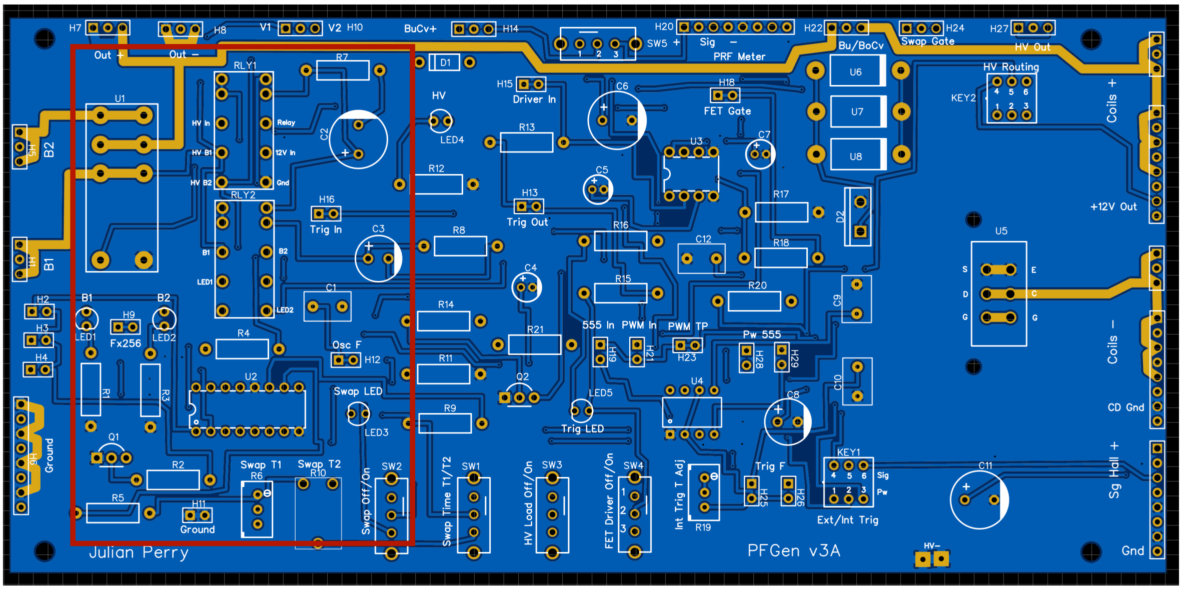
Battery Swapper & Timer Circuit

The battery swapper is a central and important part of the circuit comprising an accurate timer and a set of relays.

Its role is to allow one of the two batteries to be pulse charged while the other supplies the energy to the circuit and any external load, and then, after a preset time, swap over their respective roles.

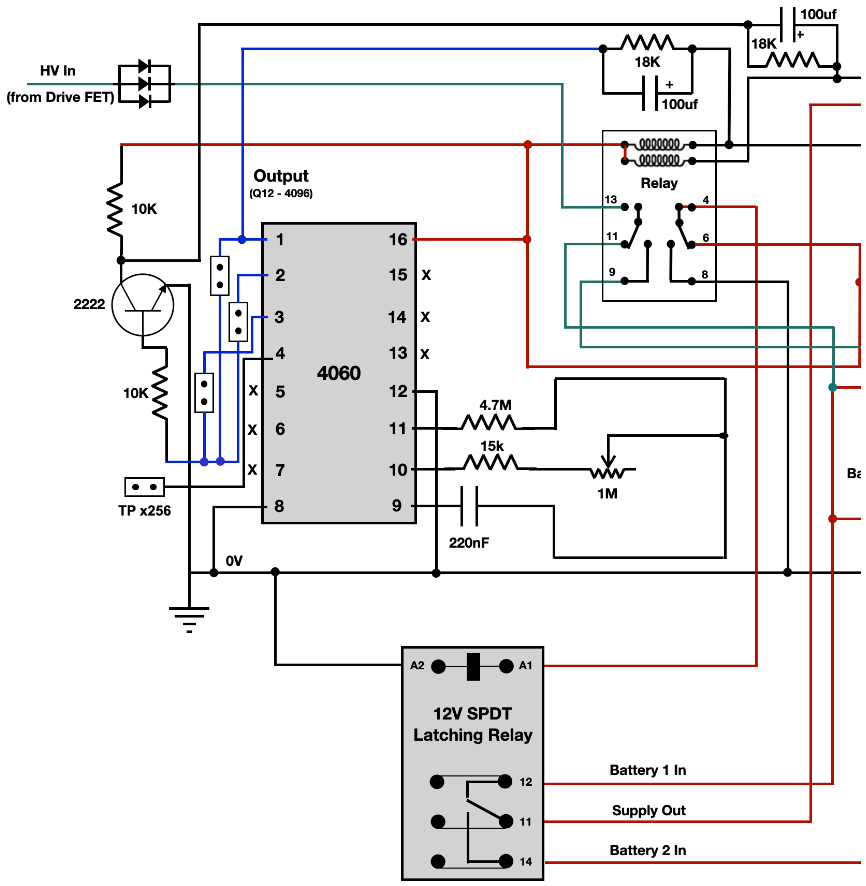
As has been explained elsewhere, the interval between the swaps is an important factor in the CoP and power results since it determines the whereabouts on the charging profile that the pulses act on the battery and will be influenced by the load used and the rate at which the battery responds to the HV pulses at a given PRF.



