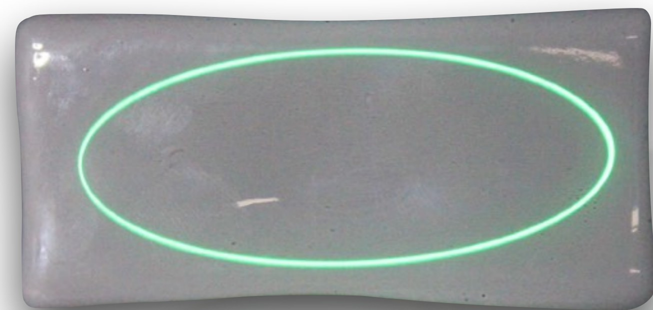
170 See the Advanced Customisation Manual for other tubes
171 The "light level" at this time will have no effect. It operates when the beam is modulated by the digital and analogue board.
172 https://www.merriam-webster.com/dictionary/oblate
173 Always finish with the focus adjustment.
174 See the How the CRT Works section where phosphor burning is discussed. https://en.wikipedia.org/wiki/Screen_burn-in; The How it works – CRT section contains information on phosphor burning and how to avoid.
175 downwards if you have wired the tube for a vertical case arrangement.
176 But fun…
177 Small function generators can be bought easily on ebay.
178 https://en.wikipedia.org/wiki/Lissajous_curve

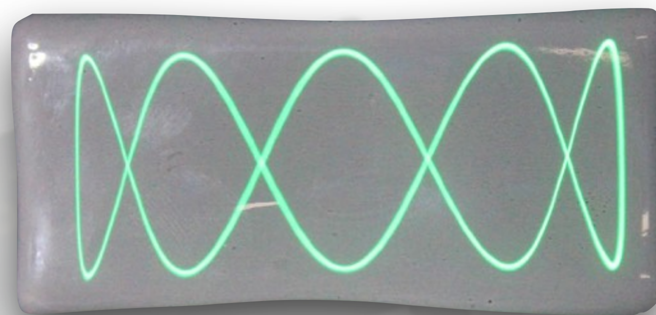
The tests below are just what I did and recorded. You might play for longer…

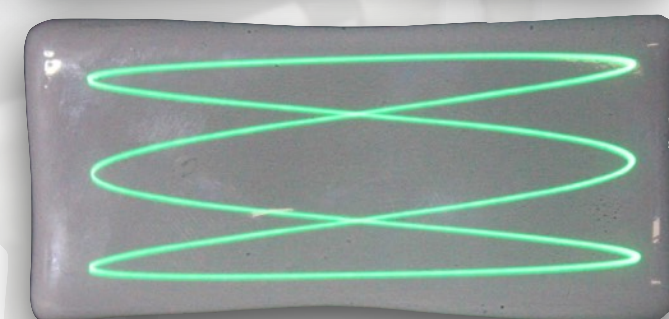


The function generator's channel 1 was set to produce a 1V peak-to-peak sine wave and this was connected to the X input, channel 2 was set to the same setting except with a 90º phase shift, i.e. a cosine wave. Sine and cosine waves will produce a circle. Therefore adjust the "X Size" and "Y Size" trim pots to produce a circle and the "X Pos" and "Y Pos" trim pots to centre the circle:

You can then play with the frequencies, phase, wave shape and DC offset[179]







Selecting frequencies that are only slightly different, say, 1000Hz and 1000.1Hz will produce curves that rotate slowly. Selecting low frequencies, say less than 10Hz, and the spot movement will become distinctly visible (and quite good dynamic fun). Adding a positive DC offset to the X input will move the image to the left (the inputs are inverted) and to the Y input move the image down.

<u>Warning</u>

<u>Again, do not leave the CRT lit with a bright static Lissajous curve as you may burn the tube</u>

Switch off the bench PSU when bored and allow a few minutes for the capacitors to discharge.

<u>Step 9</u>

Finally, you can test the unblanking amplifier. For this test, disconnect the function generator from the Y input to the deflection amplifier and connect it to the unblanking "Beam On" test point 32 located near the board inter connector X5. Set the function generator as follows:

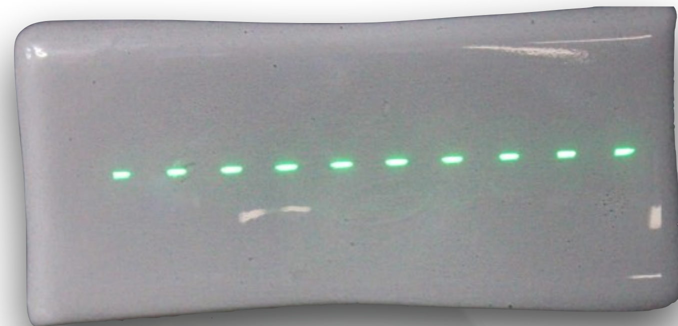
- Set the channel feeding the X deflection amplifier to a sawtooth wave at 1kHz.
- Set the amplitude and/or the X Size trim pot to obtain a horizontal line.
- The unblanking channel should be set to a 5V amplitude square wave at 10kHz.

[179] Depending on the capabilities of your function generator…

Now

- Set the Light Level trim pot to minimum – fully anti-clockwise.
- Adjust the Dark Level trim pot so that the line on the CRT is visible.
- Now reduce the Dark Level – turn anti-clockwise – until the line has just disappeared.
- Now increase the Light Level – turn clockwise – and a dashed line should appear with 10 dashes.
- Adjust the tube Focus as required.

It will look like this:

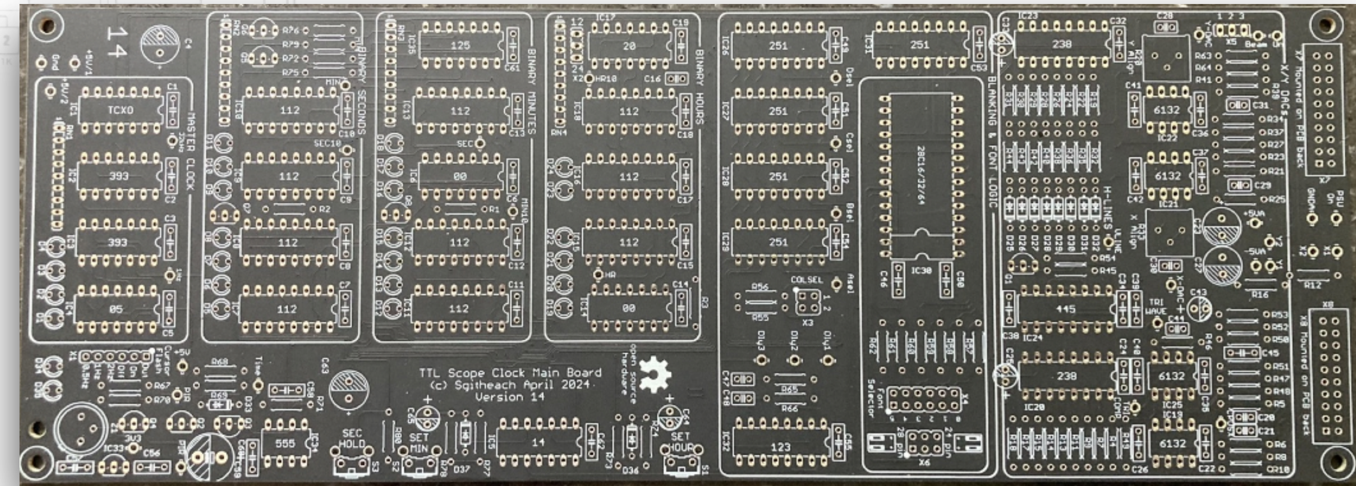


You can change the frequencies of the function generator to vary the number of dashes visible.[180] Switch off the bench PSU and allow a few minutes for the capacitors on the board to discharge.

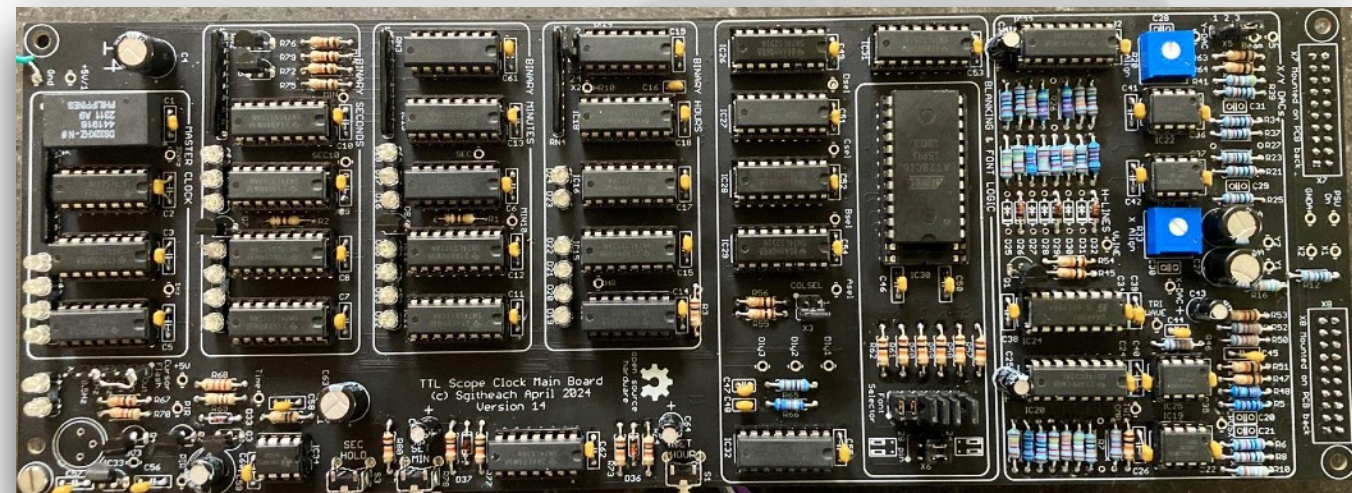
Clear the bench and get ready to assemble the Digital & Analogue board!

[180] The dashes will only appear cleanly when the two function generator channel frequencies are an exact multiple of each other.

Digital & Analogue Board Assembly



The bare digital and analogue board



The fully populated board (without PIR)

Errata

If the battery backup PSU board is used then the power supply to IC5 needs to be changed from +5V to the +5V/1 supply. How to do this is described below in the board assembly section.

Parts List[181]

Check that these parts are present in the Digital and Analogue board kit bag and tick them off. If there are any missing components then please notify us so they can be supplied. An alternative parts list where it is organized in component size order can be found at the end of the document here.

Tick	Quantity	Part Number	Value	Component
☐	45	C1, C2, C3, C5, C6, C7, C8, C9, C10, C11, C12, C13, C14, C15, C17, C18, C19, C22, C24, C26, C32, C34, C35, C36, C37, C38, C39, C40, C41, C42, C45, C46, C49, C50, C51, C52, C53, C54, C55, C56, C57, C58, C60, C61, C62	100n see Note 1.	ceramic
☐	4	C4, C23, C27, C63	1000µ 6V3	electrolytic
☐	1	C16	220p	ceramic
☐	3	C20, C28, C30	22p C0G/NP0	ceramic
☐	1	C21	10p C0G/NP0	ceramic
☐	2	C25, C33	10µ 10V	electrolytic
☐	3	C43, C64, C65	1µ 16V	electrolytic
☐	3	C44, C47, C48	1n C0G/NP0 1%	ceramic
☐	1	C59	100µ 6V3	electrolytic
☐	26	D1, D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12, D13, D14, D15, D16, D17, D18, D19, D20, D21, D22, D23, D24, D34, D35	LED	green 3mm
☐	8	3D printed spacers for the LEDs. Two 2 way, two 3 way and four 4 way.		
☐	6	D26, D29, D32, D33, D36, D37	1N4148	diode
☐	5	IC19, IC21, IC22, IC25, IC34	DIL 08	IC Socket
☐	9	IC1, IC2, IC3, IC4, IC5, IC6, IC14, IC17, IC35	DIL 14	IC Socket
☐	19	IC7, IC8, IC9, IC10, IC11, IC12, IC13, IC15, IC16, IC18, IC20, IC23, IC24, IC26, IC27, IC28, IC29, IC30, IC31	DIL 16	IC Socket
☐	1	IC30	DIL 28-6 see note 2	IC Socket
☐	1	IC1	DS32KHZN	IC
☐	2	IC2, IC3	74LS393N	IC
☐	1	IC4	74LS05N	IC
☐	1	IC5	74LS14N	IC
☐	2	IC6, IC14	74LS00N	IC
☐	10	IC7, IC8, IC9, IC10, IC11, IC12, IC13, IC15, IC16, IC18	74LS112N	IC
☐	1	IC17	74LS20N	IC
☐	4	IC19, IC21, IC22, IC25	LM6132	IC

[181] This Parts List is also available as a spreadsheet on the project Dropbox to assist component ordering if you are not using a kit.

Tick	Quantity	Part Number	Value	Component
☐	2	IC20, IC23	74HCT238	IC
☐	1	IC24	DG445	IC
☐	5	IC26, IC27, IC28, IC29, IC31	74LS251N	IC
☐	1	IC30 (depends on which EEPROM you are using)	AT28C64B AT28C32 AT28C16	IC
☐	1	IC32	74LS123N	IC
☐	1	IC33	3V3 LDO Regulator	IC
☐	1	IC34	NE555	IC
☐	1	IC35	74LS125N	IC
☐	6	Q1, Q4, Q5, Q6, Q7, Q8	2N7000	MOSFET
☐	1	Q2	MPSA56	PNP BJT
☐	1	Q3	MSPA06	NPN BJT
☐	2	R1, R2	470R	5% Carbon Film
☐	24	R3, R45, R47, R49, R51, R54, R55, R56, R57, R58, R59, R60, R61, R62, R63, R64, R67, R72, R73, R75, R76, R77, R79, R80	10k	5% Carbon Film
☐	1	R4	28k7	1% Metal Film
☐	7	R5, R8, R19, R23, R25, R37, R39	10k0	1% Metal Film
☐	1	R9	100k	1% Metal Film
☐	2	R10, R16	499k	1% Metal Film
☐	2	R11, R41	49k9	1% Metal Film
☐	4	R13, R46, R50, R52	33k2	1% Metal Film
☐	1	R14	24k9	1% Metal Film
☐	5	R6, R15, R30, R31, R38	20k0	1% Metal Film
☐	1	R17	16k5	1% Metal Film
☐	1	R18	14k3	1% Metal Film
☐	2	R20, R33	20k0	trim pot
☐	2	R21, R34	2k00	1% Metal Film
☐	2	R12, R53	1k00	1% Metal Film
☐	2	R22, R29	13k3	1% Metal Film
☐	2	R24, R28	40k2	1% Metal Film
☐	1	R32	12k1	1% Metal Film
☐	1	R35	8k06	1% Metal Film
☐	1	R36	9k31	1% Metal Film

Tick	Quantity	Part Number	Value	Component
☐	1	R40	124k	1% Metal Film
☐	1	R42	41k2	1% Metal Film
☐	2	R43, R44	15k4	1% Metal Film
☐	1	R48	3M30	1% Metal Film
☐	1	R65	6k20	1% Metal Film
☐	1	R66	143k	1% Metal Film
☐	1	R68	2k2	5% Carbon Film
☐	1	R69	100R	5% Carbon Film
☐	1	R70	3k9	5% Carbon Film
☐	1	R71	100k	5% Carbon Film
☐	2	R74, R78	1k	5% Carbon Film
☐	4	RN1, RN2, RN3, RN4	330R	Bussed 8 way network resistor
☐	3	S1, S2, S3	Push button	R/A OFF-(ON)
☐	1	X1	1x5 male header fitted across pins 2 to 6	
☐	1	X1	female socket to wire patch lead - solder to pin 1 “Out”	
☐	1	X2	1x3 male header	12 vs 24 Hr Selection
☐	1	X3	2x2 male header	Colon Selection
☐	1	X4	2x6 male header	Font Selection
☐	1	X6	2x3 male header	EEPROM 24/28 device
☐	11	X2, X3, X4, X6	Jumpers	
☐	2	X7, X8	2x10 male header see note 3	
☐	1	Z1	EKMC1601112	PIR
☐	2	M3x11mm stand-offs, M3x6mm bolt and nut. note 4		
☐	1	PCB		

Notes:

1. C48 is only required if IC30 is in a 24 pin package. It does no harm to fit it anyway.
2. If IC30 is in a 24 pin package then this socket can be DIL24-6 however a DIL28-6 can still be used but the IC must be fitted correctly.
3. These are 2x10 male headers and are **mounted on the back of the board.**
4. These stand-offs are used to keep the boards separated during testing.
5. Voltage ratings of electrolytic capacitors can be higher than those stated. For example a 6.3V rated capacitor is listed but a 10V rated component may be supplied in its stead.

Further suggestions

IC1 and IC6 require five of their leads to be stepped like this:

If a part with straight leads has been supplied then form them before fitting the part to the board. The distance between the straight and dog-legged leads should be about 5mm. Fitting IC1 and IC6 to the PCB together with their heat-sinks can be a bit of a fiddly job. One method is to first insert the IC into the holes in the PCB (there is enough friction to hold it in place), then insert the heat-sink into the PCB and then pass a screw through the hole in the IC and the adjacent hole in the heatsink. Attach the nut to the screw and tighten so that the IC is firmly, flatly and squarely mated to the heatsink. Press down on the heatsink so it's squarely sitting on the PCB and then solder the leads of the IC. It's a good idea to NOT solder the pins of the heatsink until testing is completed.

It is also suggested to not install X7, X8, X9, X10, and X11 until you have planned out how you are going to run the lead wires to the CRT. This will allow you to orient the direction of the openings for the wires that best suits the CRT wire routing. However, you do need them installed to test the board with a CRT. If you are not sure then just install them as the silk-screen suggests.

Horizontal Case Board Components

If you intend to use a horizontal case then the following are supplied:

Tick	Quantity	Part Number	Comment
☐	1	3D Printed part	
☐	1	M3 brass melt-in, 4.3mm diameter 3mm long	To mount Z1 horizontal
☐	1	M3x6mm bolt and washer	

The list includes M3 melt-in (or heat-set) brass inserts. There are loads of videos on YouTube showing how these can be placed using a soldering iron. Additionally you will need some glue as explained below.

Vertical Case Board Components

If you intend to use a vertical case then the following are supplied:

Tick	Quantity	Part Number	Comment
☐	1	3D Printed part	
☐	1	M3 brass melt-in, 4.3mm diameter 3mm long	To mount Z1 vertical
☐	2	M3x6mm bolt and washer	

Other Components

There are a few components that are not listed above as they are not fitted as part of the default clock configuration. If you have customised the display font then they may be needed. Clock font customisation has its own manual[182] as it is a complex subject.

The components not fitted by default are:

- C29, C31
- D25, D27, D28, D30, D31
- R7, R26, R27
- Test point loops.
- X5 is just a wire link and there is no header component in the kit.

Instructions for fitting the jumpers, headers and the PIR are given below. The board has many test points. Optionally you can fit test point loops which give a good connection point for oscilloscope leads etc (these were described in the prior PSU construction section).

Assembly

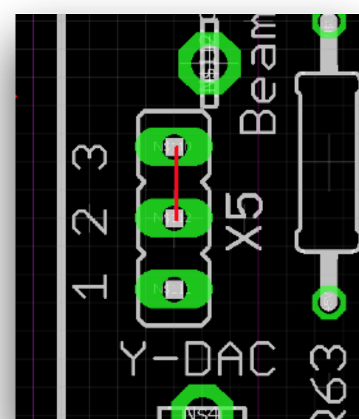
Proceed systematically, fitting all the smallest components first and work towards the largest electrolytic capacitors. Many components have a polarity or orientation which must be observed:

- Transistors
- Diodes
- LEDs
- IC sockets[183]
- Electrolytic capacitors

The last operation to carry out is fitting all the ICs[184]. You could fit them in stages to check board operation progressively but it is probably not worth it. Any malfunction is going to be fairly obvious.

Some Specific Assembly Notes

The role of jumpers X4 (Font Selection), X3 (Colon Shape), X1 (Colon Speed) and X2 (12/24 Hr Operation) have already been discussed here.

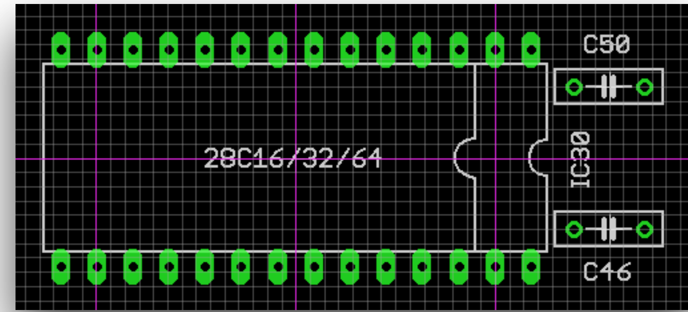


Jumper X5 – This jumper sets the polarity of the unblanking signal. It is provided in case this board is to be used with another CRT board that has a different unblanking amplifier. Assuming you are using the standard kit and CRT board then link (using a resistor lead cutting) pads labelled 2 and 3:

[182] See the Advanced Customization Manual for details.

[183] If you haven't noticed already then all the DIL ICs (except IC30) point in the same direction – with the orientation mark towards the two inter-board connectors. IC30 bucks the trend but it is mounted at right angles to all the smaller ICs.

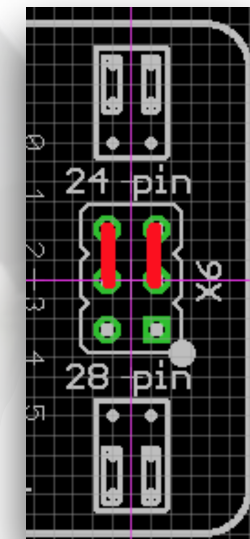
[184] The easiest fault to introduce is to bend an IC lead accidentally so that it doesn't engage with the socket properly.



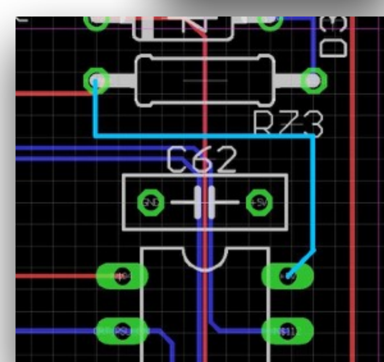
IC30 Socket - The board will use the 24 pin AT28C16 or the 28 pin AT28C32 and AT28C64 EEPROMs.

