

Measuring Calculator Current

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Introduction

The most important measurement of a semiconductor or semiconductor device is its current usage. I once visited an assembly house in Asia that packaged integrated circuits, IC's, (commonly called chips) into plastic packages. The finished IC's were then 100% tested using a massive computer controlled very expensive digital signal tester. I noticed that the tester wasn't in use and I asked why. The test engineer explained that they had found that they could simply measure the quiescent current and they could determine 99.9% of the time that the circuit was working. Besides, the hundreds (and often thousands) of specific digital conditions of the IC functions took much longer by a factor of at least ten.

Calculators are semiconductor products and measuring the current that they draw under various usage/mode conditions provides a good indication of what is happening. Pressing "on" with a blank calculator display just doesn't tell you very much.

Current is the most problematic basic electronics measurement – vs. voltage or resistance. Modern digital multimeters, DMMs, are cheap, accurate, and readily available. All too often, however, you will find that the current range doesn't work – usually because of a blown internal fuse. Most electrical measurements are made by placing the probes across two points on the component or circuit under test. Measuring current, however, requires that you insert the meter into the circuit. This means that you must cut or unsolder the circuit and this is usually not convenient.

Current Range

An interesting aspect of electronics is the very wide range of values that are involved. Current is measured in amperes. Your car starter may require 200 to 500 amperes to turn over the engine. A digital watch may require a millionth of an ampere to run. $1/1,000^{\text{th}}$ of an ampere is a milliampere, mA, and $1/1,000,000^{\text{th}}$ of an ampere is a microampere, μA . Nanoamperes and picoamperes are becoming more common specifications of IC currents in today's advanced low power IC's.

The current that a calculator will draw will vary greatly from low microamperes to low milliamperes. This range of 1,000 to 1 may instantly change with the press of a key. These highly variable electrical conditions add to the challenge of calculator current measurements. These considerations are:

- (a) Inserting the meter into the circuit – a mechanical and technique issue.
- (b) Using the correct meter and or range – an experience issue
- (c) Keeping meter resistance under control – an expertise/understanding issue.
- (d) Measuring and range changing – an experience/expertise/understanding issue.

All of these issues apply and the last one needs further explanation. When you turn on the switch of an electrical device current flows from the power source. Suppose there is something very wrong and the device is shorted or presents near zero ohms to the power supply. What prevents 1,000 amperes from flowing and turning all conductors cherry red? There are several reasons. The wiring involved may be

very small – resistance of the wire may limit the amount of current that will flow. The power source may have a “built in” resistance that may limit the amount of current that will flow. Calculators are usually battery powered and the internal resistance of the physically small battery will usually limit the current. This source resistance is what the calculator electronics sees.

When you insert your current meter into the circuit between the battery and the calculator the calculator will see the meter resistance and the battery resistance in series. Both the meter and the battery will have its source resistance dependent on the conditions at the moment.

The battery source resistance will be quite low when it is first used⁽¹⁾. The internal resistance will slowly increase as the battery supplies energy, and it will be quite high at the end of life.

The meter resistance will change when the range is changed. A high current range will have a much lower resistance than the low current range.

Digital Circuits are “Time” Sensitive

We have all heard that digital circuits are very fast. Most human activities such as key press times, reaction times, or neural response times are measured in the low millisecond range. Digital circuits respond a million times faster and the circuits that interface to the human world must be slowed down or time conditioned in order to avoid confusing the digital circuits.

Calculators have special turn-on circuits (reset circuits) that address the mechanical switch bounce of keys, switches, and users messing with electrical connections in trying to measure calculator current. All users have observed “strange” behavior when using their calculators, and they intuitively know that this is the nature of digital circuits. Computers are the same way and when in doubt – restart/reboot first.

Breaking the Circuit

The mechanics of breaking the battery circuit of a calculator means that you must get your two meter leads between the battery and the power input of the calculator. This is a mechanical problem and you just want to make a quick measurement. I am sorry, but making that “quick” calculator current measurement is not going to be very quick, or all too often, not very easy.

There is a resurgence in interest in the HP-41 because of Monte’s Newt project, the HP-41CL, so I will use the HP-41 as an example of applying the concepts discussed above. The first task is getting a DMM that has a low enough current range to measure at least as low as 1 μ A up to 10 mA as a minimum range(s).