Looking at the design of the v3 board in the diagram above, and which will be redesigned to reflect the project findings, the swapper is located on the left hand side immediately after the input from the batteries. This location, shown by the red box, is so that the relay can route the current from the supply battery to both the circuit and the external load, and also route the HV pulses to the receiving battery, before swapping them over whereby the contacts within the main relay pick up the other battery input.

The two other smaller relays, which can only handle a maximum of 3A, serve to trigger the main relay and also route the HV pulses to one or other battery. They also operate the LED indicators that indicate which battery is providing power at any moment.

The relays used must be able to handle the maximum expected current and most of that demand will result from external load. As such, and particularly importantly for the PCB tracks from the main relay to the output terminals of the PCB (H7, H8) and shown as the wide yellow tracks where they are exposed Copper, the tracks can be thickened with solder. Without the addition of the solder, the tracks would need to be impracticably wide to accommodate up to 20A.



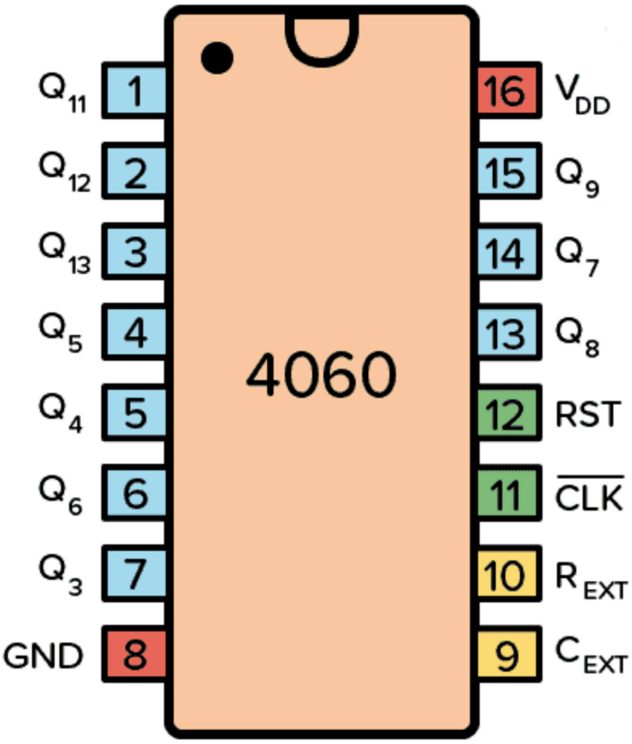
The need to have an accurate timing mechanism allows for the optimum setting of the charging on the charging profile by determining how much energy and capacity from the supply battery is discharged before the switch over.

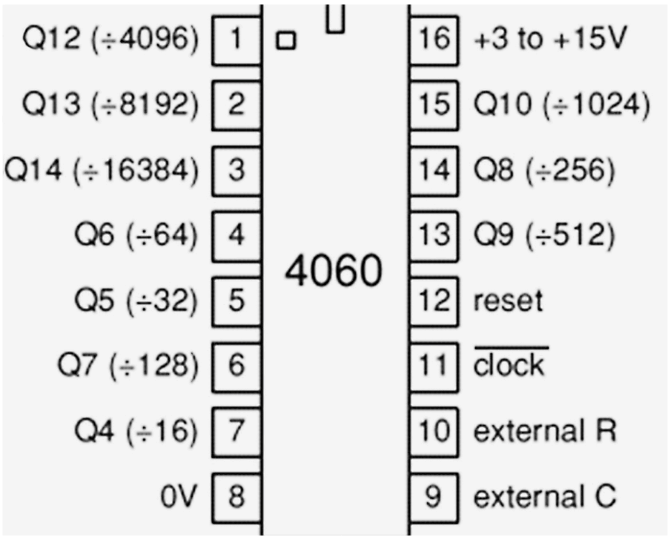
The basis of this timing mechanism is the CD4060BE decade counter which has a built in oscillator and is fairly independent of temperature drift. The onboard oscillator frequency is set by several external resistor and capacitor components, in the same way that a 555 timer will use them to set up an RC circuit.

Once the oscillator is running, then the square wave pulses it produces are counted up by the various registers in the chip and result in the various pins going from low to high after a fixed number of cycles and then back to low after the same number of cycles.