The silkscreen for IC30 guides you on how to fit a 24 or 28 pin socket:

If you are using a 28 pin device then there is only one way to fit the socket, observing polarity of course! If you are using a 24 pin device then you can either use a 24 pin socket in which case it should be fitted as shown on the silkscreen, fully to the left in this graphic, with the orientation mark to the right. Alternatively, you can use a 28 pin socket[185], in which case the device is fitted at the end away from the orientation mark, fully to the left in this graphic.



Jumper X6 must be set depending on the device fitted. The silkscreen guides you to which connection points to link. If you are using a 24 pin device then link these connection points: It should be fairly obvious how to link them if you're using a 28 pin device. You can use resistor lead offcuts to make the links.

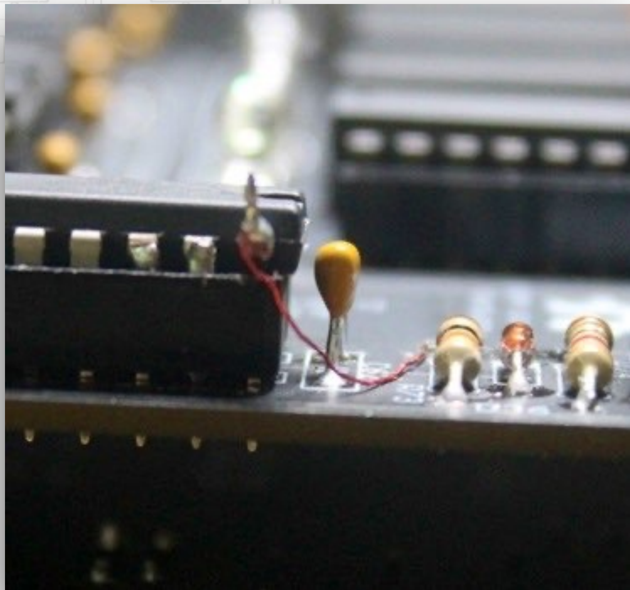


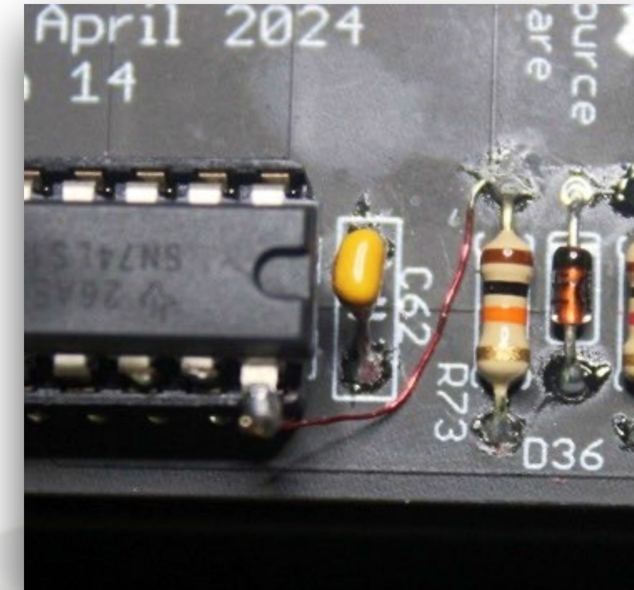
If you are using the battery back up power supply then a small correction needs to be made to the board.

IC5 (74LS14) needs to be supplied from the +5V/1 supply. It is best to do this just as you are fitting IC5 to the board. Before you fit the chip, bend pin 14 up and out so that when plugged in it will not make contact with the IC socket. Then use the short length of insulated wire to connect IC5 pin 14 to the end of R73 as shown in cyan in the image here.

[185] This is the most flexible arrangement as it allows both a 24 pin device or a 28 pin device to be fitted.

It should look something like this:





The kit includes a short length of polyurethane coated wire. This wire has the advantage that the polyurethane coating does not need to be scraped of like ordinary enamelled wire but the heat of the soldering iron will melt the plastic. You can tin and solder the wire very easily.

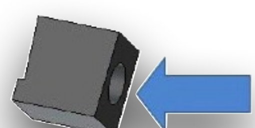
Mounting the PIR sensor Z1

The PIR needs to be mounted so that it eventually has a good view of the room so it gets triggered by movement to keep the clock display on.

- For the standard horizontal case kit it needs to be mounted parallel with the PCB so it will ‘look’ horizontally at the room.
- For the standard vertical (mirror) case kit it needs to be mounted at right angles to the board so when rotated through 90° it will again ‘look’ horizontally at the room.
- If you are using your own case then you will need to adapt the mounting accordingly. There is no reason why you should not use wire leads to install the PIR remote from the board.[186]

3D printed parts and fittings are supplied in the kit to mount the PIR appropriately, depending on case style.

Mounting Z1 in the horizontal case

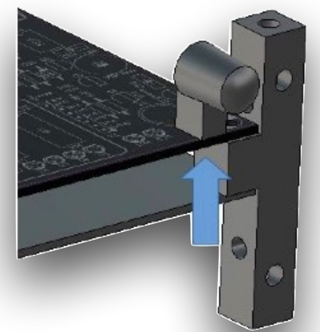
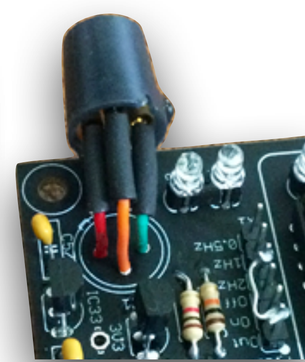


Put the M3 melt-in insert into the bottom of the hole through the 3D printed PIR support part.

The PIR is mounted so it is at right angles to the PCB and so faces forward. Glue the PIR to the 3D printed part. Avoid getting glue down into the screw thread or on the face of the PIR sensor!

[186] But please keep the leads as short as you can.

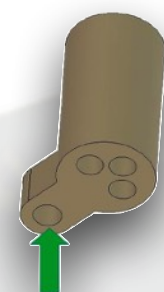
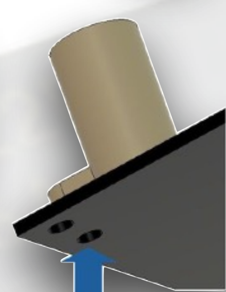
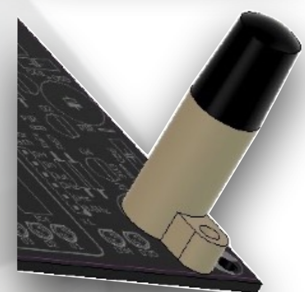
The PIR should be glued with the PIR ground case pin on the right hand side when viewed from the back. The PIR is then mounted on the PCB using a M3 6mm bolt and washer.

Attach three short leads attached to connect the PIR pins to the PCB. The leads run straight and do not cross over. The solder joints are protected with short lengths of heat shrink.

I used coloured wires for clarity in this photograph but I would suggest black wire normally (aesthetics).

Mounting Z1 for the vertical case

Put the M3 melt-in insert into the bottom of the hole through the 3D printed PIR support part.

Attach the 3D printed PIR mount to the Digital and Analogue board using M3x6mm bolt and washer: Extend the PIR leads using short bare leads (perhaps resistor off-cuts) and thread the leads down the holes in the PIR mount. Pull the wires taught and solder the leads to the board.

Board Assembly Completed

This completes the digital and analogue board assembly which can now be attached to the power supply and CRT board to continue with testing.

<u>The following only applies if you are using the battery back up board:</u> The PSU and CRT board section that you completed will have told you *not to fit J1 on its board if the back up battery PSU is being used*. If you are using the battery backup you will have fitted X3 to connect to the battery backup board. However, it may be more convenient to test the digital and analogue board without the backup battery board connected. In this case temporarily fit J1 on the PSU and CRT board and do not connect the backup battery board. **You must remember to remove J1 before connecting the battery backup board**.

The two boards are naturally spaced at one end by the inter-board connectors. However, at the other end, the high voltage end, the boards must not be allowed to touch so you must use the 11mm stand-offs provided in the standard kit. *TTL chips and the HT/-EHT supplies are not happy partners and like sheep and cows they do not mix.*[187] Whilst you could fit the ICs by function and check that each section works in turn, you might as well just fit them all and then fault find any section that is not working.

Check that the two 2x10 headers are mated correctly. If offset then severe damage can occur to both boards. As previously said, to fault find this board you really do need an oscilloscope! If you are impatient and wish to see if the clock is working immediately then skip to Step 7.

---

[187] This actually a myth, you can graze sheep and cows together. See, you learn something new every day! (you're welcome)

Step 1

Remove jumpers X6 and X9 from the Power Supply and CRT board. This will ensure that the heater power supply and HT/EHT power supply do not start up. All we need at this stage are the various LT supplies.

Reduce the 12V bench power supply current trip to 1A.

Switch on the 12V bench power supply. The current should be about 100 – 130mA depending on the LED brightness..

No problems? Nothing gets hot? No smoke!

Step 2

Check that the correct low voltages are arriving on the board, specifically the following test points:

Schematic Name	PCB silkscreen	Expect reading about
TP4	+5V/1	+5V
TP6	+5V	+5V
TP37	+5VA	+5V
TP28	-5VA	-5V

Step 3 – Optional

If you have an oscilloscope then you can test the +5V/2 which is available on TP3. This is not DC but a PWM supply to the LEDs but you are going to test this immediately in the next step.

Step 4

If there are no problems you should be greeted with a lot of flashing LEDs. Note that the counter flip-flops wake up in random states so it is possible that the time shown on the LEDs (more on this below) is illegal i.e. minutes > 59, and for a 24 hour clock hours > 23, or for a 12 hour clock hours > 12.

Check the following:

- The LED brightness can be varied by adjusting the “LED Brightness” trim pot R96 on the Power Supply and CRT Board. Adjust the LED brightness to taste.
- Master Clock LEDs (D1 – D4) should be flashing between 0.5Hz and 4Hz.
- The Binary Seconds section LEDs (D5 – D11) should count in binary coded decimal (BCD) with D5 – D8 showing seconds and D9 – D11 showing 10’s of seconds.
- Press and hold the SEC HOLD button S3, the seconds LEDs should all go out (i.e. zeroed).
- Release the button and they should start counting again, from zero.
- If you wait for the seconds to count until they roll over 59 to 00 then you should see the Binary Minute section LEDs (D12 – D18) increment by one .
- Press and hold the “SET MIN” button S2. The minute LEDs (D12 – D18) should now count, incrementing once per second.
- Check that the minutes LEDs (D12 – D15) correctly increment the 10’s of minutes LEDs (D16 – D18) when they roll over.
- Continue to keep the “SET MIN” button pressed until the minutes roll over 59 to 00 and check that the Binary Hour section LEDs (D19 – D24) increment.
- Release the button and the minutes should stop advancing once per second.

- Press and hold the "SET HOUR" button S1. The hour LEDs (D19 – D24) should now count incrementing once per second.
- Check that the hours LEDs (D19 – D22) correctly increment the 10's hours LEDs (D23, D24) when they roll over.
- Check the hours and 10's hours counting is correct for the 12/24 hour clock setting on header X2:
  - If 12 hour clock is selected the count displayed should be 01 through 12.
  - If 24 hour clock is selected the count displayed should be 00 through 23.
- Release the button and the hours should stop advancing once per second.

Step 5 – Optional

With the LEDs correctly counting and showing the time, albeit in BCD, you can test the clock's time keeping accuracy if you wish. With an accurate frequency meter you merely check the signal on TP1, "32kHz" for a 32.768kHz square wave. Without a frequency meter you can let the clock boards run for, say 24 hours, and see it the board keeps time. Here's how.

Set the clock's time by using three buttons S1 – S3, let's say the time is 8:52 and you want to set the time;

- Make sure the time the currently shows a legal[188] hours : minutes : seconds. If not
  - Allow the seconds counter to roll over and show a legal count.
  - Press and hold the SET MIN button S2 until the minutes roll over and show a legal minute count.
  - Press and hold the SET HOUR button S1 until the hours roll over and show a legal hour count.
- Now to set the time, press and hold the SEC HOLD button S3.
- Press the SET MIN button until the minutes LEDs show a count slightly in advance of the current time, say, in this example 54.
- Press the SET HOUR button until the hours LEDs show the exact hour count, say, in this example 08.
- Watch the clock you are synchronising the time with and release the SEC HOLD button when the displayed time (on the synchronising clock) is exactly the same, say, in this example 08:54:00.
- This procedure should enable you to set the time to within a second.

Repeat these steps if you are not satisfied with your skill or if you overrun the time you were aiming at. Now just leave the clock running for as long as you like and check back to see if it is keeping accurate time (as far as you can visually judge).

Step 6 – Optional

You should now have proven the time-keeping logic is all working. You can now check that the BCD time is converted into the analogue signals to be fed to the deflection and unblanking amplifiers. To do this you need to inspect various test points with an oscilloscope. If you have read the earlier basic explanation of how the clock works you will know there are five signals to examine:

- Triangle wave generator output.
- X character position DAC output.
- X line centre point DAC output.

[188] One power up the clock can show an illegal time such as 34:78:01 as the counter flip-flops are randomised.

- Y line centre point DAC output.
- Unblanking signals.

These signals have all featured in the detailed how it works section so rather than duplicate the section here, please refer to it if you want to check the analogue signals.

Step 7

Now it is time to power the whole clock. If you had removed them, replace jumpers X6 (fit the jumper between the centre, “CRT PSU”, and the “ON” pin) and X9 on the Power Supply and CRT board. This will allow that the heater power supply and HT/EHT power supply to start up.

Set the 12V bench power supply current trip as before when testing the PSU board.[189]

Switch on the 12V bench power supply. The current should settle down to about 1A depending on the LED brightness..

No problems? Nothing gets hot?

After about 10 – 20 seconds something should appear on the CRT, it might be out of focus, offset in some way and either too dim or too dark. Now, let’s fine tune the display.

If nothing appears then turn the Dark Level trim pot clockwise until something appears. If you followed the steps in the Power Supply and CRT Board testing and now nothing appears then you will need to troubleshoot the board. If you didn’t follow the Power Supply and CRT Board testing steps then we suggest you go back and do them now.

Step 8[190]

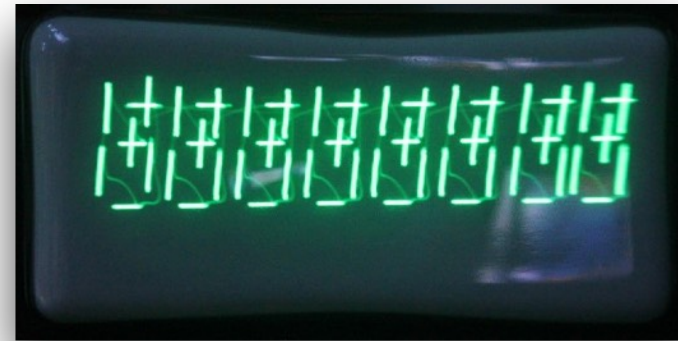
Set the X Align (R33) and Y Align (R20) trim pots[191] to be roughly centred.

First we need to check that all the lines in all the characters are lit. To do this:

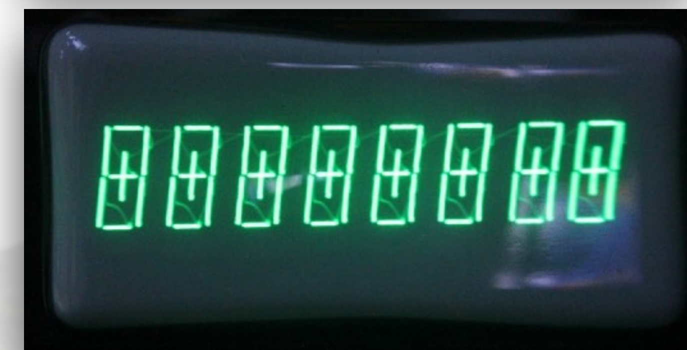
- Turn the Light Level trim pot fully anticlockwise.
- Adjust the Dark Level trim pot to get a well lit image that will look something like this[192].

[189] See the PSU section above for the peak start up current settings.
[190] If when you get to this point, you see what looks like the time showing, do not be fooled, carry on with Steps 8 etc, you will need to use the X-Align and Y-Align pots soon…
[191] On the Digital & Analogue Board.
[192] In that is will be an offset mess of horizontal and vertical lines – it is most unlikely to look *exactly* like this…

Now adjust the X Pos and Y Pos controls to centre the image and adjust the X Size and Y Size trim pots to get a good centred and sized image.



Adjust the X Align (R33) and Y Align (R20) trim pots so that the lines meet up neatly at the corners. Personally, I like to adjust the trim pots so that there is a small gap between line ends at each corner. In this photo you can see the 8 characters and that each character is made up of 8 lines.



In this photo and the previous one you can also see additional artifacts on the face. These appear at this stage because the beam is permanently on. When the time is made visible in step 10 they will disappear.

<u>Step 9</u>

Rotate the Focus trim pot R70 and sharp, well defined lines should be possible. If the horizontal lines look slightly wider than the vertical lines then try adjusting the Astigmatism trim pot. Adjust the Dark Level to keep a nice bright image, as adjusting the Astigmatism control will alter the image brightness. The cycle of adjusting Astigmatism, Dark Level and Focus may need to be repeated to get the best image possible.[193] It is very common with CRTs[194] that you will not achieve a perfect focus over the whole of the CRT face. Often the tube edges, especially in the X direction with a 3SP1, will focus differently to the tube centre. Adjusting the image size and focus pots may be a bit of a compromise on image focus and quality over the whole of the tube face.

<u>Step 10</u>

Adjust the Light Level trim pot clockwise and the clock face should appear[195]. Cycle between the light and dark level trim pots to get a good brightness. Then adjust the astigmatism and focus trim pots again:

If the image is rotated then check that the CRT itself is simply rotated. If the image cannot be corrected then check the X and Y deflection

[193] As before, always finish with the Focus adjustment.
[194] Except expensive high performance ones. A tube like a 3SP1 in no way can be considered high performance.
[195] No magic, just engineering was involved.

wiring. If parts of the clock face are incorrect e.g. lines missing, colons wrong etc. then first go over the jumper settings on the Digital & Analogue Board if everything looks correct then go to the detailed how it works section and read up on the problem area. By all means contact us!

At this point you should have an eight character HH:MM:SS display but the time is wrong.[196] The font should be as selected, the colon should be as set (on, off, flashing) and the colon characters should be as selected. Set the clock's time by using the three buttons S1 – S3[197], let's say the time is 09:36 and you want to set the time:

- Make sure the time the currently shows a legal hours : minutes : seconds. If not
  - Allow the seconds counter to roll over and show a legal count.
  - Press and hold the SET MIN button S2 until the minutes roll over and show a minute legal count.
  - Press and hold the SET HOUR button S1 until the hours roll over and show a legal hour count.
- Now to set the time, press and hold the SEC HOLD button S3.
- Press the SET MIN button until the minutes LEDs show a count slightly in advance of the current time, say, in this example 38.
- Press the SET HOUR button until the hours LEDs show the exact hour count, say, in this example 09.
- Watch the clock you are synchronising the time with and release the SEC HOLD button when the displayed time (on the synchronising clock) is exactly the same, say, in this example 09:38:00.
- This procedure should enable you to set the time to within a second with a little practice.

During this process there is one more thing to observe, and also observe as the clock runs normally. When the clock seconds roll over 59 – 00 and the minutes are incremented, you should see the whole clock face jump slightly either left or right and/or up or down. This is a CRT phosphor anti-burn measure. The clock face moves slightly each minute so that the same area is not used all the time.

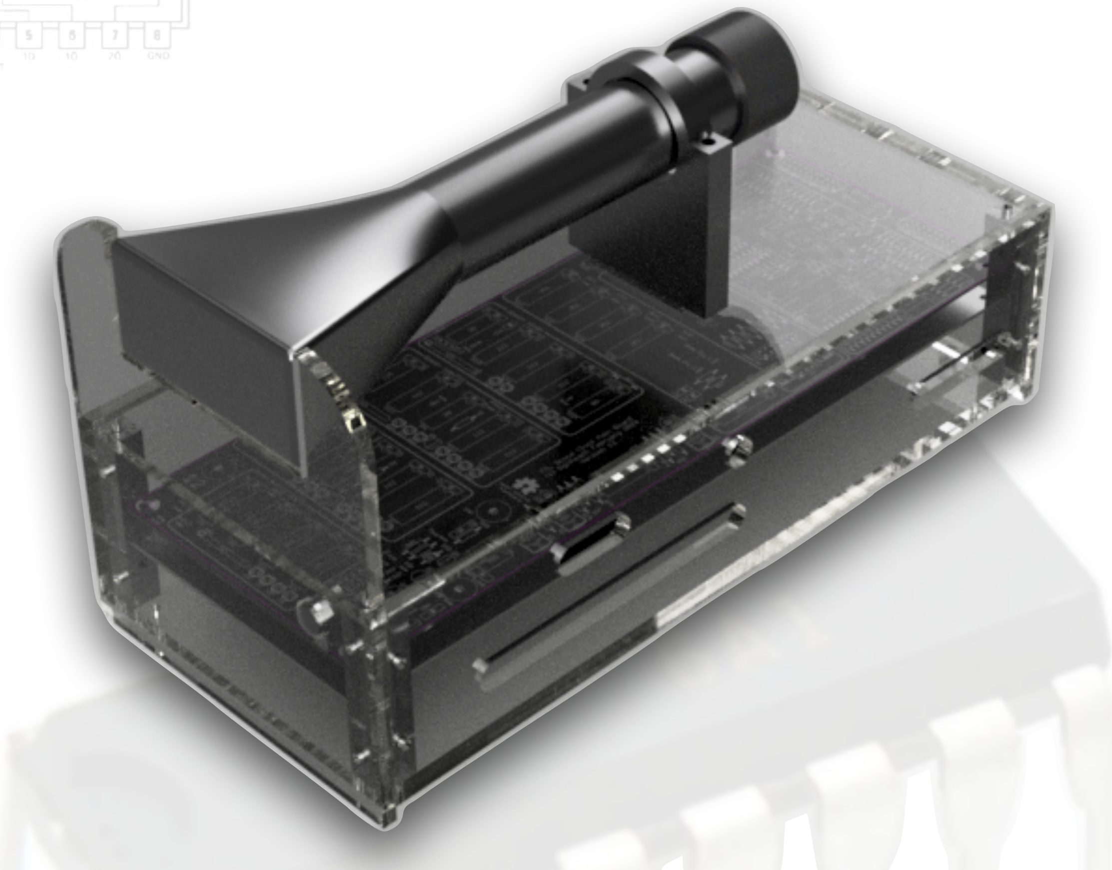
<u>Step 11</u>

Congratulations! You now have a functioning TTL based Scope Clock. Time to move on to installing it in a case. If you want the PIR to function, you'll need to change X6 to select "CRT PSU" and the "Auto" pin header.