The HP-41 uses a spring loaded battery pack that holds four N cells connected in series to apply 6 volts DC to the calculator. See Fig. 1. Each calculator has its own specific mechanical requirements, but the basics



Fig. 1 – HP-41 N cell battery pack.

described here will apply to most calculator current measurement situations.

I favor inserting a piece of double sided circuit board between the battery contact and the calculator. Newer machines will require a much thinner circuit board. The space is often very tight (especially with coin cells) and I have even used folded aluminum foil covered with scotch tape.

Fig. 2 shows the details of a piece of circuit board. The soldered leads, covered with heat shrink tubing, are shown in Fig. 3. This provides a physically strong assembly.

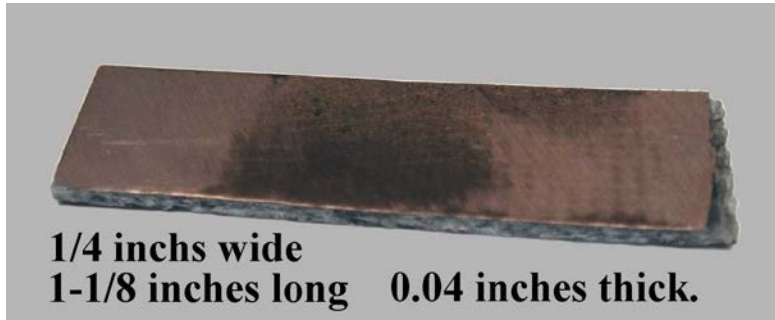


Fig. 2 – Double sided printed circuit board, PCB.



Fig. 3 – PCB with leads attached.

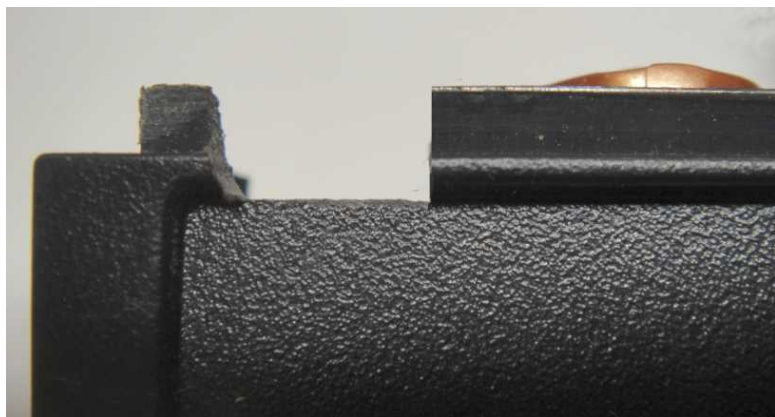


Fig. 4 – HP-41 Battery holder with filed notch – at negative end.

I have several HP-41's with spare parts. I modified one battery holder by filing a notch as shown in Fig. 4 by using a square file. The notch is on the negative end of the N cell holder. I did this many years ago and I don't remember why I chose this end.

Fig. 5 shows the battery pack installed with the "current probe" in place. The "current probe" may easily be pulled out. Inserting the probe requires holding it in place as the battery pack is slid in.

The internal "battery change capacitor" used for the HP-41 is large enough that it will retain a program in memory for many hours – often overnight. Because of this you may have to "reset" the machine by placing a jumper across the two outside battery compartment bumps and holding it there for at least 15 seconds. A calculator latch up may occur when you change current ranges on simple DMM's.

Here are some very simple measurements of an HP-41C to illustrate.

OFF^[1] – 0.5 μ A.

ON^[2] - 0.53 mA.

Loop^[3] - 4.19/4.22 mA

Pressing Key^[4] – 4.13 mA.

Loop^[5] – 4.26 mA

Notes:

- [1] The value slowly drifts down to 0.1 μA which is the lowest resolution of the \$3 (Harbor Freight sale) DMM. Comparing this DMM to a laboratory standard shows that it is quite accurate.
- [2] In Fix 4 display.
- [3] Using a simple (LBL 01, BEEP, GTO 01) loop.
- [4] Any pressed key draws about the same value.
- [5] Using a digit entry loop: LBL 03, 123456789 GTO 03.

If you duplicate the measurements using the same meter you will notice that the calculator won't turn on if the selected range is left on the lowest range (200 μA). Use two switch positions higher in the 20 mA. position of the rotary switch.

