Notes on the HP Classic calculator display drivers.

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Light Emitting Diodes (LEDs) are a great and easy way to display numerical or alphanumerical information.

LEDs require current passing through them to create light. This current is usually in the 10 to 20 millamp (mA) range and when this current flows, the LEDs will develop a voltage drop across them. For red LEDs, this voltage is about 1.7 volts. Most circuits that have LEDs are powered by a voltage higher than this and if you try to drive a LED directly from this higher voltage it will be damaged from too much current flowing through it. One common method to reduce the current is to place a resistor in series with the LED.

If we decide that the LED requires 20mA to be bright enough for an application powered by a 3.75 volt supply then by Ohms Law we can decide the resistor value. If the LED drops 1.7 volts, then the resistor will have 2.05 volts across it. \((3.75 - 1.7 = 2.05)\) The current flowing through the resistor generates a small amount of heat which could be considered a waste of energy.

\[
R = \frac{V}{I} = \frac{2.05}{0.02} = 103 \text{ ohms}
\]

As you can see, this simple LED circuit consumes little power, but If you consider a 15 digit, 7 segment LED display which could have up to 87 LEDs on at any time then the energy consumed becomes a problem because the battery will not last long trying to drive that sort of load. \((87 \times 20\text{mA} = 1.74 \text{amps})\)

It was found that supplying a short duration pulse of high current at regular intervals could also drive the LEDs at the required brightness. This current could be in the 100’s of milliamps, but is only for very short periods of time and does not cause any detrimental effects on the LED. In fact by using this method, the LEDs are mostly turned off. With some clever electronic design, a multiple LED display could be driven like this and is how the Classic display works.

It takes 280uS (millionths of a second) to refresh the display and out of this, each LED is on for about 5uS. In other words, each LED is turned on for approximately \(1/56^{th}\) of the display refresh time. The refresh process that controls which LEDs are on or off happens so fast that the human eye cannot detect any flicker. The result is a bright display with a much smaller amount of power being used to drive it.

Further power savings were realised by charging small inductors and then discharging them into the LEDs to light them. This meant that the series resistors were not required and thus the power they consumed was eliminated. Another feature is that the displays are powered directly from the battery which means the power supply circuit does not have to be beefed up enough to supply the extra power.

Two specialist integrated circuits were developed to drive the display in this manner. One is called the Anode Driver and the other is the Cathode Driver. These match the connections to the LEDs which also have an anode and a cathode.

The cathode driver sequentially activates each of the 15 display digits one at a time. It can do this because the cathodes of each display LED are connected together. The anode driver then sequentially turns on each of the appropriate LED anodes for that digit. Each digit is active for 20uS and therefore a full display refresh takes 280uS. \((\text{But 15 digits} = 300\text{uS} ???)\) This anomaly is due to the fact that while the decimal point is displayed in a separate digit, it is actually lit up during the same 20uS for the digit that it follows.
The Arithmetic & Register Circuit (ARC) has 5 data lines connected to the anode driver. These lines labelled A, B, C, D and E transfer partially decoded display information. The anode driver fully decodes this information into eight output lines which connect to the 7 LED segments of each display and one to the decimal point. The reason for the partial decoding is to help reduce power consumption and probably simpler design.

The quad inductor packages have different colours because of the decimal point LED. The 7 LED segments of each digit require one 130uH inductor each to store the charge. The decimal point LED being lit for half the time of the others, only requires a 68uH inductor. Therefore one quad package has 4 x 130uH inductors and the other has 3 x 130uH and 1 x 68uH inductors*.
ELECTRICAL PATHS FOR THE LED DISPLAYS

In the following diagram, the anode switch for LED segment (a) is closed. The cathode driver has selected Digit 1 to display information. The inductor (La) charges from the battery, through the anode switch and back to battery again. The charge process is allowed to continue for 2.5uS for LED segments a – g, and 1.25uS for the decimal point.

After the time interval, the anode switch opens and the cathode switch stays closed. The inductor stops charging and now discharges through the cathode transistor and the LED segment which briefly lights it up. The anode switches open and close at spaced intervals of 1.25uS. The LEDs are diodes so they help to isolate each inductor from discharging into each other. The discharge time is about 5uS for segments a – g and 2.5 seconds for the decimal point. The inductors have to be discharged before the cathode driver selects the next digit or those LEDs may light briefly causing a bleed effect from one digit to the next. There is not much time available for the decimal point to discharge before the following digit needs to light which explains the faster timing requirement.

If the cathode driver is faulty and the cathode switch is not turned ON for a digit, then when the anode switch opens, the inductor discharge current has nowhere to go. That current will still try to flow and most likely it will push through the junctions of the just turned off anode driver transistor. Eventually, if not straight away, the transistor will be damaged and the corresponding display segment may stay on permanently or not come on at all.
The anode driver provides the master clock pulses (Ø1 and Ø2) for all the calculator circuits, including the ARC chip. The ARC chip is responsible for partially decoding the required display information and sends it to the anode driver to decode it fully for the 7 segment displays. However, the ARC chip and the anode driver don’t have a complete display timing reference between each other.