If you temporarily fitted J1 on the PSU and CRT board then remove it now before you connect the battery backup board.

[196] I've not calculated the odds of the clock waking up to the correct time but they must be pretty long.
[197] If you have followed all of the steps above then you will have carried out this process already.

Scope Clock TTL – Horizontal Case Assembly



This case is a design that is a very common build for scope tubes – the tube is horizontal with the boards underneath. The digital and analogue board faces upwards so all of the binary counter LEDs are clearly visible through the acrylic top panel.

A link on the project website[198] will take you to a 3D render of the case that can be rotated, zoomed etc.

The case is made from 3D printed parts and laser cut acrylic. There are two sets of files for the laser cut acrylic: one set for 6.35mm thick acrylic (USA) and one for 5mm thick for everyone else. The STL files for the 3D printed parts and DXF files for the laser cut acrylic are available from the project Dropbox[199].

At present the design is only suitable for a 3SP1 CRT. Modified versions will be needed for other CRTs. Do not assemble the boards into the case until they are thoroughly tested and adjusted.

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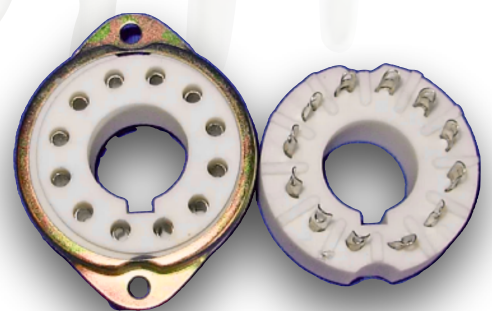
198 http://www.sgitheach.org.uk/scope4.html#case
199 http://www.sgitheach.org.uk/scope4.html#documentation

Parts List

Tick	Quantity	Part	Notes
☐	1	CRT B12-43 socket	See note 1
☐	2	3mm brass melt-in insert 5mm diameter 6mm long	To mount the CRT socket into the socket shield
☐	2	M3x6mm bolt	
☐	6	3D printed part	See 3D part section below
☐	6	Laser cut acrylic panel (not in the kit)	See acrylic section below
☐	4	M4 brass melt-in insert 6mm diameter 5.6mm long	To mount the Neck Support onto the Top acrylic plate, and to mount the CRT clamp onto the top of the Neck Support
☐	2	M4x12mm bolt	
☐	2	M4x16mm bolt	
☐	24	M3 brass melt-in insert 5mm diameter 5mm long	To insert into the corner pillars
☐	24	M3x2mm bolt	To mount the acrylic panels onto the corner pillars and form a box
☐	4	M3x20mm bolt, washer and nut	To mount the boards onto the peg on each corner pillar
☐	1	Spiral wrap	
☐	1	Shrink wrap	
☐	1	Foam rubber	

Notes:

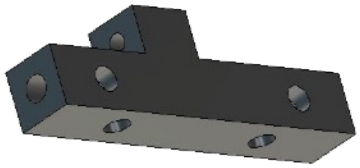
1. The D12-43 (B12A) base supplied in the standard 3SP1 kit that the 3D printed part has been design to use looks like this (see right):
2. HT and EHT wire for a 3SP1 CRT is supplied in the PSU & CRT kit.
3. The 3D printed PIR support is in the digital and analogue board kit.
4. The list includes M3 and M4 melt-in (or heat-set) brass inserts. There are loads of videos on You Tube showing how these can be placed using a soldering iron.
5. The kit comes without the six acrylic panels. The DXF files are available on the Project Dropbox so you can use a laser cutting business near to you. If you are in the UK then the web page gives details of the cutter I use. If you are in North America then Stock's Clocks may offer to provide the cut acrylic.[200]



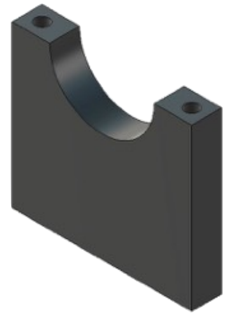
[200] For a price!

3D Printed Parts

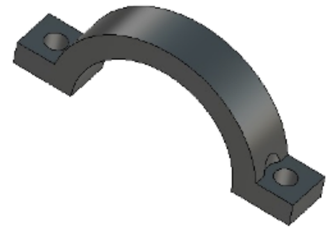
Socket Shield



Corner Pillars



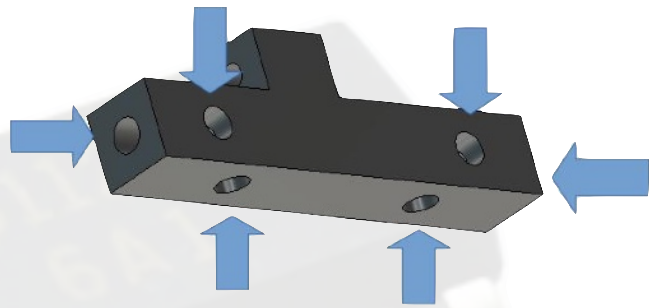
Neck Support



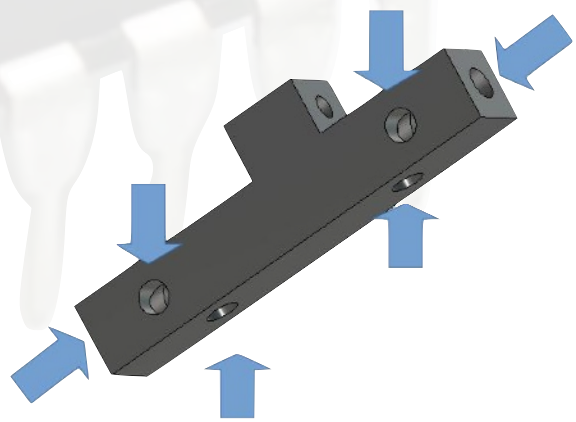
Neck Clamp

The brass melt-ins are fitted as follows.

Two of the 3D printed Corner Pillars each take six M3 brass melt-in on two adjacent sides and the two ends:

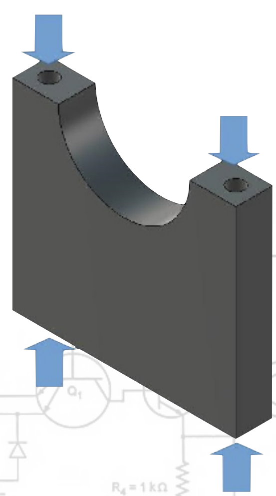


The other two Corner Pillars each take the six M3 brass melt-ins but mirrored on the sides adjacent to the peg:



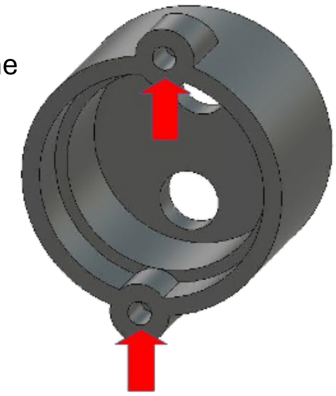
If this is not that clear to you, then wait to fit them until the step where the corner pillars are attached to the boards. The pillars are arranged so the melt-ins face outwards so the acrylic can be attached.

The 3D printed Neck Support takes four M4 brass melt-in inserts into the two top holes and two bottom holes.



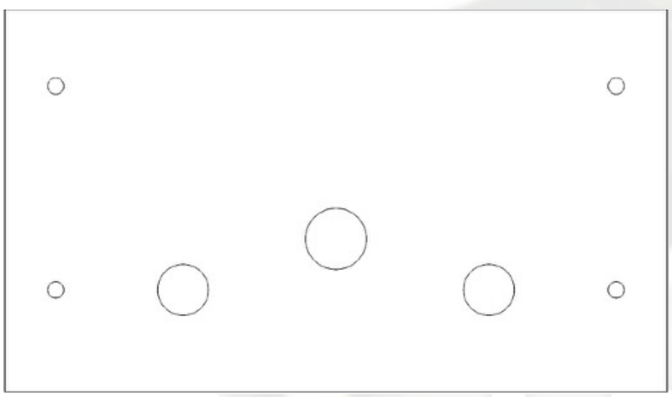
Finally, the CRT Socket Shield takes two M3 brass melt-ins:

It can take some practice to cleanly install the brass inserts and there are some jigs available to assist in getting them in nice and straight available on the usual online marketplaces. Don't fret if you screw one up as printing another part is very straightforward. If you need the brass inserts pre-installed, then please ask and for a small sum this can be accommodated.

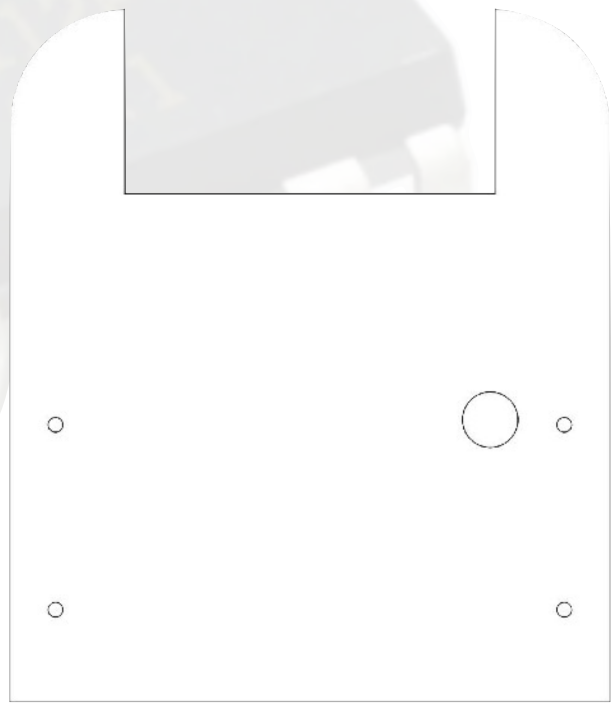


Acrylic Panels[201]

It is recommended to read the "Sgitheach – Acrylic Care" PDF in the Commoners folder of the Sgitheach public Dropbox. Also when handling and assembling the acrylic it is worthwhile wearing (cheap) cotton gloves to avoid finger prints on the acrylic panels once the protective film has been peeled off.



Back Panel

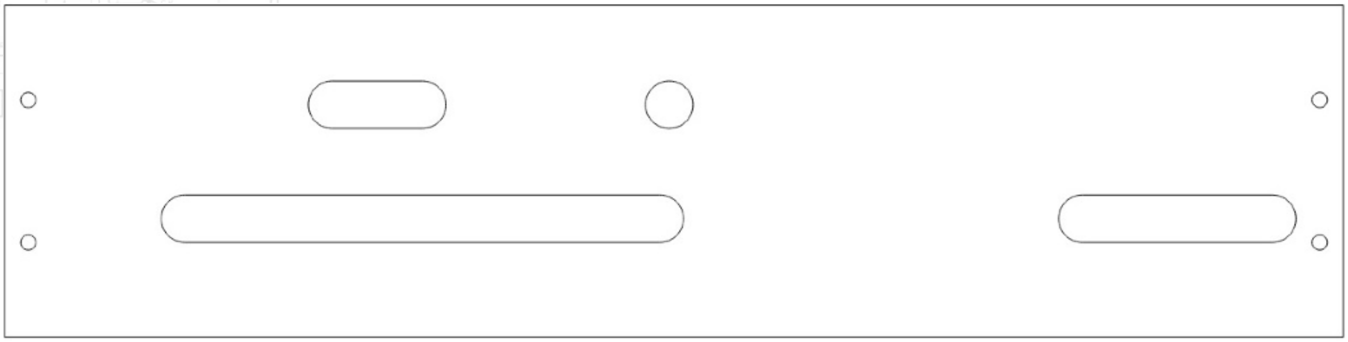


Left and Right mean when viewed from the front of the clock.

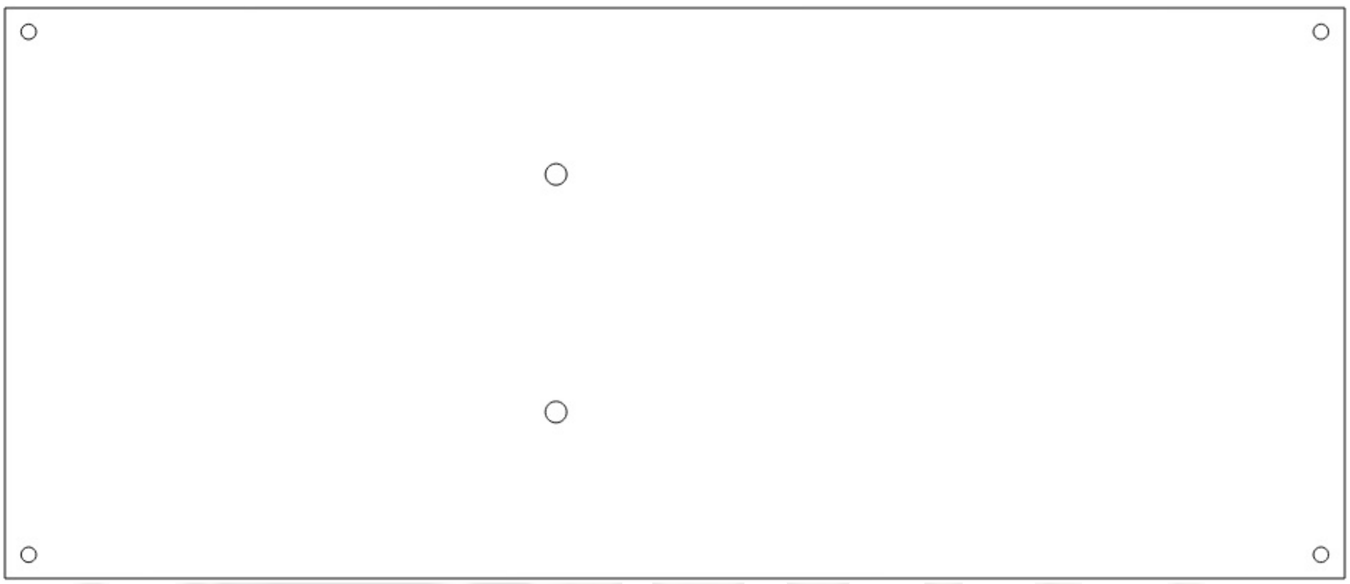
Left Panel

Front Panel

[201] These are **not** supplied in the kit.. all the plans are Open Hardware Design, so if you're building your own feel free to make your own colour statement!



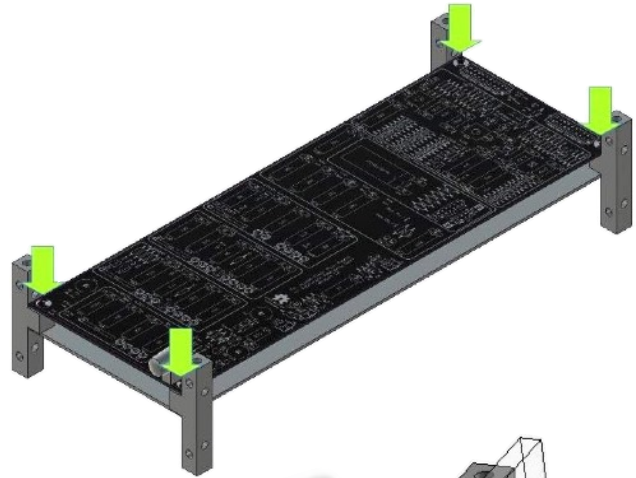
Right Panel



Top Panel

Bottom Panel

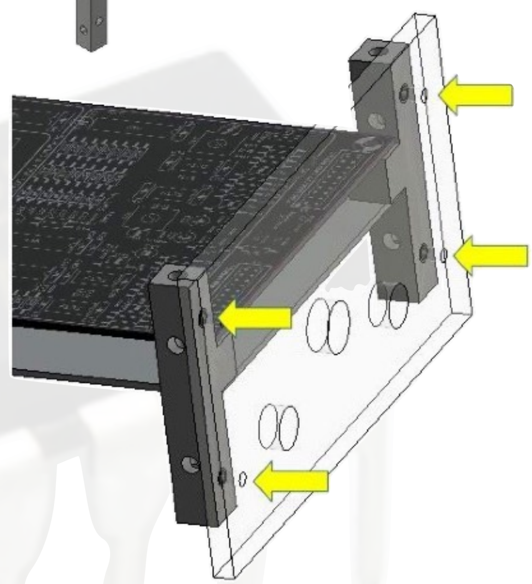
Assemble the PCBs onto the pillars



Fit the two PCBs together using the two inter-board connectors. Take the four Corner Pillars and insert the peg into each corner of the PCB pairs so that the pillar is on the long edge of each board and the brass melt-ins are all facing outwards. The longer leg of the pillar should be on the PSU & CRT board side.

Fix the boards into place using the M3x20mm bolts, washers and nuts.

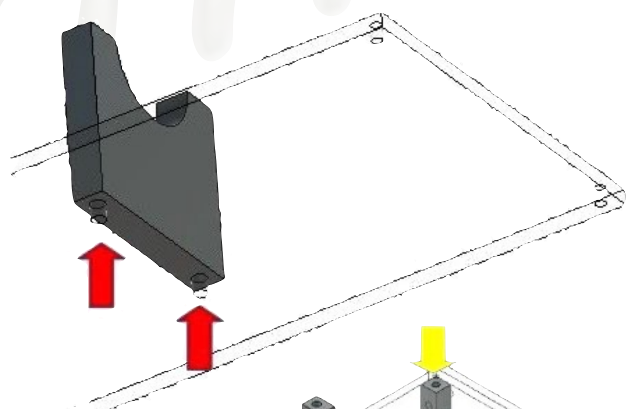
Attach the rear panel



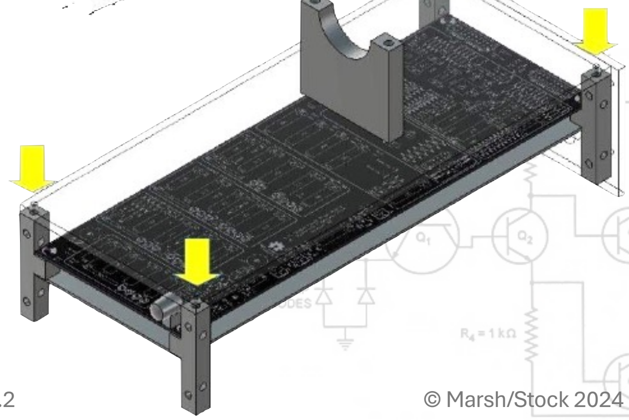
At this stage leave the protected film attached as it will be easy to remove it later and it will reduce the chance of damaging the acrylic as you complete the clock wiring.

Attach the rear acrylic panel to the rear two corner pillars using four M3x12mm bolts.

Prepare the neck support and attached the top panel



Attach the 3D printed neck support to the acrylic top panel using two M4x12mm bolts.



Attach the top panel to the tops of the corner pillars. Note that the neck support is offset from the centre of the top panel. The top panel should be attached with the neck support closer to the back of the clock.

Complete the wiring

During clock testing the B12-43 CRT socket was wired with lengths of HT and EHT wire. Arrange the wires into two bundles

1. Deflection plates and acceleration anodes (5 wires)
2. Heater, cathode, grid, focus anode (5 wires)

When installing and positioning the wiring try to keep these two bundles separated or else noise from the second bundle can transfer to the deflection wiring inducing glitches on the image. The kit contains shrink wrap to protect and strengthen the socket connections and spiral wrap to form neat bundles of the wiring.

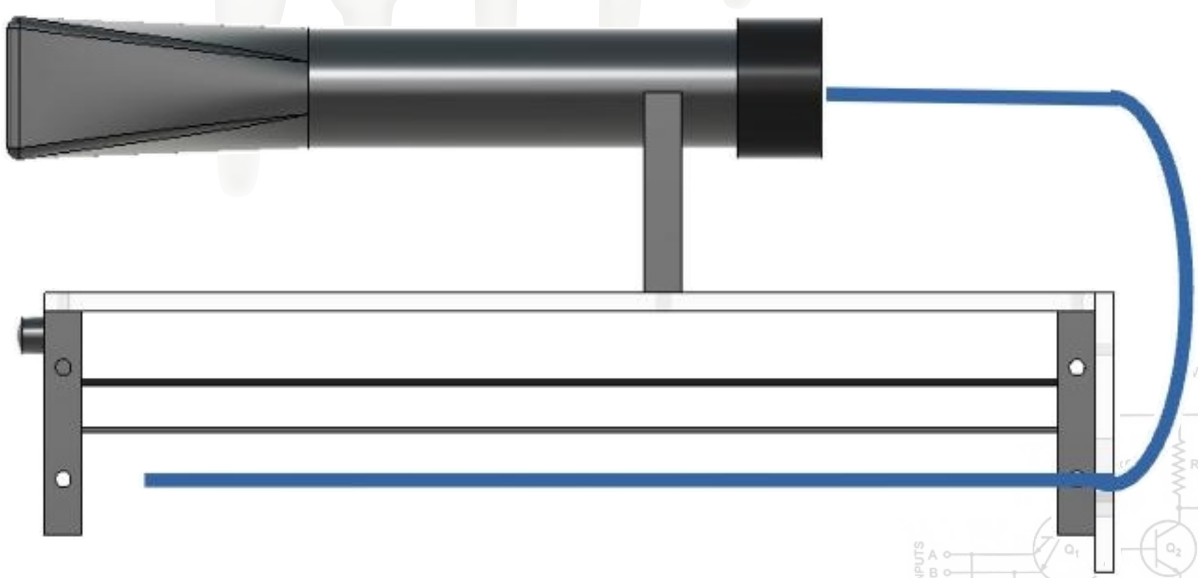
Thread each bundle through the holes in the socket shield, slide the socket shield up to the socket. Fix the socket using the socket's metal ring and two M3x6mm bolts. Make neat bundles of the wires using two lengths of spiral wrap. Try to push the spiral wrap up into the holes in the socket shield.