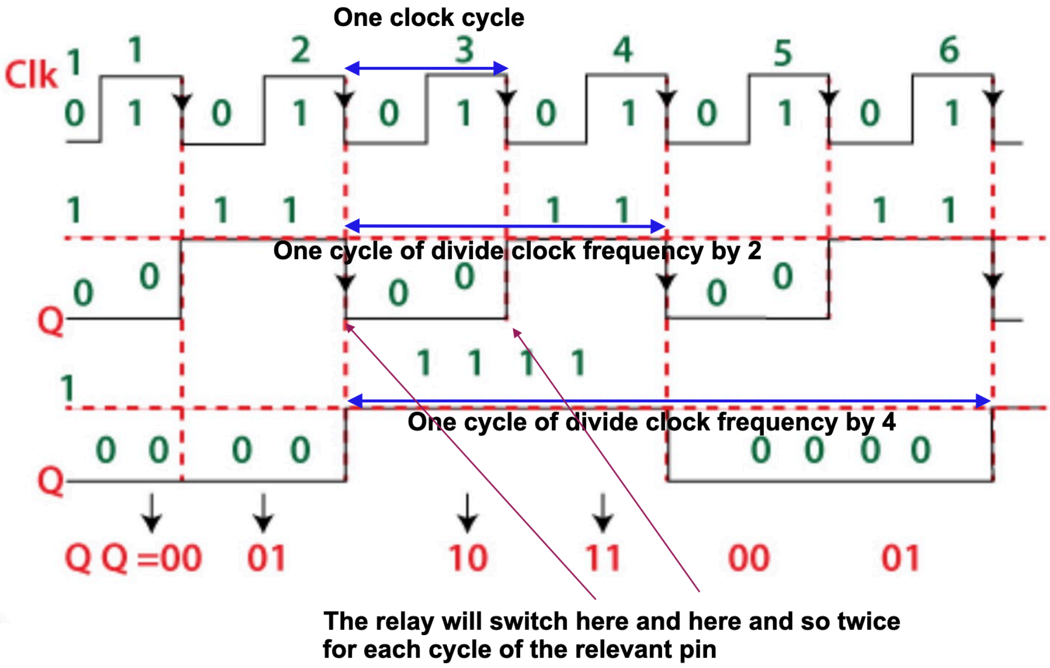
When this happens the output of the chosen pin is routed via a transistor to one of the coil inputs on one of the small relays, the other input arriving directly from the 4060 output pin. It is the fact that one of the relay coil inputs is high and the other low, due to the action of the transistor, that results in the coil being activated and operating the relay and which then sends its 12V output to the larger latching relay to operate that.

Looking at chip's outputs in more detail, with reference to the figure below, we can see that the pins are annotated with the letter Q and a number, for example, pin 5 is Q4 representing 2^4 (16). This means that after every 16 cycles of the clock/oscillator, pin 5 will go high and low again after another 16 cycles. So in effect it is dividing the clock frequency by 16 or 2^4.





Similarly pin Q12, will undergo a change from low to high every 4096 (2^{12}) cycles of the oscillator and is therefore diving the oscillator frequency by 4096.



The relay will switch here and here and so twice for each cycle of the relevant pin

The chips can vary as to the location of the various Q values, as shown in my circuit and the two figures, but it will be accurately described on the spec sheet for a particular make of component.

The value of this dividing function is that we can set the oscillator frequency such that the output of a pin will change at any desired time based on the clock frequency and the output pin we choose to use. The pin output, in going from low to high, can be used to trigger a relay coil and flip the relay or, in this case result in the sequential triggering of another larger one.

In the above figure we can see that for every complete cycle of the clock (from any point on the square wave back to the same position), the pin below on the second row only does half a complete cycle and the one below that a quarter of a cycle.

It is important to note that, having explained how the chip can divide frequencies, that the interval between each swap event is half the time for a complete cycle. This is simply because the relay will switch when the pin goes both high and low and so, with reference to the middle row for example, for each cycle (or period if you want to think in terms of time), then the relay will switch twice. This is why I refer to the swap interval and not the period as the period is the time taken for a complete wavelength (cycle) to occur and using the same term will cause confusion (if you're not already!)

So, without going into details of the internal cascading process, the clock frequency and the different pins provide us with a means to set the interval for the battery swapping.

To Calculate:	**From a desired swap time T in minutes**	**Comments**
Osc. Frequency (Hz) using J1	34.43/T	From RC components: 1/(2.2xC1xR1)
Osc. Frequency (Hz) using J2	68.86/T	
Osc. Frequency (Hz) using J3	137.72/T	
Q4 Frequency (Hz)	2.15/T	'X256' test point
To Calculate:	**From an oscillator frequency**	
Swap time (min) using Q12	34.43/F	Using Jumper 1
Swap time (min) using Q13	68.86/F	Using Jumper 2
Swap time (min) using Q14	137.72/F	Using Jumper 3

JI, J2 & J3 refer to the jumper positions, to the left of the 4060 chip, to enable other outputs to be used for swap times larger than 15min (with the present RC values)

Now let’s move on to an easier, albeit more arithmetical, look at the settings and how we can adjust them.