The timing diagram shows Q1 and Q2 repeat the same sequence during the T1 – T4 phases, but Q3 and Q4 have different bit patterns. These are the ones that could be out of sync with the ARC chip. If the T1 – T4 cycles are not synchronised, the anode driver cannot decode the patchy information and the display will show garbage. The method chosen to do the synchronisation is quite clever as it requires no extra data lines and is quite transparent to the display operation.

When the B and D lines from the ARC chip are logic HI and Ø1 is logic LO, the anode driver circuit detects this and sets Q3 HI and Q4 LO before the rising edge of the Ø1 pulse at T3. This then puts those clock lines in the correct logic state during the T2 cycle. The dotted lines on the timing diagram reflect this. Now if nothing changes that timing should stay synchronised until power off, but if there is a “glitch in the matrix”, then the display will briefly show garbage until the timing is reset automatically during digit updates. The reset will occur on any digit that requires the B and D lines to go HI. ie. Digits 0, 2, 3, 8, 9 and ‘d’. (As in HP-65 “Crd”)

At switch on the display on the Classics always has a [0] displayed so I assume then, that on the very first display refresh the digits will most likely show garbage until that first [0] is decoded, however this will happen too fast for the eye to see. The diagram shows the digital reset path when B and D go HI. Flip flops, B1 and B4 receive the reset pulse. Red represents Logic HI, green represents Logic LO.
The HP-45 patent document (4,001,569) shows an image of the required data for the anode driver to decode the digit ‘9’. The image on the right shows the corresponding trace from an oscilloscope. The time base is 10μS. The yellow trace is set to 2V/div.

The first digit to be sent to the anode driver from the ARC is the mantissa sign, followed by the exponent ones, exponent tens, exponent sign, and then the mantissa digits 10 down to 1. The first mantissa digit (9 in this case) is the last digit to be sent to the anode driver before the cathode driver is reset to start the next display scan. This reset is caused by the falling edge of the RCD pulse.

This next trace shows the voltage appearing on the anode driver pins for LED segments A and B while the LED display is showing 0.00. The timing discrepancy is due to the calculator RC timing which can vary due to temperature, component tolerances and aging effects. (20us designed vs 22us actual)
After the power is turned on, these images show a Classic display showing \(0.00\), plus the trace on an oscilloscope as it monitors the A B C D and E inputs to the anode driver, and the Reset Cathode Display (RCD) line from the ARC to the cathode driver.
As mentioned, not all LED segments are lit at any one time, however the display refresh process is so fast that the eye only sees whatever is meant to be displayed. The following single digit (.8) sequence with a display showing .823 takes about 20uS, including the decimal point. By staggering the time that each LED turns on, the current inrush that would occur if all segments were turned on together is reduced. Notice that only 1 digit is active at any one time and the LEDs in all the other digits are turned off. They will be excited in turn as the cathode driver sweeps across the display.
The schematic of the cathode driver chip shows that on reset, digit 15 is first out. This is the Mantissa Sign.

This image of a logic trace shows the A – E pulses, Ø1, Ø2 and the anode to cathode driver step signal. (C. CL) The time base is 10μS. The yellow line is the RCD pulse - 5V/div. The display is showing **0.00**.
This next image shows the 56 clock pulses between each of the RCD pulses. This represents one Word (or instruction) time for the classic calculator and takes 280uS.

First out is digit 15 – Mantissa Sign (20uS)  
Last out is digit 14 – Mantissa Digit 1

The time base is 50uS. The yellow trace is set to 2V/div, the purple trace is set to 5V/div.

See if you can decipher the digits shown on the display 😊

Hint, if you can count to 10 you are on the right track.
The Classic display driver LEDs are connected together in a multiplexed method and the Anode and Cathode drivers are responsible for sending the display information to the correct LED segment.

The Anode driver, as discussed, decodes the five display lines into 7 segment information and outputs that data to the LED anodes. The Cathode driver is responsible for selecting the correct LED digit and does this by sequentially enabling each LED digit in turn. At the start of a display sequence, the RCD line is cycled to reset the Cathode driver to start a new display sequence.

Fourteen pulses are sent to the Cathode driver from the Anode driver every display sequence. One RCD pulse is sent from the ARC on the main CPU board, for every display sequence. You might notice that the display refresh for this calculator is 310µS, not the specified 280µS. This is most likely due to changes over time with the oscillator components. The following image shows this process. The horizontal scale is 50µS/Div. The vertical scale is 2V/Div.

Note that in this image, there are no decimal points being shown on the display. The calculator is a HP-65 and the PRGM/RUN switch has been placed in the PRGM mode with the display showing 00 00.

When the PRGM/RUN switch is placed in the RUN position with the display showing 0.00, you can now see the decimal point has been decoded and the extra step has been added by the Anode driver.
The next image is a close up of the relationship between the RCD pulse and the first step pulse. The horizontal scale is 50μS/Div. The vertical scale is 2V/Div.

This image shows a close up of the extra step for the decimal point.

This image shows that there are multiple decimal points on the display. At the hardware level, the decimal point will be included on the display when any of the Register B digits have bit 2 set to 1. That is, any digit 2, 3, 6 or 7. This is a snapshot of the HP-65 signals while running the small program listed below. While the program is running, the HP-65 internal microcode transfers much of the 2367236723 number to Register B, and it also toggles the display on and off which displays all those decimal points.

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LBL A
  2367236723
ENTER
GTO A
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