Thread the wrapped bundles of wires through the two holes in the rear acrylic panel. The deflection plate and anode wire bundle should go through the right hand hole (when viewed from the front). The heater, cathode etc. bundle should go through the left hand hole.

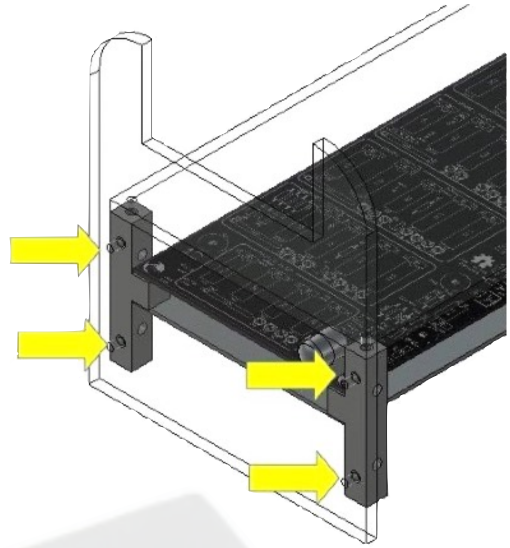
Judge where the socket will be with the CRT in place, use the CRT as a guide if you wish but I do not recommend mounting at this time. Shorten the deflection plate and anode bundle and make the connections to X7 and X8 on the PSU & CRT board.

Unwind the two heater wires from the spiral wrap as they pass near X11. Shorten the wires and make connections to X11.

Shorten the remaining bundle and pass it across the board to X10. Make the remaining three connections to X10. This is the sort of trajectory that the bundles should follow. They'll probably be more floppy.



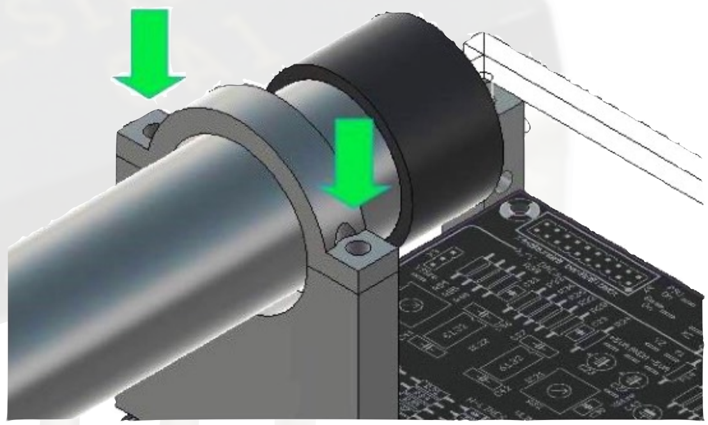
Fit the face plate and the CRT



Now it is time to start fitting the acrylic without the protective film.[202] Remove the top plate and the back plate and remove the protective film if you left it on and replace onto the pillars.

Remove the film from the front acrylic plate and attach using four M3x12mm bolts to the front pillars.

Stick a short length of foam rubber to the neck support for the neck to rest on and line the face plate opening with foam for the face to rest on. Orientate the socket to the key way is to the left (when viewed from the front) and then plug the CRT into the socket rotating as necessary to mate with the keyway[203].



Now lower the CRT into the neck support and face plate. Stick a short length of foam rubber to the neck clamp. Attach the neck clamp using two M4x16mm bolts and gently, very gently, apply enough pressure just to gently hold the tube in place.

RULE 1[204]:

NEVER, NEVER, NEVER USE THE CRT AS A HANDLE TO PICK THE CLOCK UP BY[205]

Final Adjustments and Testing

You now have a small pile of case components left, the two side panels, the bottom panel and some M3x12mm bolts. Now is a good time to make final adjustments to the various trim pots and jumpers. The tube can be influenced by the Earth's magnetic field so, if you can, make these adjustments with the clock in its intended operating position.

Final acrylic panels

After final testing and adjustment fit the remaining acrylic panels to the pillars using M3x10mm bolts. It should be fairly obvious how the acrylic fits so I'm not going to make out that it is byzantine and needs another graphic.

Job Done! Enjoy!

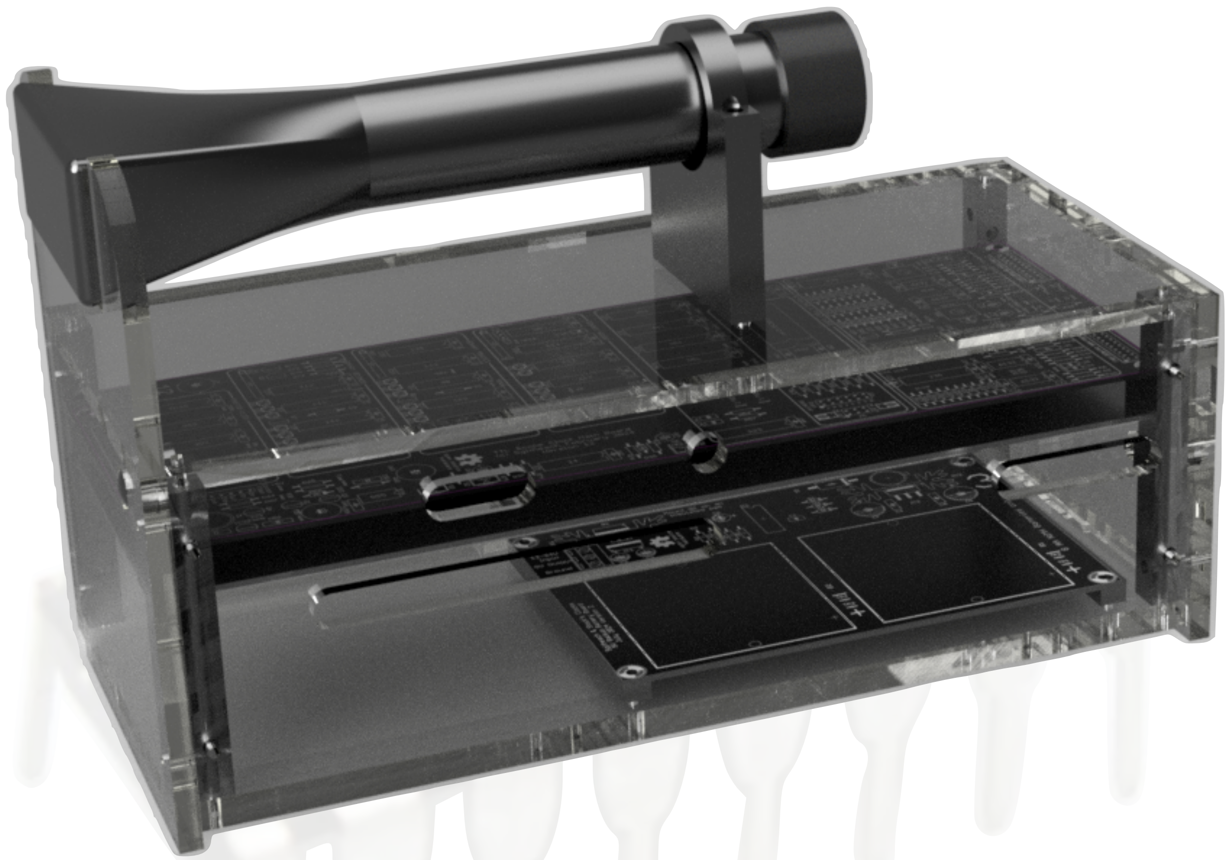
[202] Now is the time to wear cotton gloves so you don't get finger prints on the acrylic. Finger prints on the *inside* can be a bugger to clean off.
[203] If you don't do this then the clock face will be upside down! But a fault that is easy to correct.
[204] Also Rule 2, 3, 4 and 5....
[205] In this case, not "Do not act incautiously when confronting little bald wrinkly smiling men!"

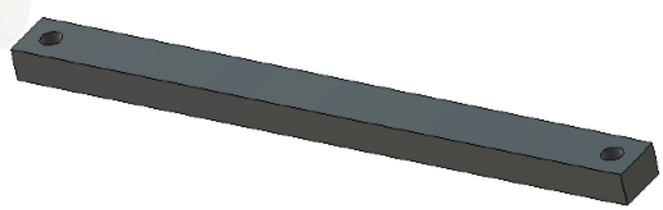
Changing the jumper settings

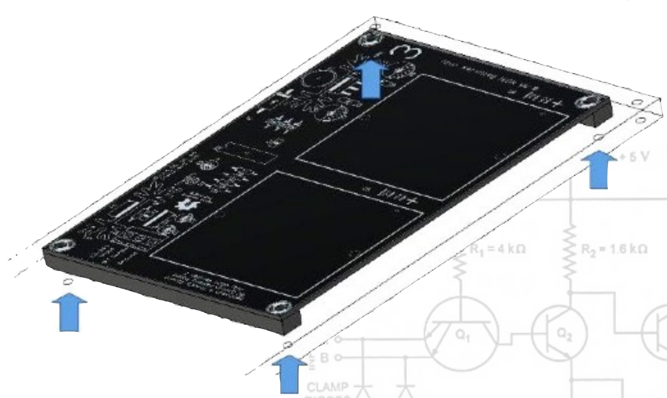
At some stage you might want to change the settings on the Digital and Analogue board. Settings like the selected font, selected colon, 12/24 hour display etc. To do this release the four M3 bolts holding the acrylic top plate on and lift it back and to one side. There should be sufficient play in the CRT leads to do this easily. Adjust. Reassemble.

Scope Clock TTL – Horizontal Case with Battery Backup and Charger

This case is an enlarged version of the case described in the previous section. The box section is made 25mm taller to accommodate the battery back up and charger board.[206]







The side acrylic panels are taller and the corner pillars are stretched to give the extra height. Assembly is identical with the just the addition of the battery backup and charger board. This is mounted on the bottom acrylic through four new M3 holes. A spacer separates the board from the acrylic.

Four M3x15mm bolts, washers and nuts are used to mount the board through the spacer.

Three wires link the board to the CRT & PSU board 3 way screw connector X3. N.B. Jumper J1 on the CRT & PSU board must **not** be fitted.

206 http://www.sgitheach.org.uk/batterybu.html

Scope Clock TTL – Vertical Case Assembly[207]

This case design was inspired by the unique Simpson Mirroscope.[208] This oscilloscope has the tube mounted vertically and a mirror for front viewing of the tube. The oscilloscope has a small footprint on the equipment bench. The vertical case version does the same! The CRT is mounted vertically with a mirror for front viewing. The digital and analogue board faces forward so all of the binary counter LEDs are visible.

A link on the project website will take you to a 3D render of the case that can be rotated, zoomed etc.

The case is made from 3D printed parts and laser cut acrylic. There are two sets of files for the laser cut acrylic: one set for 6.35mm thick acrylic (USA) and one for 5mm thick for everyone else. The STL files for the 3D printed parts and DXF files for the laser cut acrylic are available from the project Dropbox.

At present the design is only suitable for 3SP1 CRT. Modified versions will be needed for other CRT. The modifications are simple to make.

63

Frank J. Moch says—
"there is no other OSCILLOSCOPE like the NEW Simpson MODEL 476 MIRROSCOPE"

FRANK J. MOCH, president of the National Alliance of Television and Electronics Service Associations.

Simpson's new and completely advanced type of oscilloscope—Model 476 MIRROSCOPE—is designed to eliminate certain inherent disadvantages found in the conventional type of oscilloscope by use of the "Mirroscope principle." In this kind of construction the 5-inch cathode ray tube is mounted in a vertical position, thus reducing bench space requirements to an area of only 9" x 8" thereby permitting better concentration of associated equipment for any type of test procedure. The cathode ray image is reflected from an optical type front surfaced mirror mounted in the adjustable cover at the top of the cabinet bringing the viewing surface of instrument near eye level when instrument is used on benches of normal height. The mirror angle is quickly and easily adjusted to any position of the operator. The cover with integral side wings forms an effective shield against external light sources or may be closed down for protection of the tube and mirror when the instrument is not in use. The upright construction permits location of controls and connections for maximum convenience and allows for internal cathode ray tube connections at the front of the panel instead of the rear.

SENSITIVITY:
Vertical direct.......12 volts rms per in.
Vertical amplifier.20 millivolts rms per in.
Horizontal direct.....14 volts rms per in.
Horizontal amplifier.....38 millivolts rms per in.

INPUT IMPEDANCE:
Vertical direct.....10 megohms, 15 mmf.
Horizontal direct...10 megohms, 15 mmf.
Vertical amplifier.300,000 ohms, 30 mmf.
Horizontal amplifier......500,000 ohms, 15 mmf.

Horizontal trace expansion is over 4 times tube diameter. This makes it possible to examine minute portions of a response pattern for finer detail.

Linear Sweep frequency is continuously adjustable in five overlapping ranges from 15 cycles to 60,000 cycles. Internal, external or line frequency synchronization with variable amplitude is available.

Means for intensity or "Z axis" modulation is provided. Approximately 14 volts peak will blank a trace of normal intensity.

The vertical amplifier frequency response is within 3 DB from 20 cycles to over 300,000 cycles and is usable to well over three megacycles. Square wave slant and over-shoot is held to less than 5 per cent of amplitude. This response will be found adequate for all phases of television receiver service including observation and diagnosis of Sync. signals.

TUBE COMPLEMENT:
5UP4 Cathode Ray Tube.
4—6J6 Horizontal and Vertical Amplifiers.
1—12AU7 Vertical pre-amplifier.
1—6J6 Linear Sweep oscillator and Sync. injector.
2—6X4 High voltage rectifiers.

LINE VOLTAGE: 105-125 volts, 50-60 cycles.
SIZE: Height 16¼"; Width 9⅛"; Depth 8" over all
WEIGHT: 25 lbs.; Shipping weight 30 lbs.
Hight Frequency Crystal Probe...$7.50
DEALERS NET PRICE including operators manual $179.50

CONSERVE CRITICAL MATERIALS

SIMPSON ELECTRIC COMPANY
5200 W. Kinzie St., Chicago 44, Ill.
Phone: Columbus 1-1221
In Canada:
Bach-Simpson Ltd., London, Ontario

BURTON BROWNE ADVERTISING

MAY, 1951

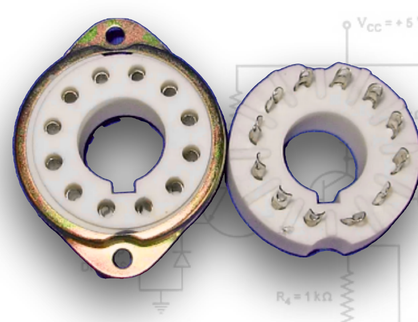
[207] https://en.wikipedia.org/wiki/Vehicle_Assembly_Building
[208] https://www.oscilloscopemuseum.org/oscilloscope-simpson-476-sxxx.html

Parts List

Tick	Quantity	Part	Notes
☐	1	CRT B12-43 socket	See note 1.
☐	2	Long M3 brass melt-in insert 5mm diameter, 5mm long	To mount the CRT socket on the 3D printed CRT socket holder
☐	2	M3x6mm bolt	
☐	5	3D printed part	See note 2. See 3D part section below
☐	5	Laser cut acrylic panel	See acrylic section below
☐	1	Laser cut acrylic mirror	70mm x 100mm
☐	1	120mm length 6mm diameter aluminium or acrylic rod	Supplied oversize to be cut to length
☐	2	Short M3 brass melt-in insert 4.3mm diameter, 3mm long	Mirror holder rotation
☐	2	Long M3 brass melt-in insert 5mm diameter, 5mm long	Mirror holder rod locks
☐	2	M3x12mm grub screw	To lock the rod in place
☐	2	M3x10mm thumb screw	To lock the mirror support in place
☐	2	M4 brass melt-in insert 6mm diameter, 5.6mm long	To mount the mirror bracket onto the top plate
☐	2	M4x20mm bolt	
☐	18	M4 brass melt-in insert 6mm diameter, 5.6mm long	To mount the acrylic panels onto the sides of the top and bottom 3D printed plates
☐	18	M4x0mm bolt	
☐	2	M4x16mm bolt	Mount the mirror bracket onto the top plate
☐	4	M3x20mm bolt	To mount PCBs back-to-back on the top and bottom plates
☐	4	M3 washer	
☐	4	M3 nut	
☐	3	M4 brass melt-in insert 6mm diameter, 5.6mm long	To mount the CRT socket support onto the base plate
☐	3	M4x10mm bolt and washer	
☐	1	2.1mm plug and lead	Pre-assembled
☐	1	2.1mm chassis mounting socket	DC-022
☐		HT and EHT wire	
☐		Spiral wrap	
☐		Shrink wrap	

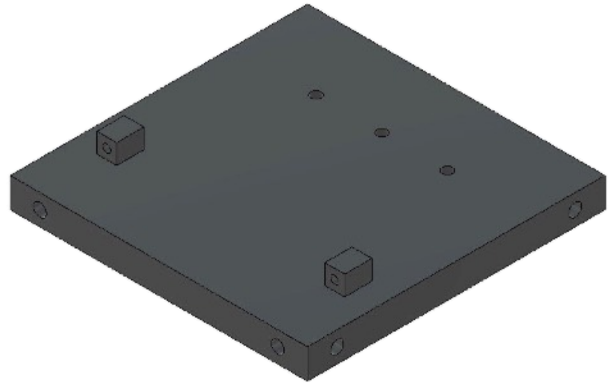
Notes:

1. The D12-43 (B12A) base supplied in the standard 3SP1 kit that the 3D printed part has been design to use looks like this (see right):
2. HT and EHT wire for a 3SP1 CRT is supplied in the PSU & CRT kit.
3. The 3D printed PIR support is in the digital and analogue board kit.
4. The list includes M3 and M4 melt-in (or heat-set) brass inserts. There are loads of videos on You Tube showing how these can be placed using a soldering iron.
5. The kit comes without the acrylic panels. If you want them, then the files are available of the project Dropbox our if you're in the US, StocksClocks can provide them.

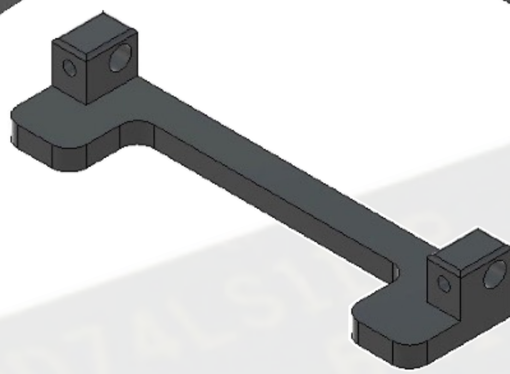


3D Printed Parts

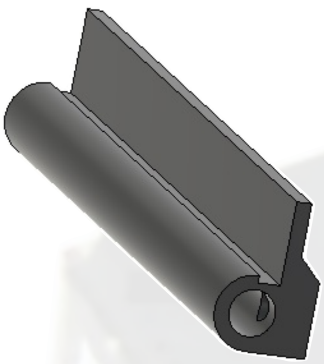
Top Plate



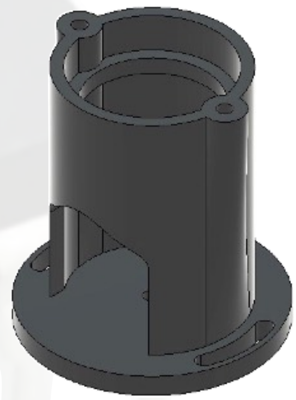
Bottom Plate



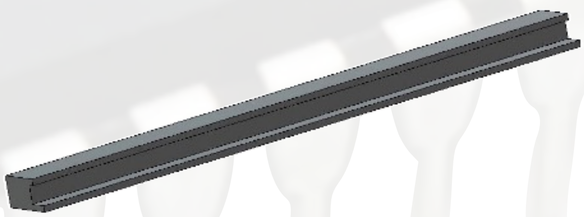
Mirror Bracket/Hinge



Mirror Holder

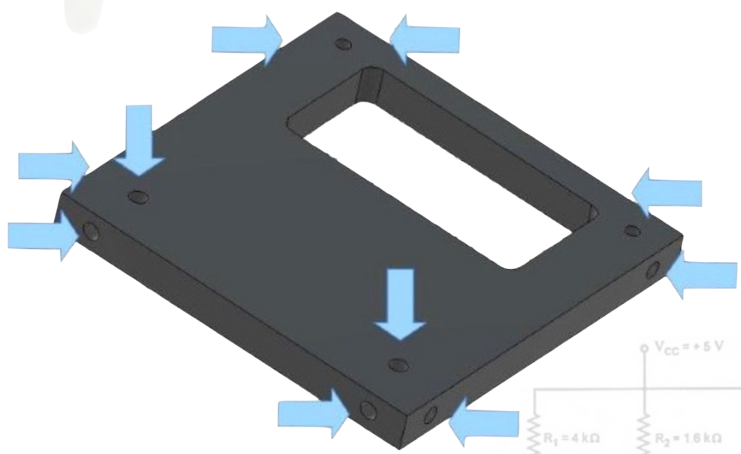


CRT Socket Holder



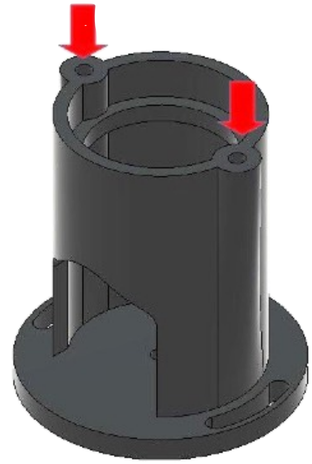
Mirror Guard

The brass melt-ins are fitted as follows.