If you want to avoid the meter switch range changing issue you may measure the current by measuring the voltage drop across a resistor inserted between the battery and the calculator. This is easy with the probe shown in Fig. 3. You just solder a one ohm resistor across the probe and you may change the meter range switch as much as you wish.

The low cost CEN-TECH DMM, however only has a 200 mV range as its lowest range and you will lose resolution. The one ohm is convenient because what you see in the display voltage wise may be converted to amperes. 1 mV is 1 mA. Even meters 10 or 20 times more expensive do not offer sub DC mV ranges. You may increase the resistor value to 10 ohms to add one more digit of resolution, but you are then back into the region where certain calculators may not turn on or operate correctly under all conditions. Certainly measuring microamperes is out of the question because a microvolt meter is much more expensive.

There is another consideration. If you are measuring sub millivolts you will have lead length (stray induced noise) issues and your electronics understanding will be further challenged.

What is a user to do? The technical issues are not too difficult and cost is not the issue. As I mentioned above measuring current is a challenge, but it does not have to be difficult.

Once again there is a mechanical solution that requires a bit of work. What you need to add to your probe set up is a normally closed push button switch connected across the two meter leads. When you want to measure the current you push the switch. Now you may futz with your meter and calculator as much as you wish without concern of switching transients disturbing the calculator and you just press the button to make your measurement. The calculator will always turn on when you need it to, and you may change ranges as needed (button is not pressed).



Fig. 5 – “Current probe” shown in place.

A More Modern Example

Many current HP calculators use coin cells for the power supply. Fig. 6 shows an example. Machines like the HP 20b, HP 30b, HP 10bII, and HP-15C LE use the CR 2032 coin cell. Fig. 6 and fig. 7 shows how the power connections are made. There is no physical space to use a “current probe” approach described with the HP-41 example.

For this situation the cells are removed and power is supplied using clip leads and miniature spring loaded connectors that are small enough to grab on and hold the small terminals of the cell holder. An external power supply of external coin cell holder is used for the power. The current meter (DMM) is connected in series with the power source.



Fig. 6 – Coin cell holder with electrical connections “buried.”

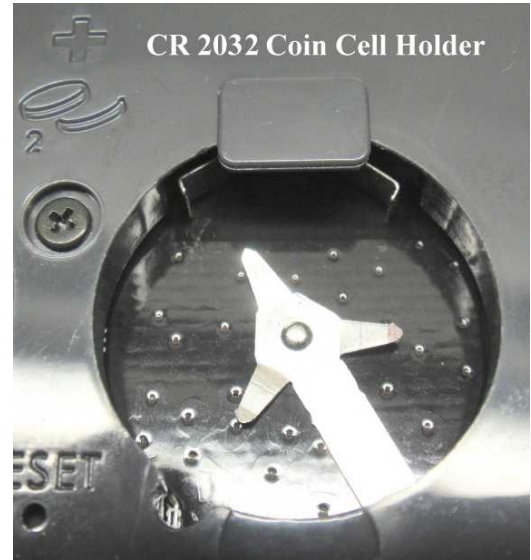


Fig. 7 – Small cell metal connections.



Fig. 8 – Miniature clips attached to the cell terminals; red positive, black negative.



Fig. 9 – Hook close up².

The primary current measuring procedure is as it always has been. Start at the highest current range and work your way down as needed. The issue with measuring calculator current is that the current will change with the various operating modes and conditions the calculator is used. The current drawn by the machine will range from sub microamperes to tens of milliamperes.

When you try to make a current measurement with your meter and it doesn't work you will soon learn that you violated this most important rule when making current measurements and you blew a fuse. Don't feel bad. EVERYONE has done it and EVERYONE will do it again. That is why making current measurements is more difficult than other fundamental electrical measurements.

How much current does your HP calculator draw? That is the subject of another article.

Measuring Calculator Current – Notes

- (1) *Drawing that first, even very small (test), amount of current from a new battery will start the chemistry working and the battery will have its life determined from that moment forward.*
- (2) *The hook shown is a lower cost knock off of the E-Z Hook model XG31. See the technical details at: <http://catalog.e-z-hook.com/item/test-hooks/all-categories-test-hooks-e-z-micro-hook-lock-hooks/xg31?> These cost about \$4 each and they are a vital requirement for making measurements on calculators.*