Above is a table of the simple numerical equations you will need to calculate the oscillator frequency for any swap time you want, within the limits set by the installed oscillator components (resistor and capacitor values), or the converse, the swap time from a frequency. Here are some practical examples so you can see how they work in practice.

Oscillator Frequency:

Suppose you have circuit values for R1 and C1 of 1MΩ and 220nF respectively and where R1 is in fact a trimmer that you can adjust from 15k to 1MΩ (the 15k is provided by a fixed resistor to stop the effect of having the trimmer set to 0Ω). If you apply the equation for Osc F from RC components then this is: $1 / (2.2 \times 1\times10^{6} \times 2.2\times10^{-7}) = 2.07$Hz and with the minimum values possible with these components: $1 / (2.2 \times 1.5\times10^{4} \times 2.2\times10^{-7}) = 137.7$Hz

These two values of 2 and 138Hz, to the nearest whole number, are the minimum and maximum values of frequency F_{Osc} of the inbuilt oscillator. Using these we can calculate the longest and shortest swap intervals that you can set depending on which output pins you choose to use. Clearly the higher oscillator/clock frequency of 138Hz will do its thing inside the chip, and cause all the pins to change their state, much faster than the lower 2Hz value.

Using the equation for ‘Swap time (min) using Q12’ which is 34.43/F, with the maximum and minimum frequencies we have determined from the components, you can see that we will have a minimum swap interval of 34.43/F = 34.43/138 = 0.25min = 15s and a maximum interval of 34.43/2 = 17.22min = 17min 13s.

Three different output pins are accessible by using one of three jumpers positioned to the left of the 4060. These connect the relevant output to the base of the transistor so that just switching the jumper position will bring a different frequency divider into play and therefore a different multiplication of swap interval.

Normally we have a swap time in mind that we want to set up and we want to know the oscillator frequency so we can quickly set that using a scope using the ‘Osc F’ test point (with the scope earth lead attached to a Ground point) and we will then have the desired swap time or interval.

For example, if we want a swap time of 10 mins then we must use the equation at the top of the table which is $F_{Osc} = 34.43/T$ which gives us 34.43/10 = 3.44Hz. To set this we adjust one of the two trimmers, one for each of the two times we can select with a switch, so that the clock frequency is 3.44Hz, then the Q12 pin will send out a high after 10min (600s) and a low after another 10min and keep on doing that until you switch off the 4060 by removing power to its pin 16 (V_{DD}).

Using other output pins:

The above calculations were done based on using the Q12 output, usually pin 1 or 2 on the component. However, you can get longer times than these by using the Q13 or Q14 outputs that divider by a further 2 and 4 respectively. This option is made available through use of the jumper pins to the left of the 4060 chip. If the top jumper in in place then Q12 is being used, the next down H3 is Q13 and H4 is Q14. This gives a greater range of options when perhaps wanting to use longer swap intervals and without having to build in excessive resistance modification to R1.

To give some examples, if you want to use a swap time of 20mins, since this is more than the 15min max using the Q12 pin, then you can set the oscillator frequency for 10mins at 3.44Hz (34.43/10) and use the Q13 output, which takes twice as long to change state than the Q12 pin. This is same as when using the equation in the next line of 68.86/20 = 3.44Hz and you won't need to think about the doubling since it is part of the numerical equation.

The circuit I use has two timer options set by a switch to T1 or T2. My own preference is to set T1 at the minimum of about 15s so I can use that to check the operation of the swapper and to make a 'manual' change to the battery that is providing the power if I need to. T2 is then set to my preferred swap interval depending on what operational parameter I need.

Here are some other examples:

To set a swap time of 8min use either jumper 1 and adjust F_{Osc} to 4.3Hz or use jumper 2 and set F_{Osc} to 8.6Hz (which using Q12 and jumper 1 would result in 4min).

To set a swap time to 25min use jumper 2 and F_{Osc} to 2.75Hz or use jumper 3 and adjust F_{Osc} to 5.51Hz

To set a swap time to 42min use jumper 3 and F_{Osc} to 3.28Hz since 42 min is longer than either J1 or J2 can generate using the RC values in place.

These techniques will allow you to easily setup your timer to swap the batteries over to within an accuracy of a few seconds. The same swapper and timer will be used for the revised circuit that hopefully will be ready by early December, together with some assembly notes. Meanwhile I hope you can digest the above without too much of a headache.

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