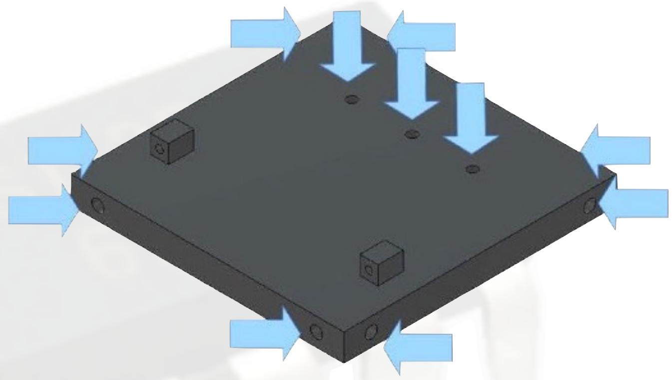


The 3D printed Top Plate takes eight M4 brass melt-in threads around the edges and two into the top. The two holes on the top face near to the CRT face opening remain unused. There are a lot of inserts here, so take your time and get them nice and straight. Whilst you can always print a new piece should things go wrong, this part does take several hours to print in a suitable quality.

The 3D printed CRT Socket Holder takes two long M3 brass melt-ins:

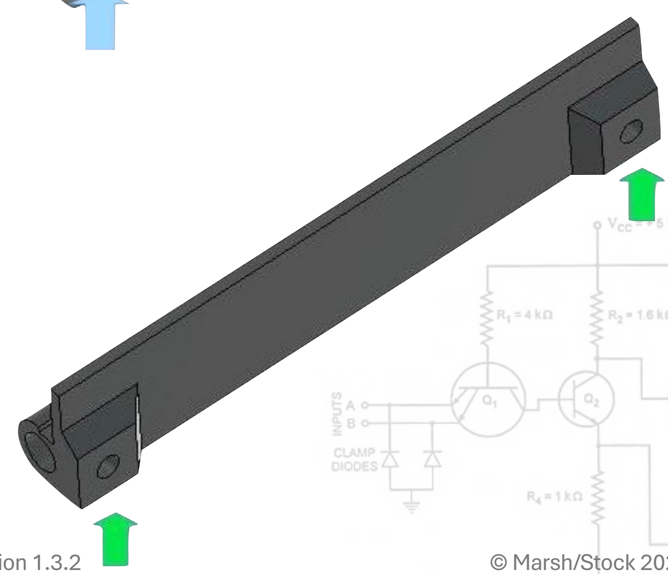


The 3D printed Bottom Plate takes eight M4 brass melt-in sockets around the edges and three into the top surface. Again, take the time to make them nice and straight and even. Make sure that they are melted in to just below the surface of the 3D print.



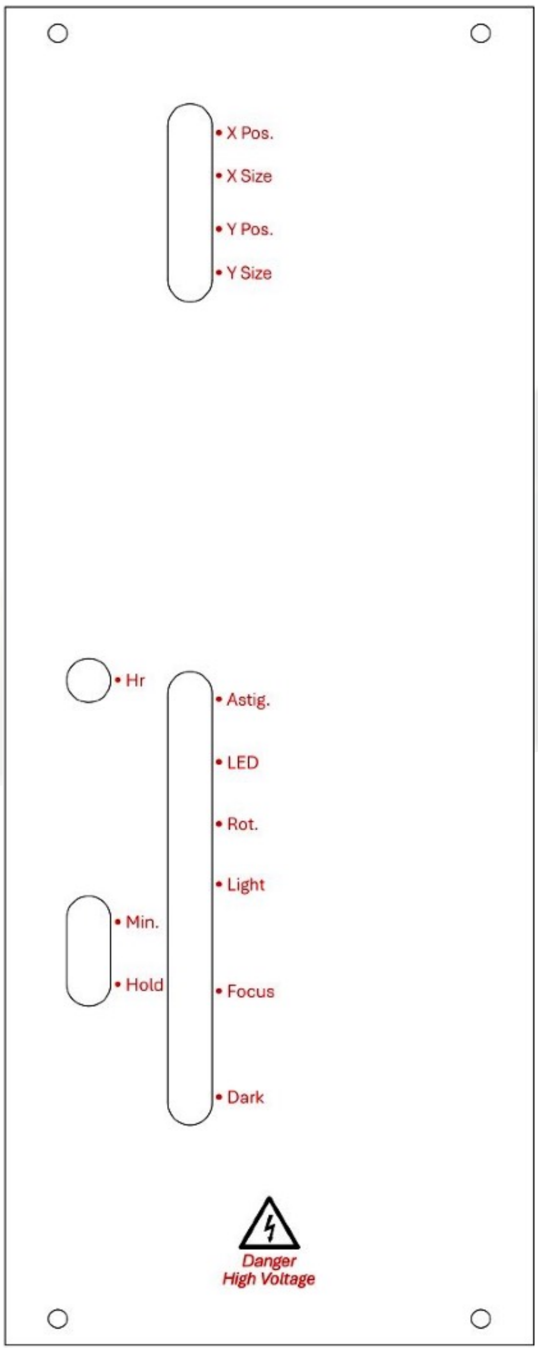
The mirror bracket takes two M4 brass melt-ins (take care not to insert too far or else the top of the part may be damaged) and two long M3 brass melt-ins:

Finally, the mirror holder takes two short M3 brass melt-ins (take care not to insert too far or the 6.5mm diameter hole for the hinge rod may be damaged and the rod won't fit):

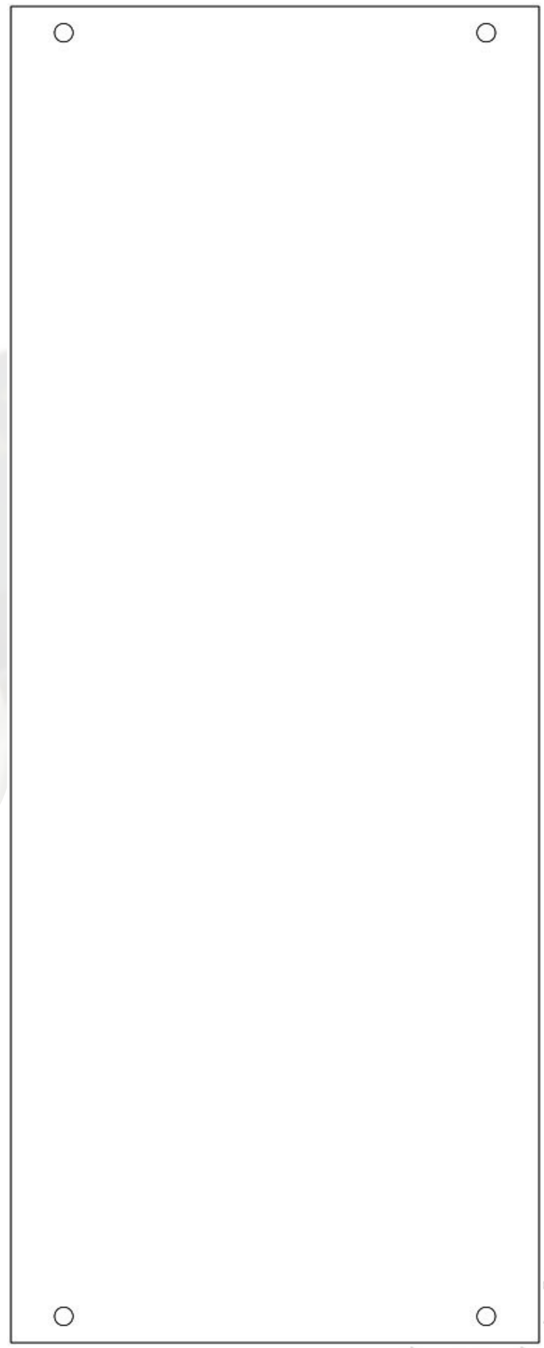


Acrylic Panels

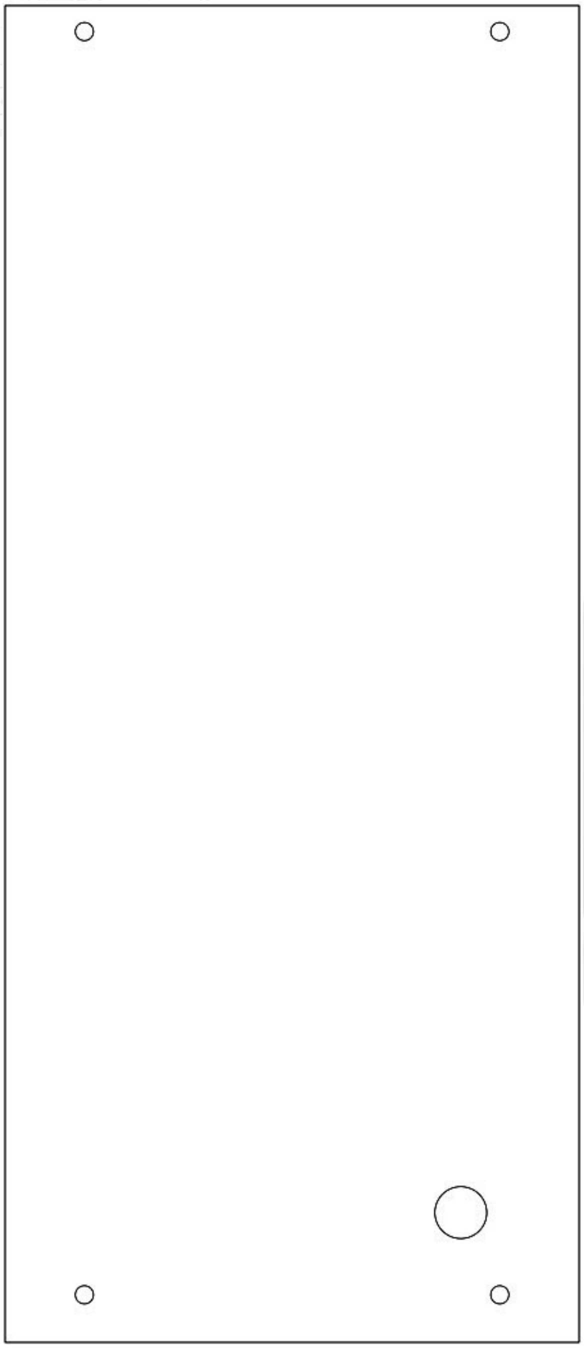
It is recommended to read the “Sgitheach – Acrylic Care” PDF in the Commoners folder of the Sgitheach public Dropbox. Also when handling and assembling the acrylic it is worthwhile wearing (cheap) cotton gloves to avoid finger prints on the acrylic panels once the protective film has been peeled off.



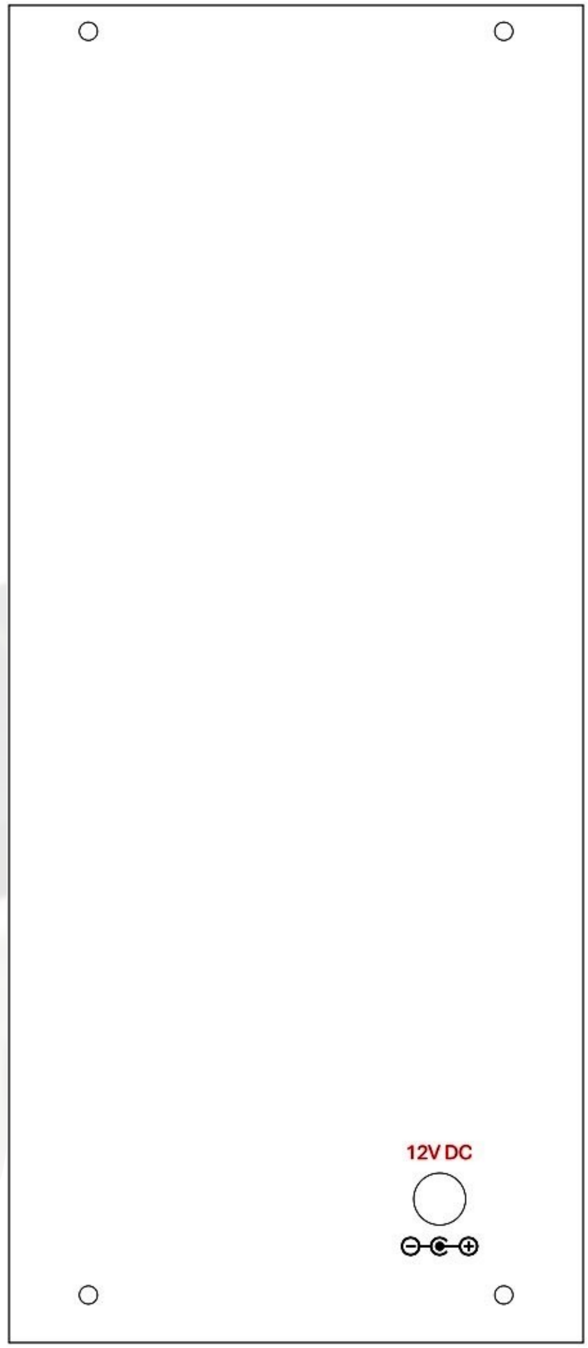
Right Plate (with engraving)



Left Plate

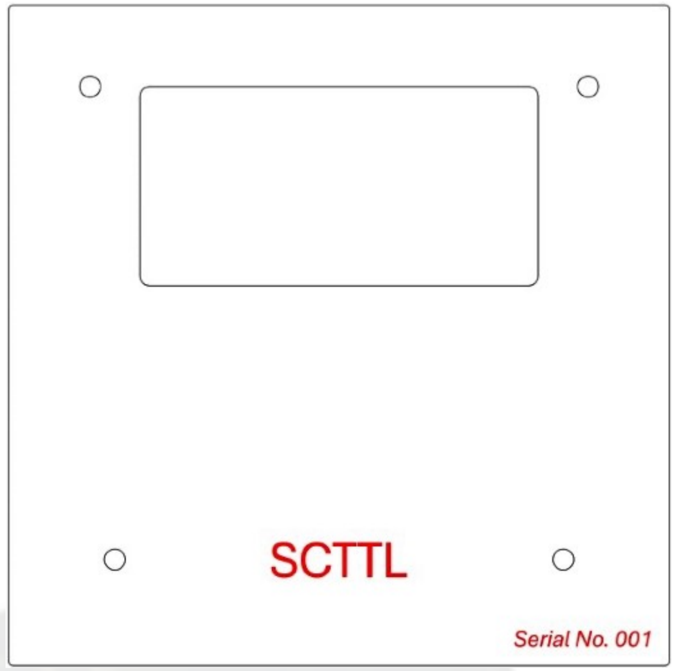


Front Plate



Rear Plate (with engraving)

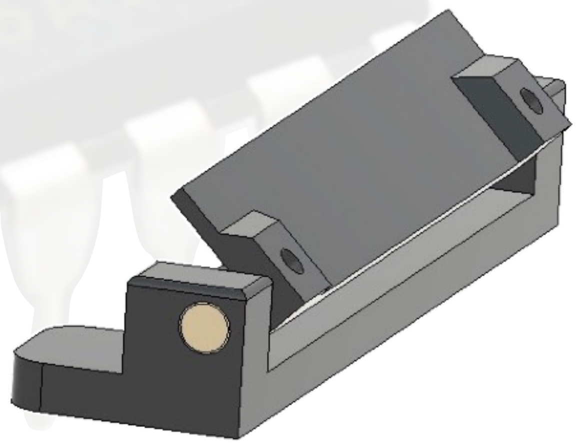
There is also a specially engraved finish plate for the top of the case in a matte black acrylic. The body of the case is supplied in a glass green style acrylic, but can also be provided in a clear version.



Finish Plate

Assemble the top plate and mirror assembly

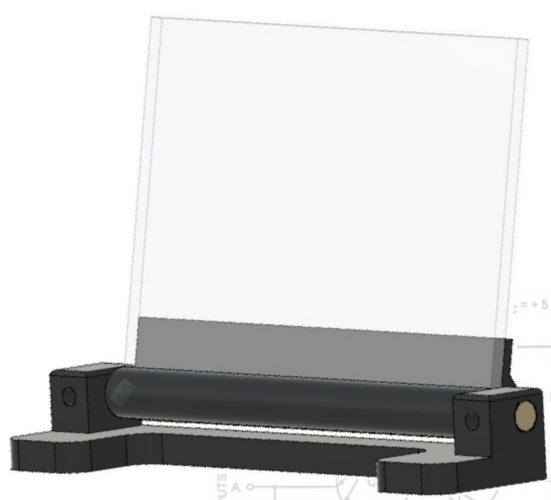
Trim the aluminium[209] or acrylic rod to exactly 100mm in length and clean the ends to give a nice appearance. Insert the M3x10mm thumb screws into the mirror holder and insert the M3x12mm grub screws into the mirror bracket. Fit the mirror holder between across the mirror bracket and push the rod through the holes in both parts:



Note the orientation of the mirror holder with the M3 inserts to the back. The mirror holder should freely rotate through about 90°. Tighten the two M3x12mm grub screws so the rod is gripped appropriately. The thumb screws can be left loose at this time.

At this time you can choose to fit the mirror or not. It will be easy to fit at a later stage.

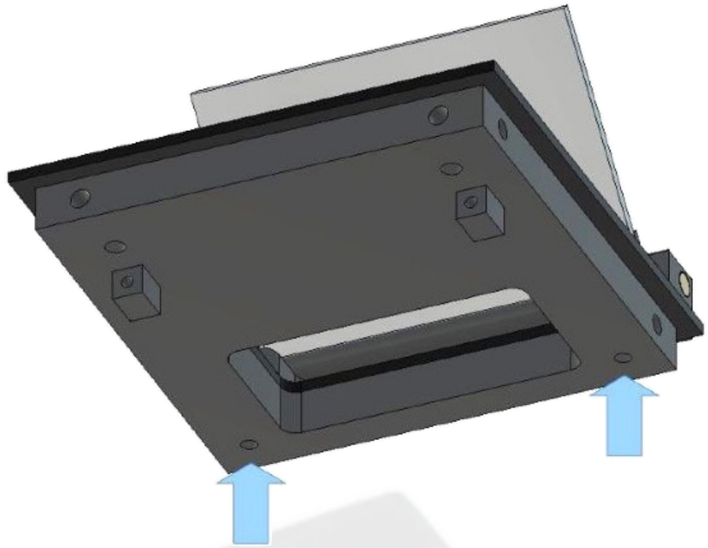
To fit the mirror, peal back the protection film along one long edge. Apply a small amount of glue[210] to the long tab on the 3D printed mirror holder and a sparingly small amount into the groove and press the mirror into place.



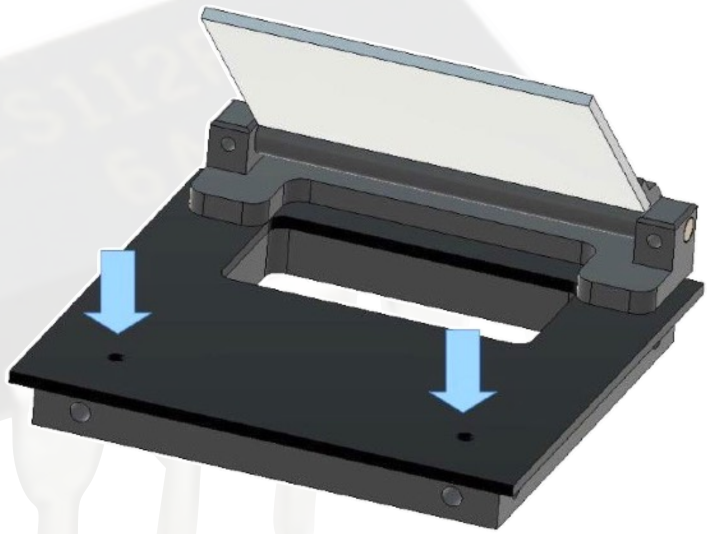
The mirror has been rendered transparent in this image. Glue the mirror guard 3D printed part along the top edge. Be careful not to use too much adhesive. **DO NOT** clean the mirror acrylic with IPA as this can cause the mirrored backing to delaminate from the acrylic.

[209] Yes. that is the CORRECT spelling. Get over it.
[210] A good quality super glue works, especially the thick viscosity stuff.. i.e. gluemasters.com

Next, fix the mirror assembly to the top plate using two M4x20mm bolts through the top finish acrylic panel from top plate from its underside.

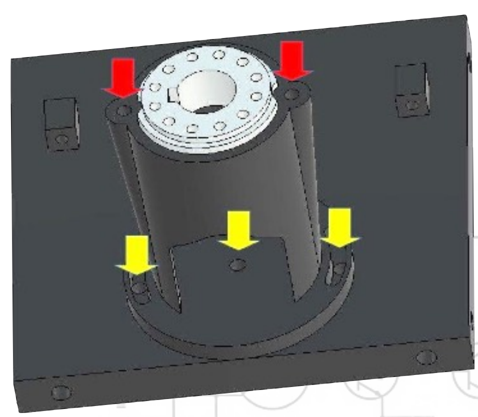


Then bolt the top finish panel down to the top plate using two M4x10mm bolts. This completes the top plate and mirror assembly.



<u>Installing the Socket</u>

Mount the 3D printed CRT socket holder onto the 3D printed base plate using three M4x10mm bolts and washers (yellow). The centre bolt should not be fully tightened as it is used to provide a point of rotation for the CRT socket. The outer two bolts can be left slightly tightened. These will be fully tightened when the CRT is fitted.



The socket should be fully wired from earlier testing. Arrange the wires into two bundles

- Deflection plates and acceleration anodes (5 wires).
- Heater, cathode, grid, focus anode (5 wires).

When installing and positioning the wiring try to keep these two bundles separated or else noise from the second bundle can transfer to the deflection wiring causing glitches on the image.

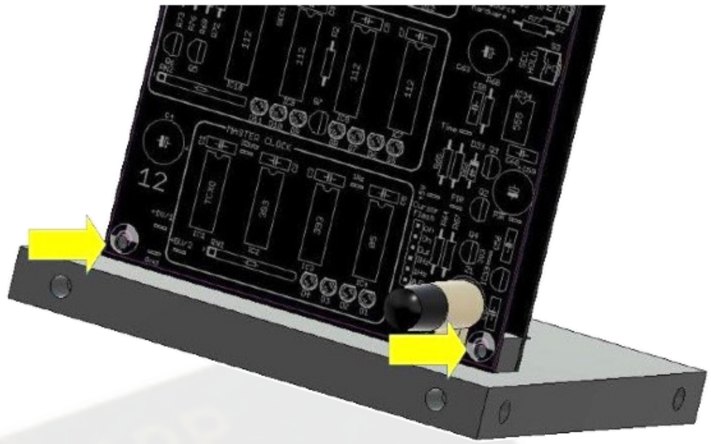
The kit contains shrink wrap to protect and strengthen the socket connections and spiral wrap to form neat bundles of the wiring.

The socket is mounted into the top of the CRT support on the bottom 3D part. The socket key is oriented to the right when viewed from the front (so to the left in the image). The socket metal retaining ring (not shown) is put in place and two M3x6mm bolts (red) are used to clamp it in place.

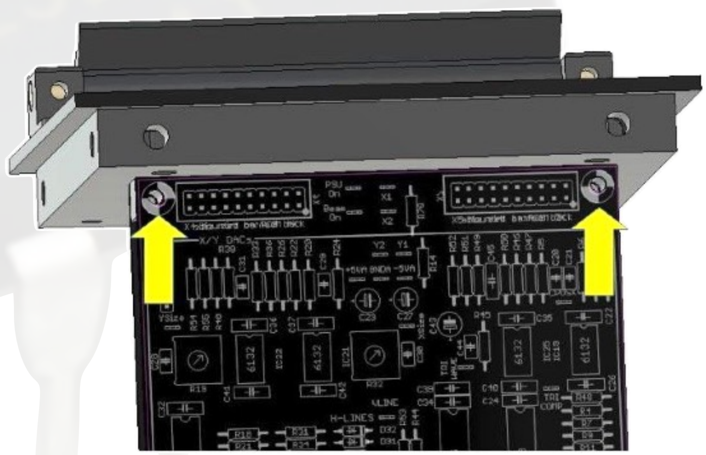
<u>Installing the Boards</u>

The boards are mounted vertically on the 3D printed base plate's square pegs with the inter-board connectors and 12V socket at the top and the PIR sensor at the bottom.

The boards are attached to the bottom plate using two M3x20mm bolts, washers and nuts.



The top plate and mirror assembly is fixed in the same way using two M3x20mm bolts, washers and nuts.



<u>Final Wiring</u>

Now you have the CRT socket in place and the PCBs fixed in position you can complete the wiring from the socket to the boards. Use spiral wrap to form neat bundles. Remember to keep the two bundles apart.

You can now fit the 3SP1 CRT. The CRT is normally a fairly tight fit in the socket so take care and take your time to work it in. The 3SP1 specification is that the key on the base should align ±10° with the CRT face. Rotate the CRT socket support to make the CRT face square with the top plate and then tighten the outer two 10mm bolts to lock it in position.

You'll now have this assembly:

Final Testing and Adjustments

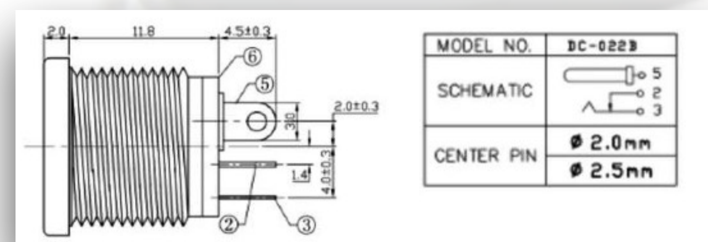
Now is a good time to make final adjustments to the various trim pots and jumpers. The tube can be influenced by the Earth's magnetic field so, if you can, make these adjustments with the clock in its intended operating position. When you are satisfied that everything is 100% then proceed.

When Fitting the Acrylic Panels

Remove the protective film from the acrylic panels.[211] It should be fairly obvious how the acrylic fits so I'm not going to make out that it is byzantine and needs another graphic!

Fitting the rear power connector

Shorten the power plug lead to about 370mm. Solder the power lead to the rear power socket. All that remains is to attach the four acrylic panels around the case including the rear power connector and lead.



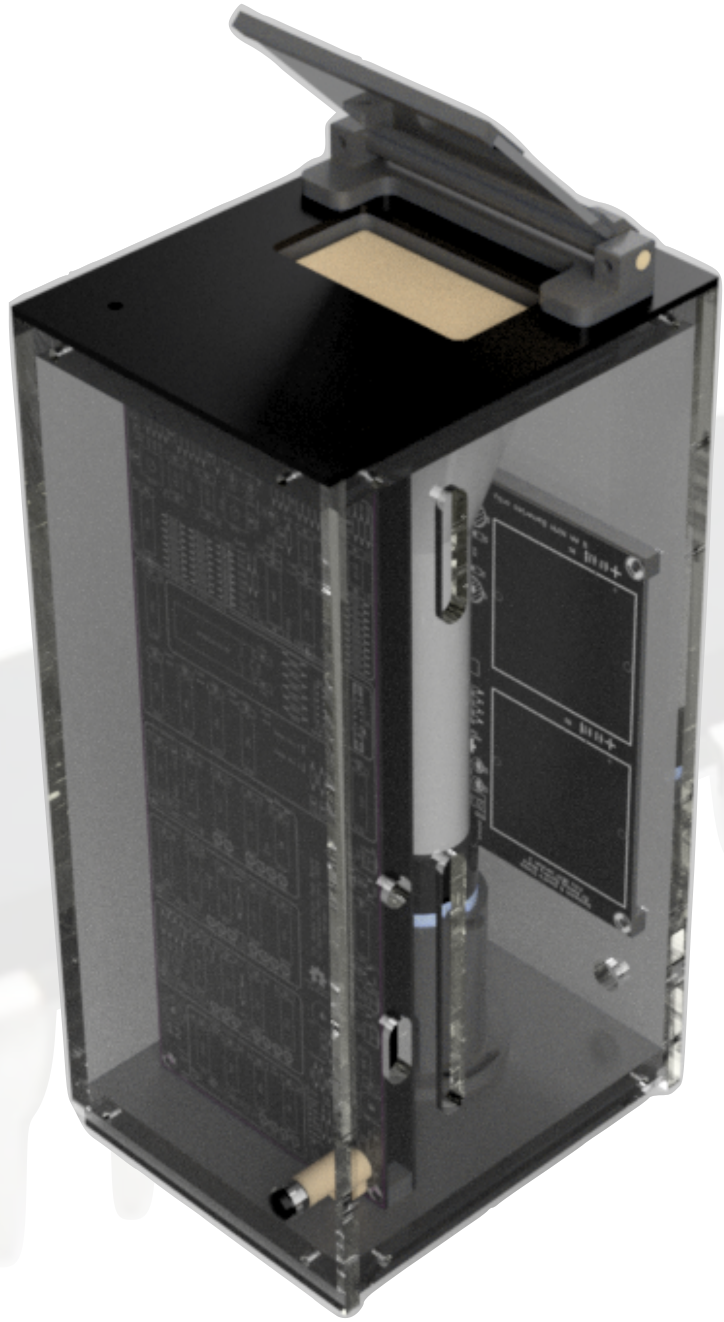
The power plug's red wire should be soldered to pin (5) on the rear power socket and the black lead should be soldered to both (2) and (3). Use short lengths of heat shrink tube to strengthen and protect the joints. **Important!** Now use a multimeter to double check that the inner hole on the power plug connects to the centre pin on the rear power socket and the outer contact on the power plug connects to the outer contact on the rear power socket. Continuity for both wires is essential. Reverse polarity is to be avoided. In either case the clock won't work! Push the rear power socket through the hole in the acrylic back panel, thread the nut over the lead and tighten the fixing bolt. When you are ready to attached the rear panel plug in the lead to the power socket on the PSU and CRT board.

Adjust the mirror for good viewing and lightly tighten the thumb screws.

Job Done! Enjoy!

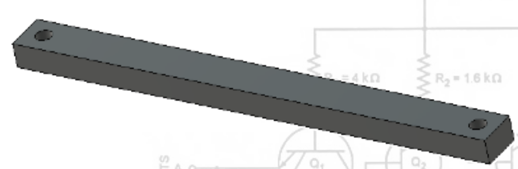
211 Now is the time to wear cotton gloves so you don't get finger prints on the acrylic. Finger prints on the *inside* can be a real bugger to clean off.

Scope Clock TTL – Vertical Case with Battery Backup and Charger



This case is an enlarged version of the case described in the previous section. The box section is made 25mm deeper to accommodate the battery back up and charger board.[212]

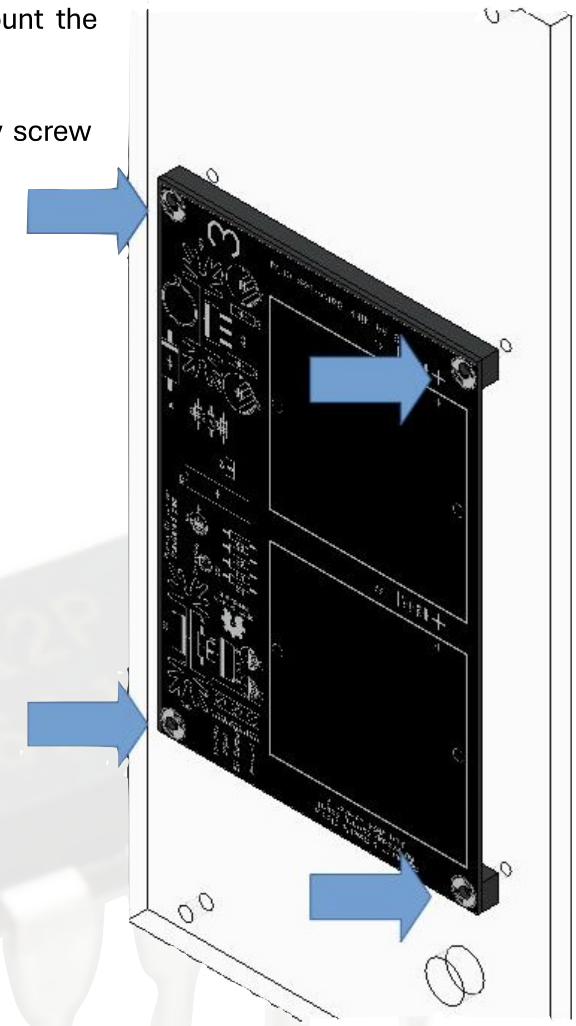
The bottom and top 3D printed parts and the top acrylic finisher panel are made larger. Assembly is identical with the just the addition of the battery back up and charger board. This is mounted on the back acrylic through four new M3 holes. A spacer separates the board from the acrylic.



[212] http://www.sgitheach.org.uk/batterybu.html

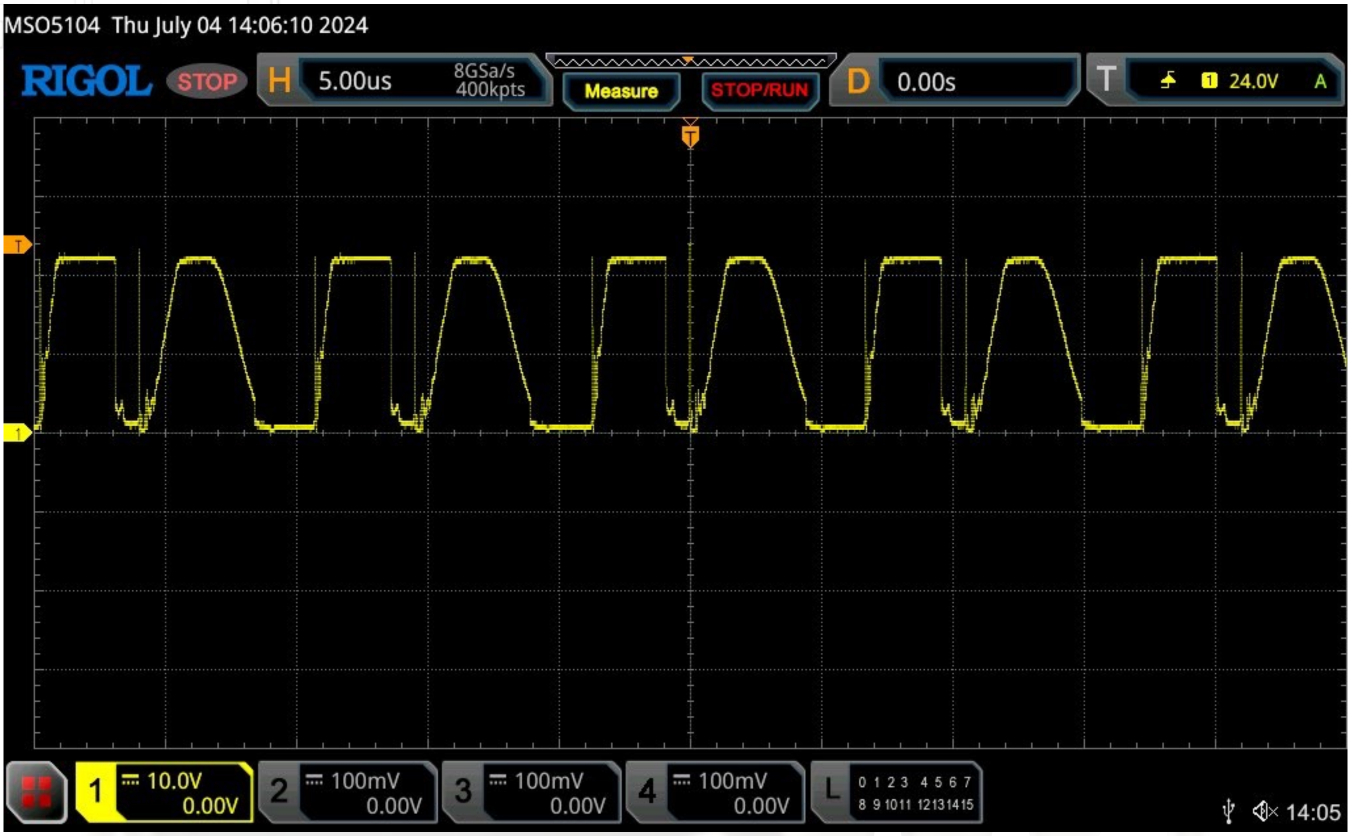
Four M3x15mm bolts, washers and nuts are used to mount the board through the spacer.

Three wires link the board to the CRT & PSU board 3 way screw connector X3. N.B. Jumper J1 on the CRT & PSU board must **not be fitted**.

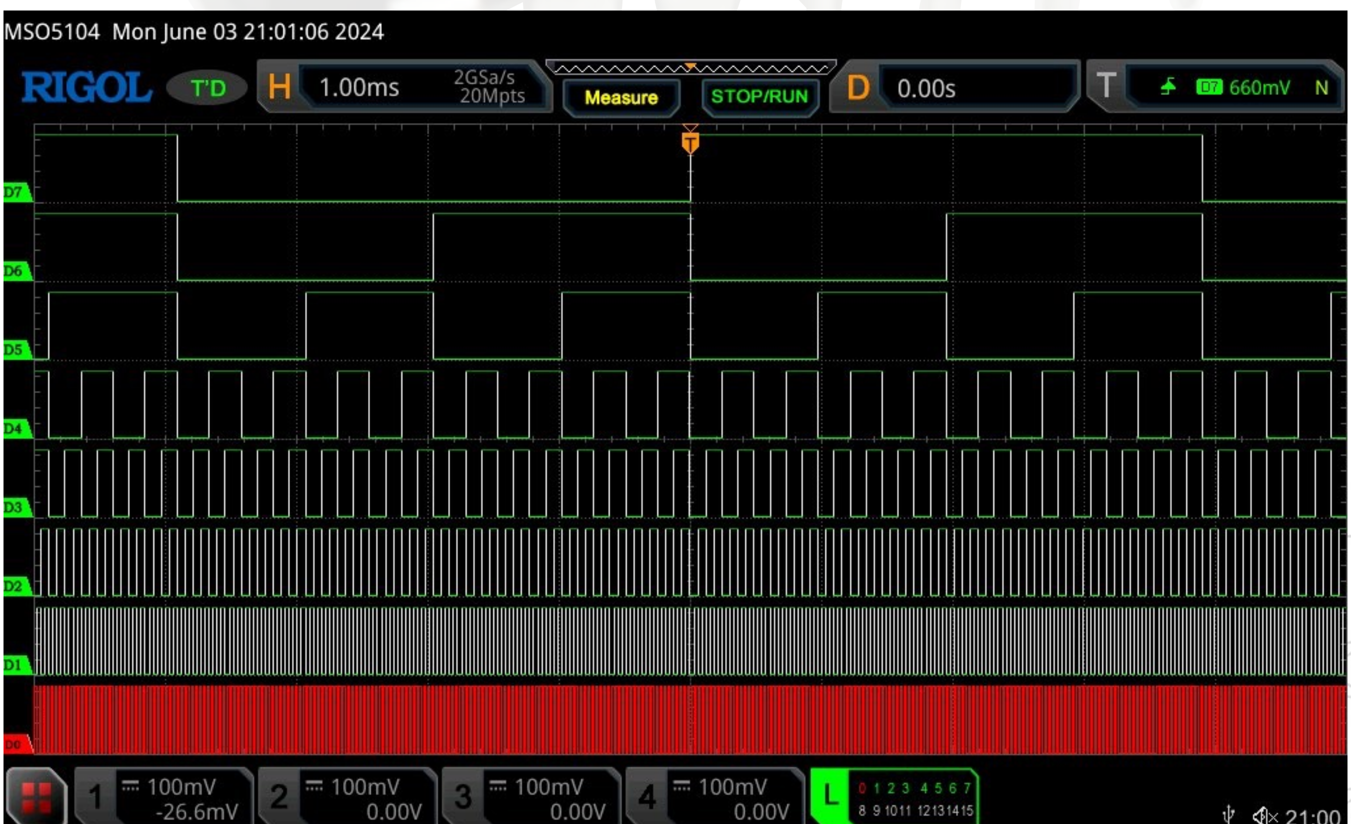


Annex A - Oscilloscope Images

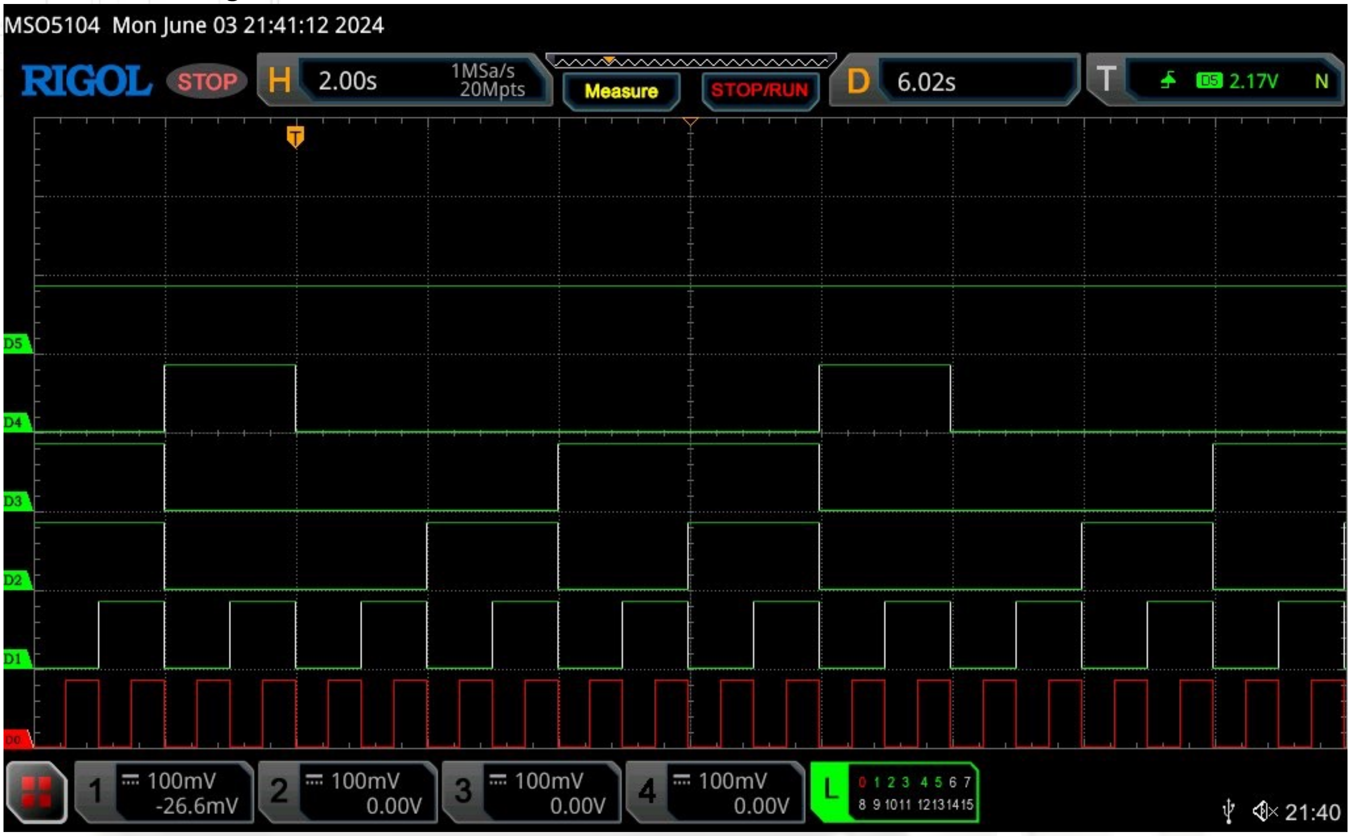
Flyback functioning



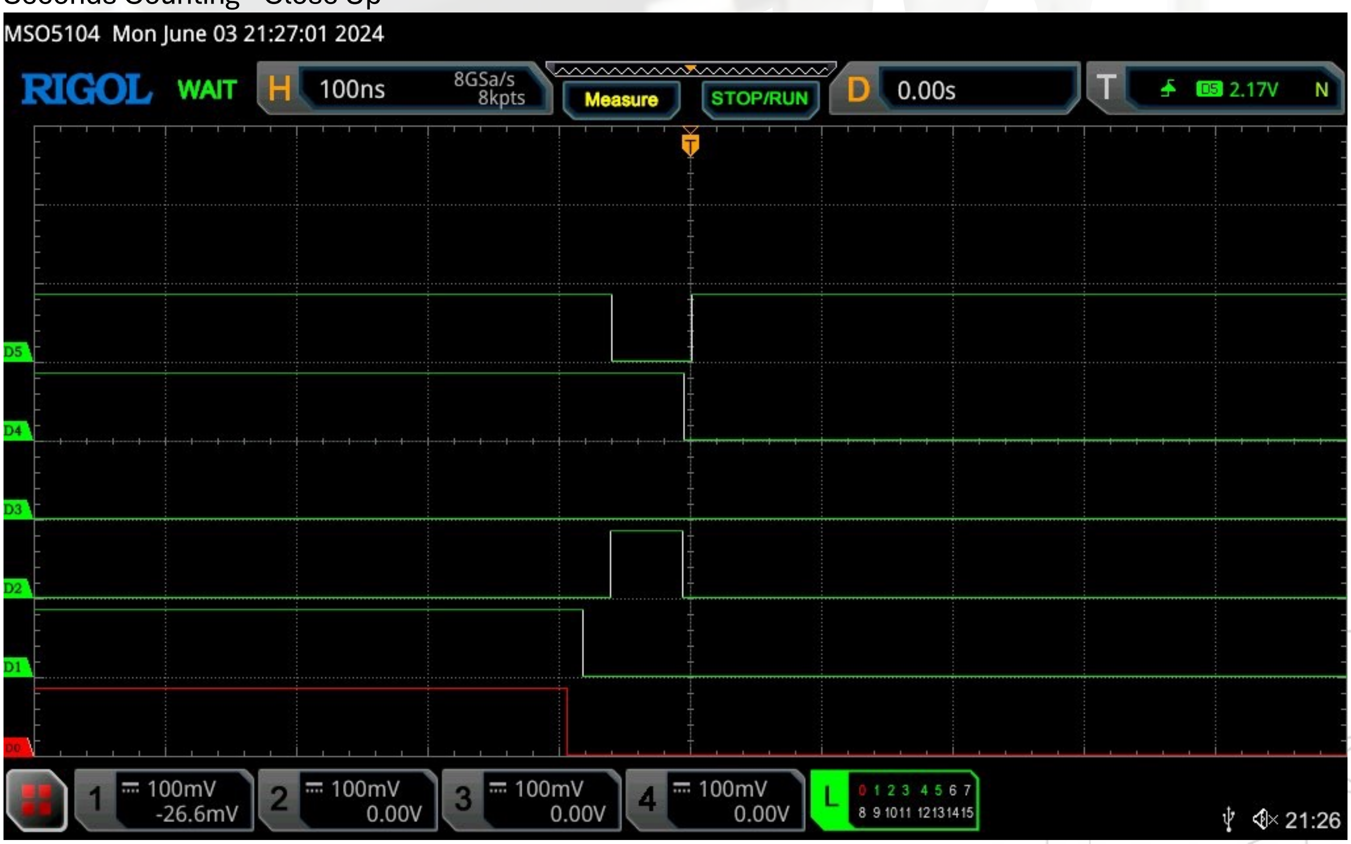
Master Clock



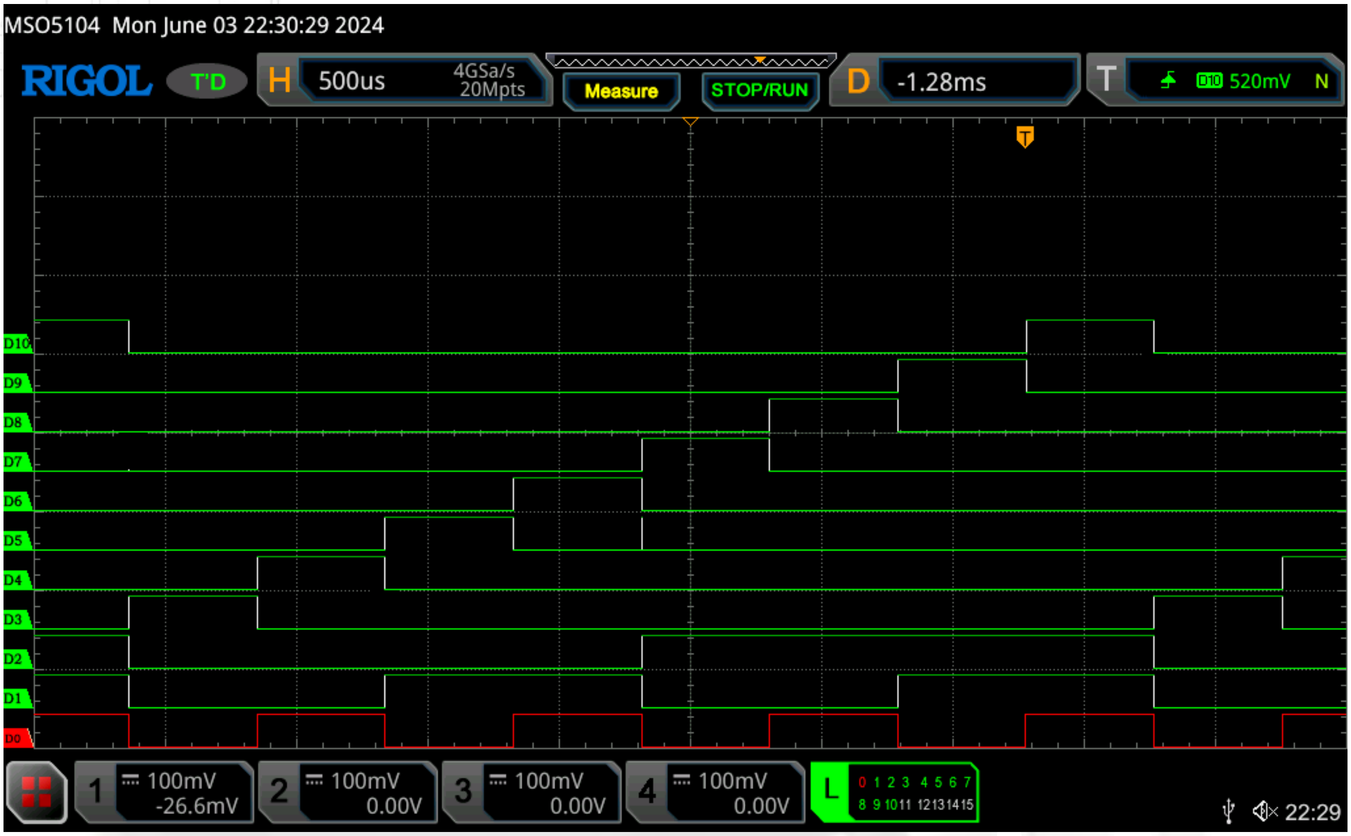
Seconds Counting



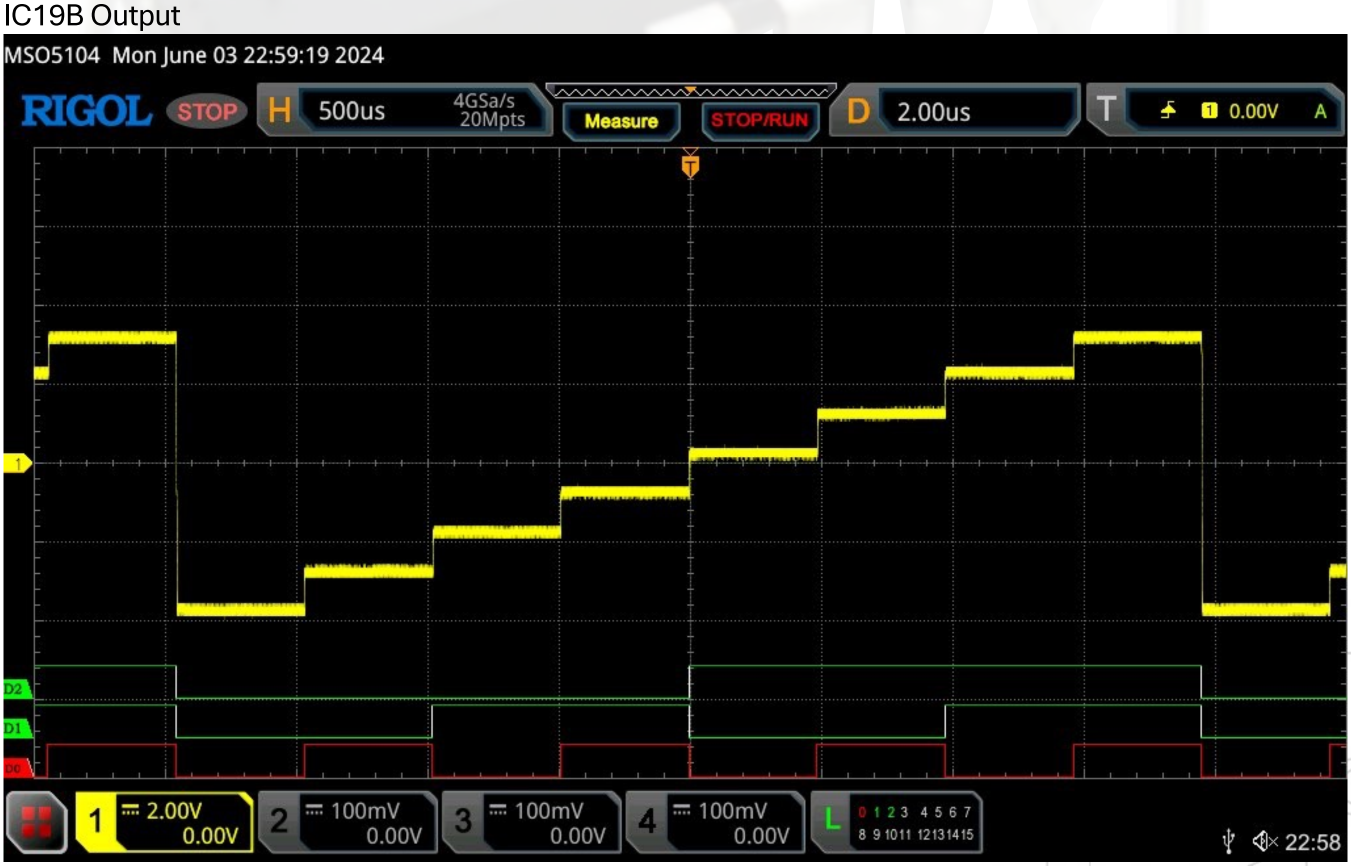
Seconds Counting - Close Up



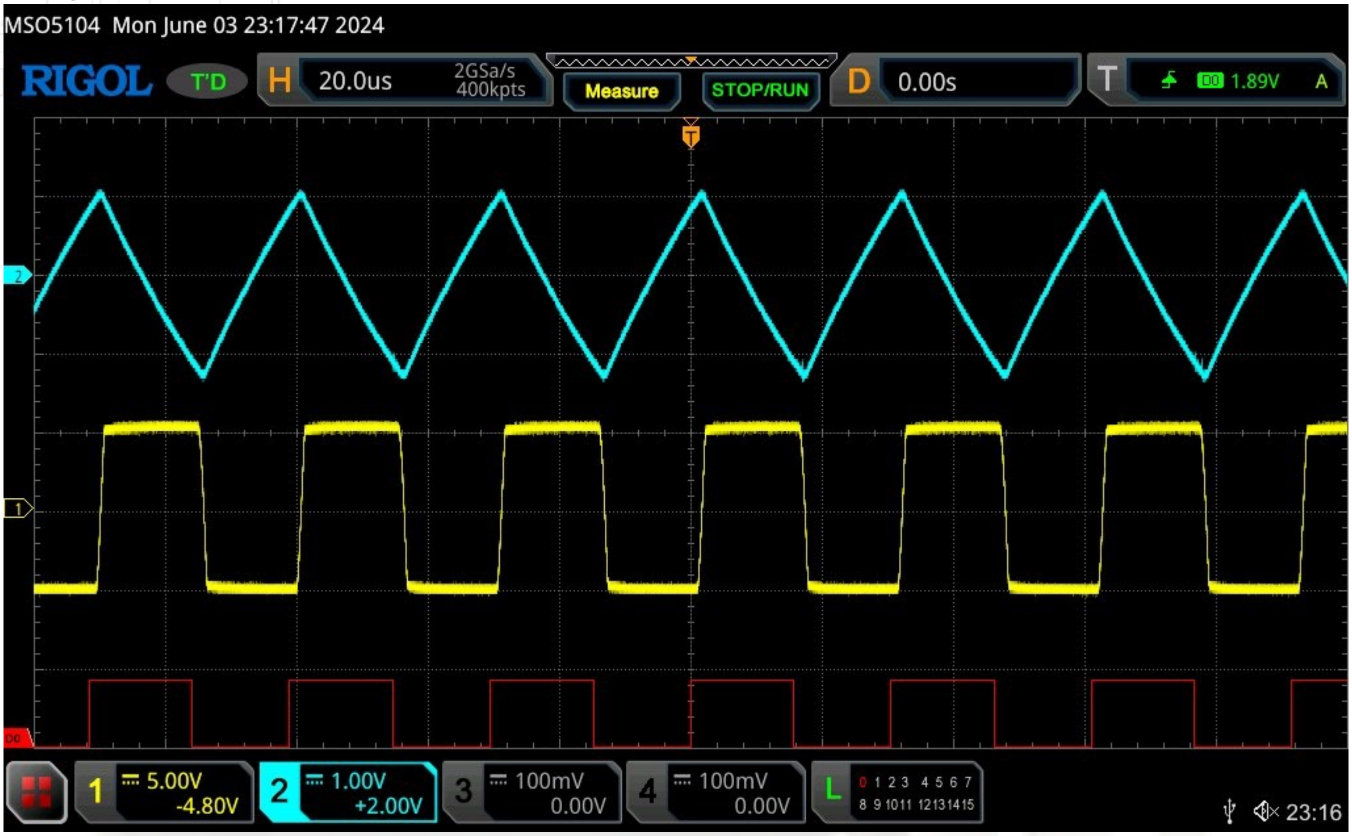
Character Position X1



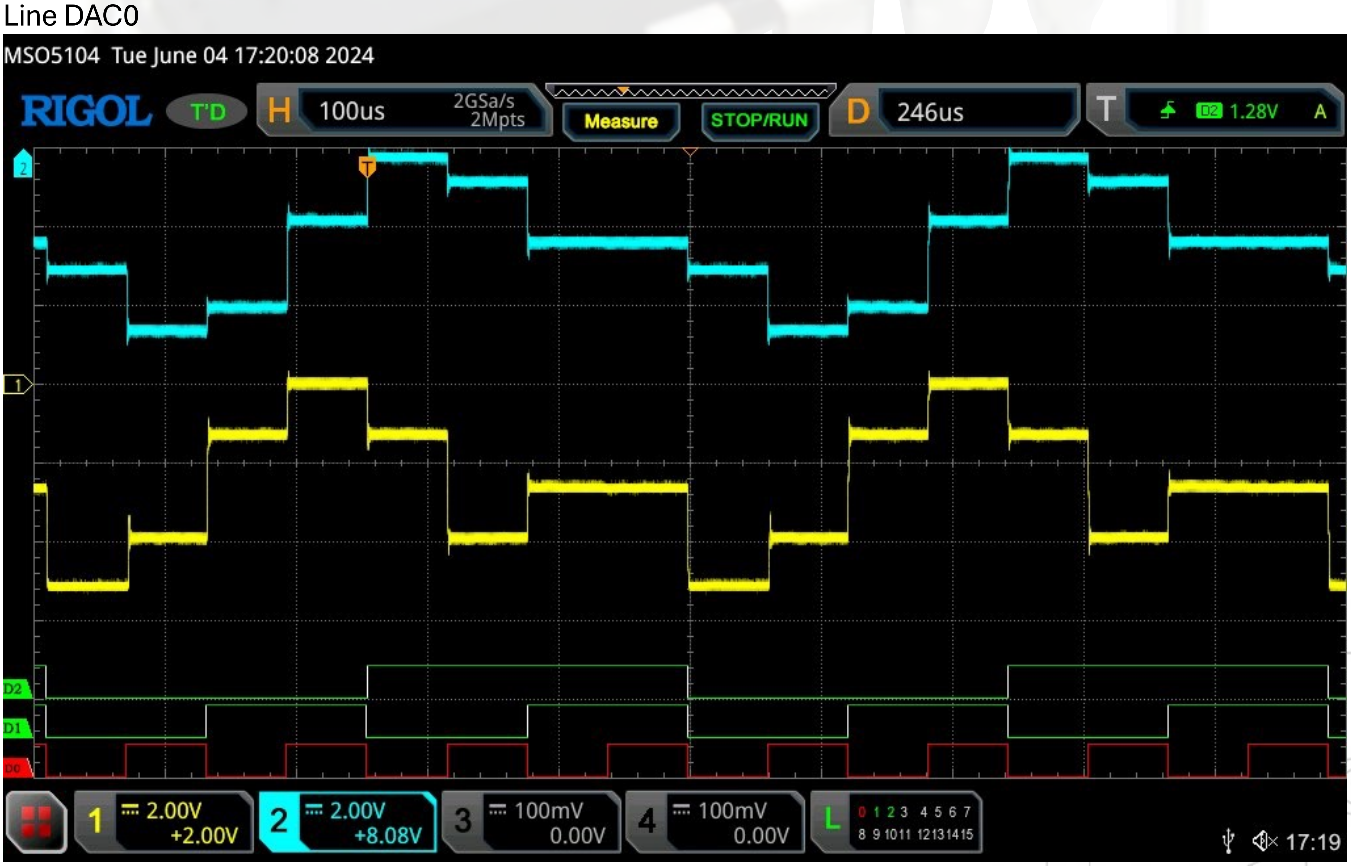
IC19B Output



Triangle Wave Output

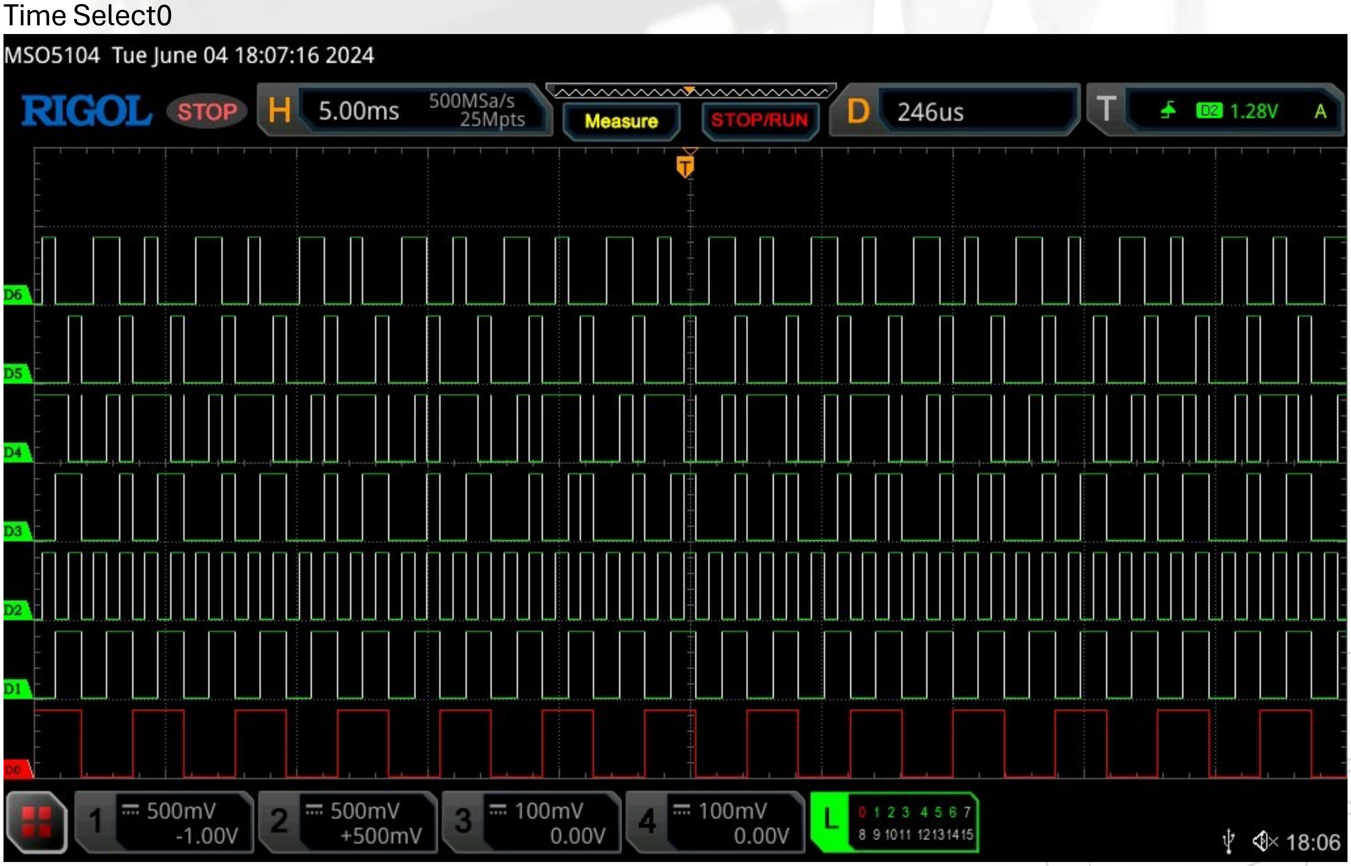


Line DAC0

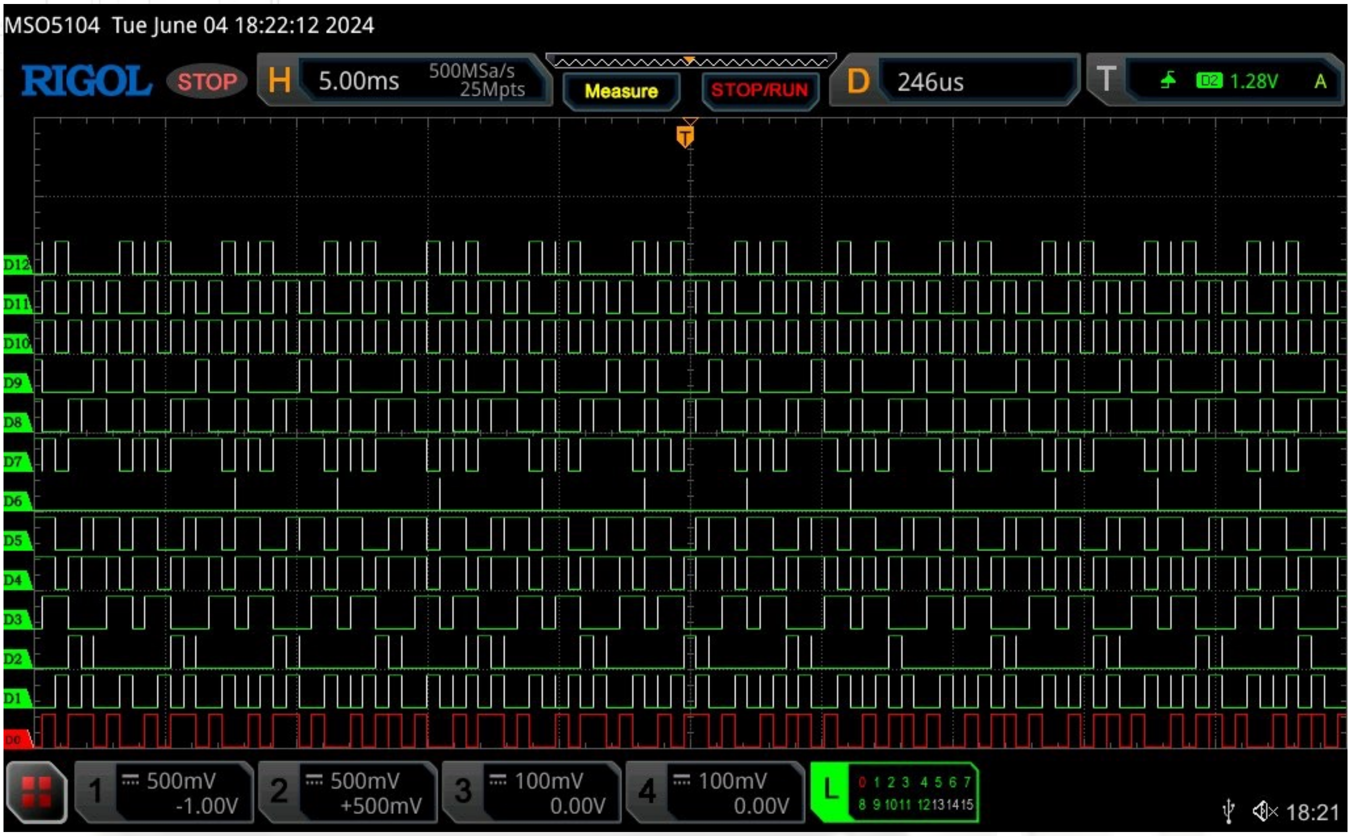


Line DAC1

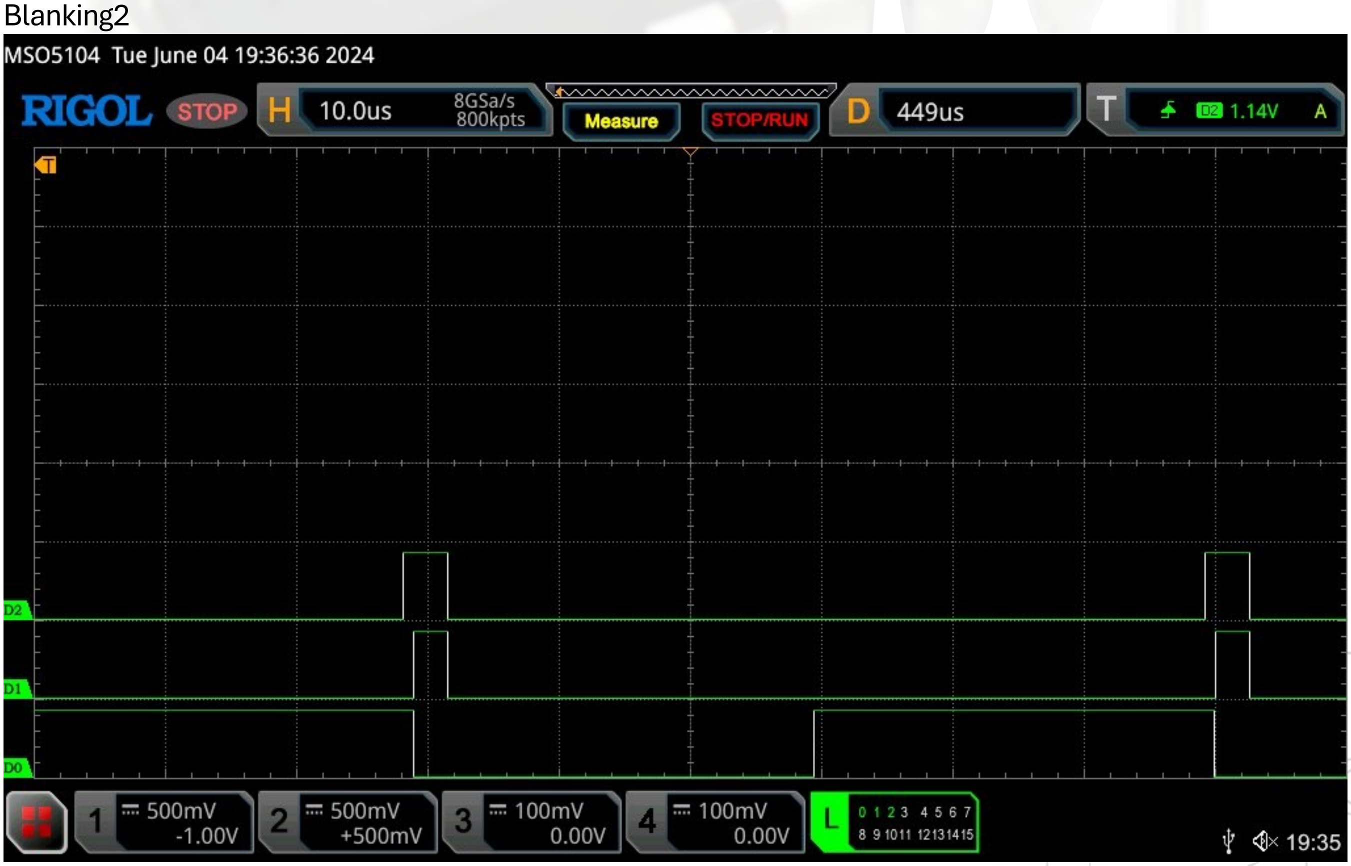
Time Select0



Time Select1



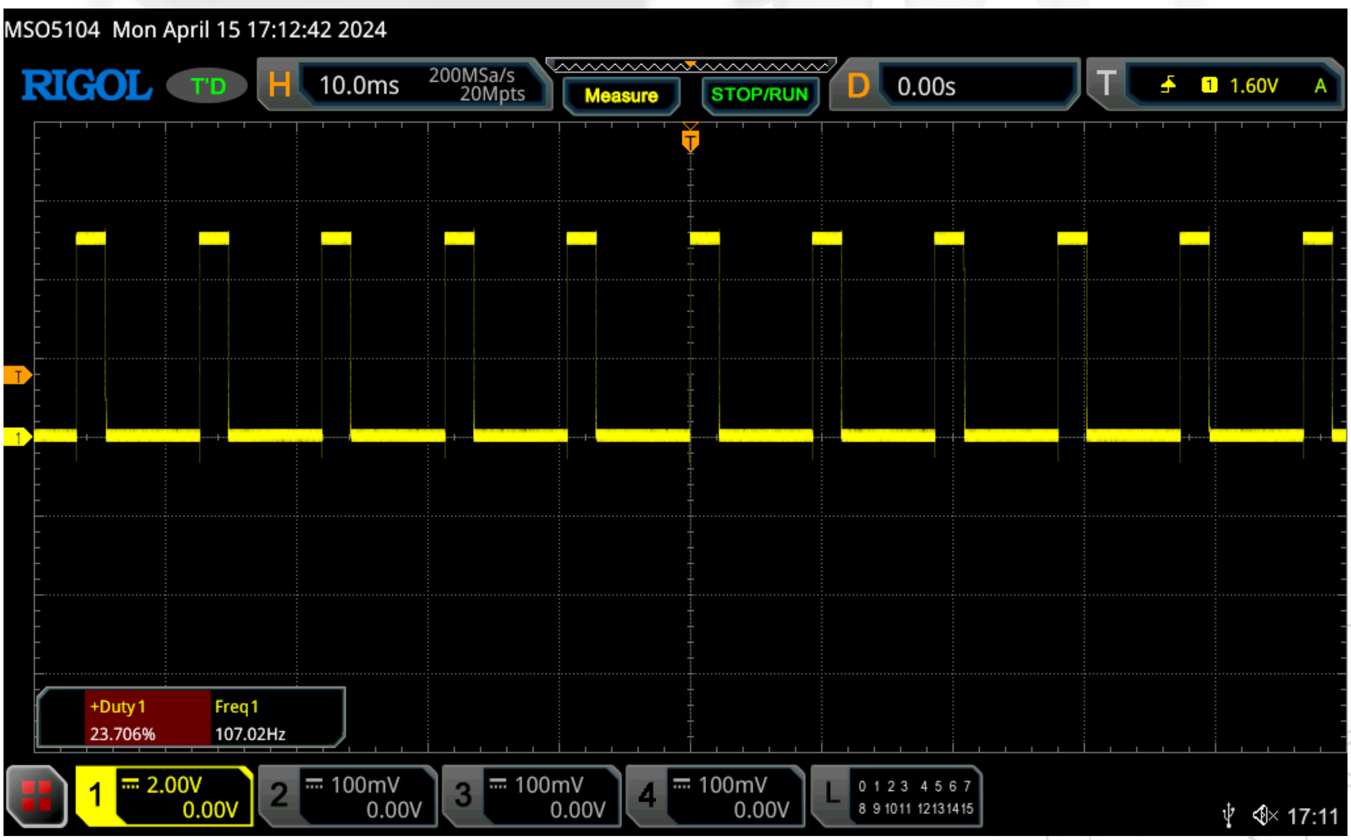
Blanking2



PIR


MSO5104 Tue June 04 23:45:07 2024
RIGOL
AUTO
H
200s
10kSa/s
20Mpts
Measure
STOP/RUN
D
461.4us
T
1.14V
A
D1
D0
1
2.00V
-2.00V
2
1.00V
-2.00V
3
100mV
0.00V
4
100mV
0.00V
L
0 1 2 3 4 5 6 7
8 9 10 11 12 13 14 15
23:44

LED PWM


MSO5104 Mon April 15 17:12:42 2024
RIGOL
T'D
H
10.0ms
200MSa/s
20Mpts
Measure
STOP/RUN
D
0.00s
T
1.60V
A
+Duty1
23.706%
Freq1
107.02Hz
1
2.00V
0.00V
2
100mV
0.00V
3
100mV
0.00V
4
100mV
0.00V
L
0 1 2 3 4 5 6 7
8 9 10 11 12 13 14 15
17:11

Annex B - PSU Board parts list (in order of component size)

Tick	Quantity	Part Number	Value	Component
☐	17	D4, D5, D8, D9, D10, D11, D14, D15, D16, D17, D18, D19, D37, D40, D41, D42, D43	1N4148	diode
☐	10	R1, R2, R35, R57, R84, R92, R93, R94, R95, R97	10k	5% carbon film
☐	8	R3, R4, R5, R6, R7, R8, R9, R10	249k	1% metal film
☐	4	R11, R12, R13, R14	330k	1% metal film
☐	4	R15, R16, R17, R18	2k20	1% metal film
☐	2	R19, R21	133R	1% metal film
☐	2	R20, R22	1k33	1% metal film
☐	6	R23, R25, R26, R29, R32, R33	20k0	1% metal film
☐	2	R46, R47	150k	1% metal film
☐	1	R48	3k3	5% carbon film
☐	1	R49	33k	5% carbon film
☐	10	R36, R37, R38, R39, R40, R41, R42, R43, R44, R45	3M3	5% carbon film
☐	1	R51	3k9	5% carbon film
☐	2	R52, R73	22k	5% carbon film
☐	1	R53	1k24	1% metal film
☐	3	R56, R62, R81	100k	5% carbon film
☐	1	R63	150k	5% carbon film
☐	1	R68	5k6	5% carbon film
☐	1	R69	2k2	5% carbon film
☐	1	R74	10R	5% carbon film
☐	1	R82	1M	5% carbon film
☐	1	R83	560R	5% carbon film
☐	2	R86, R87	680R	5% carbon film
☐	1	R88	100R	5% carbon film
☐	1	D3	1N5822	diode
☐	19	D6, D7, D12, D13, D22, D23, D24, D25, D26, D27, D28, D29, D30, D31, D32, D34, D35, D36, D38	UF4007	diode
☐	2	D20, D21	1N457	diode
☐	1	D33	P6KE18A	TVS
☐	2	D1, D39	1N4742	12V 1W Zener
☐	11	C1, C3, C5, C6, C7, C8, C21, C22, C41, C42, C43	100n	ceramic
☐	1	C27	470n	ceramic

Tick	Quantity	Part Number	Value	Component
☐	1	C31	47p	ceramic
☐	3	C2, C23, C36	100µ 20V	electrolytic
☐	1	C4	1000µ10V	electrolytic
☐	11	C9, C10, C11, C12, C13, C14, C15, C16, C17, C18, C33	47n 500V	ceramic
☐	2	C19, C20	4µ7 400V	electrolytic
☐	1	C24	220µ 100V	electrolytic
☐	1	C25	1µ 100V	electrolytic
☐	1	C26	10µ 100V	electrolytic
☐	4	C28, C29, C30, C32	4µ7 450V	electrolytic
☐	1	C35	22n 250V	low DF film
☐	4	C37, C38, C39, C40	4µ7 16V	electrolytic
☐	1	D2	CG21AS26F105MR	TVS
☐	1	F1	5A	fuse
☐	1	F1	Mini blade holder	fuse holder
☐	1	IC1	LM2576-5	IC
☐	2	IC2, IC3	LM234Z	IC
☐	1	IC4	LM6132	IC
☐	2	IC4, IC7	DIL08 socket	IC
☐	1	IC5	LR8	IC
☐	1	IC6	LM2588-ADJ	IC
☐	1	IC7	NE555	IC
☐	2	KK1, KK2	SK104 25mm	heat sink
☐	2	M3 bolt, washer, nut		hardware
☐	1	L1	100µH 2.1A	inductor
☐	1	L2	47u 1.5A	inductor
☐	1	L3	6u8 0.1A	inductor
☐	1	Q1, Q19, Q25	IRF9540	P MOSFET
☐	10	Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q14, Q16	ZTX658	NPN BJT
☐	4	Q10, Q11, Q12, Q13	MPSA06	NPN BJT
☐	3	Q15, Q18, Q21	2N7000	N MOSFET
☐	1	Q17	BS107P	N MOSFET
☐	2	Q22, Q23	IRFZ24	N MOSFET
☐	4	R24, R28, R30, R31	10k	trim pot
☐	1	R50	200k	trim pot

Tick	Quantity	Part Number	Value	Component
☐	1	R59	500k	trim pot
☐	1	R96	100k	trim pot
☐	1	TR1	Flyback Transformer	CC7306
☐	1	TR2	Royer Transformer	Ferrite Core
☐	1	TR2	Primary	0.7mm enamelled wire
☐	1	TR2	Secondary	EHT wire
☐	2	X7, X10	3 way screw terminal	
☐	2	X4, X5	Female 2x10 Header	
☐	1	X6	Male 1x3 pin header	
☐	1	X9	Male 1x2 pin header	
☐	2	X6, X9	Jumpers	
☐	2	X11, X12	2 way screw terminal	
☐	1	Z1	DC/DC Converter	
☐	1	C34	47n 1.6kV	film

Notes

1. Only one of X1 or X2 is normally fitted. Which is supplied depend on the case orientation – see below
2. X4 and X5 mount on the back of the board
3. The board has many test points. Optionally you can fit test point loops which give a good connection point for oscilloscope leads etc. Typically these look like this[213] and come in several colours so you can colour code the test point functions. They are not supplied in the standard kit but can be bought from component stockists, ebay etc.

[213] https://cpc.farnell.com/multicomp/test-1-r/test-pin-pcb-red/dp/PC02379

Annex C - Digital and Analogue Board parts list (in order of component size)

Tick	Quantity	Part Number	Value	Component
☐	6	D26, D29, D32, D33, D36, D37	1N4148	diode
☐	2	R1, R2	470R	5% Carbon Film
☐	24	R3, R45, R47, R49, R51, R54, R55, R56, R57, R58, R59, R60, R61, R62, R63, R64, R67, R72, R73, R75, R76, R77, R79, R80	10k	5% Carbon Film
☐	2	R74, R78	1k	5% Carbon Film
☐	1	R68	2k2	5% Carbon Film
☐	1	R69	100R	5% Carbon Film
☐	1	R70	3k9	5% Carbon Film
☐	1	R71	100k	5% Carbon Film
☐	1	R4	28k7	1% Metal Film
☐	7	R5, R8, R19, R23, R25, R37, R39	10k0	1% Metal Film
☐	1	R9	100k	1% Metal Film
☐	2	R10, R16	499k	1% Metal Film
☐	2	R11, R41	49k9	1% Metal Film
☐	4	R13, R46, R50, R52	33k2	1% Metal Film
☐	1	R14	24k9	1% Metal Film
☐	5	R6, R15, R30, R31, R38	20k0	1% Metal Film
☐	1	R17	16k5	1% Metal Film
☐	1	R18	14k3	1% Metal Film
☐	2	R21, R34	2k00	1% Metal Film
☐	2	R12, R53	1k00	1% Metal Film
☐	2	R22, R29	13k3	1% Metal Film
☐	2	R24, R28	40k2	1% Metal Film
☐	1	R32	12k1	1% Metal Film
☐	1	R35	8k06	1% Metal Film
☐	1	R36	9k31	1% Metal Film
☐	1	R40	124k	1% Metal Film
☐	1	R42	41k2	1% Metal Film
☐	2	R43, R44	15k4	1% Metal Film
☐	1	R48	3M30	1% Metal Film
☐	1	R65	6k20	1% Metal Film
☐	1	R66	143k	1% Metal Film

Tick	Quantity	Part Number	Value	Component
☐	5	IC19, IC21, IC22, IC25, IC34	DIL 08	IC Socket
☐	9	IC1, IC2, IC3, IC4, IC5, IC6, IC14, IC17, IC35	DIL 14	IC Socket
☐	19	IC7, IC8, IC9, IC10, IC11, IC12, IC13, IC15, IC16, IC18, IC20, IC23, IC24, IC26, IC27, IC28, IC29, IC30, IC31	DIL 16	IC Socket
☐	1	IC30	DIL 28-6 see note 2	IC Socket
☐	2	R20, R33	20k0	trim pot
☐	45	C1, C2, C3, C5, C6, C7, C8, C9, C10, C11, C12, C13, C14, C15, C17, C18, C19, C22, C24, C26, C32, C34, C35, C36, C37, C38, C39, C40, C41, C42, C45, C46, C49, C50, C51, C52, C53, C54, C55, C56, C57, C58, C60, C61, C62	100n see Note 1.	ceramic
☐	1	C16	220p	ceramic
☐	3	C20, C28, C30	22p C0G/NP0	ceramic
☐	1	C21	10p C0G/NP0	ceramic
☐	3	C44, C47, C48	1n C0G/NP0 1%	ceramic
☐	4	C4, C23, C27, C63	1000µ 6V3	electrolytic
☐	2	C25, C33	10µ 10V	electrolytic
☐	3	C43, C64, C65	1µ 16V	electrolytic
☐	1	C59	100µ 6V3	electrolytic
☐	26	D1, D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12, D13, D14, D15, D16, D17, D18, D19, D20, D21, D22, D23, D24, D34, D35	LED	green 3mm
☐	8	3D printed spacers for the LEDs. Two 2 way, two 3 way and four 4 way.		optional
☐	1	IC1	DS32KHZN	IC
☐	2	IC2, IC3	74LS393N	IC
☐	1	IC4	74LS05N	IC
☐	1	IC5	74LS14N	IC
☐	2	IC6, IC14	74LS00N	IC
☐	10	IC7, IC8, IC9, IC10, IC11, IC12, IC13, IC15, IC16, IC18	74LS112N	IC
☐	1	IC17	74LS20N	IC
☐	4	IC19, IC21, IC22, IC25	LM6132	IC
☐	2	IC20, IC23	74HCT238	IC
☐	1	IC24	DG445	IC
☐	5	IC26, IC27, IC28, IC29, IC31	74LS251N	IC
☐	1	IC30 (depends on which EEPROM you are using)	AT28C64B AT28C32	IC

Tick	Quantity	Part Number	Value	Component
			AT28C16	
☐	1	IC32	74LS123N	IC
☐	1	IC33	3V3 LDO Regulator	IC
☐	1	IC34	NE555	IC
☐	1	IC35	74LS125N	IC
☐	6	Q1, Q4, Q5, Q6, Q7, Q8	2N7000	MOSFET
☐	1	Q2	MPSA56	PNP BJT
☐	1	Q3	MSPA06	NPN BJT
☐	4	RN1, RN2, RN3, RN4	330R	Bussed 8 way network resistor
☐	3	S1, S2, S3	Push button	R/A OFF-(ON)
☐	1	X1	1x5 male header fitted across pins 2 to 6	
☐	1	X1	female socket to wire patch lead - solder to pin 1 “Out”	
☐	1	X2	1x3 male header	
☐	1	X3	2x2 male header	
☐	1	X4	2x6 male header	
☐	11	X2, X3, X4, X6	Jumpers	
☐	2	X7, X8	2x10 male header see note 3	
☐	1	Z1	EKMC1601112	PIR
☐	2	M3x11mm stand-offs, M3x6mm bolt and nut. note 4		
☐	1	PCB		

Notes:

1. C48 is only required if IC30 is in a 24 pin package. It does no harm to fit it anyway.
2. If IC30 is in a 24 pin package then this socket can be DIL24-6 however a DIL28-6 can still be used but the IC must be fitted correctly.
3. These are 2x10 male headers and are **mounted on the back of the board.**
4. These stand-offs are used to keep the boards separated during testing.
5. Voltage ratings of electrolytic capacitors can be higher than those stated. For example a 6.3V rated capacitor is listed but a 10V rated component may be supplied in its stead.