Fuses as shunts

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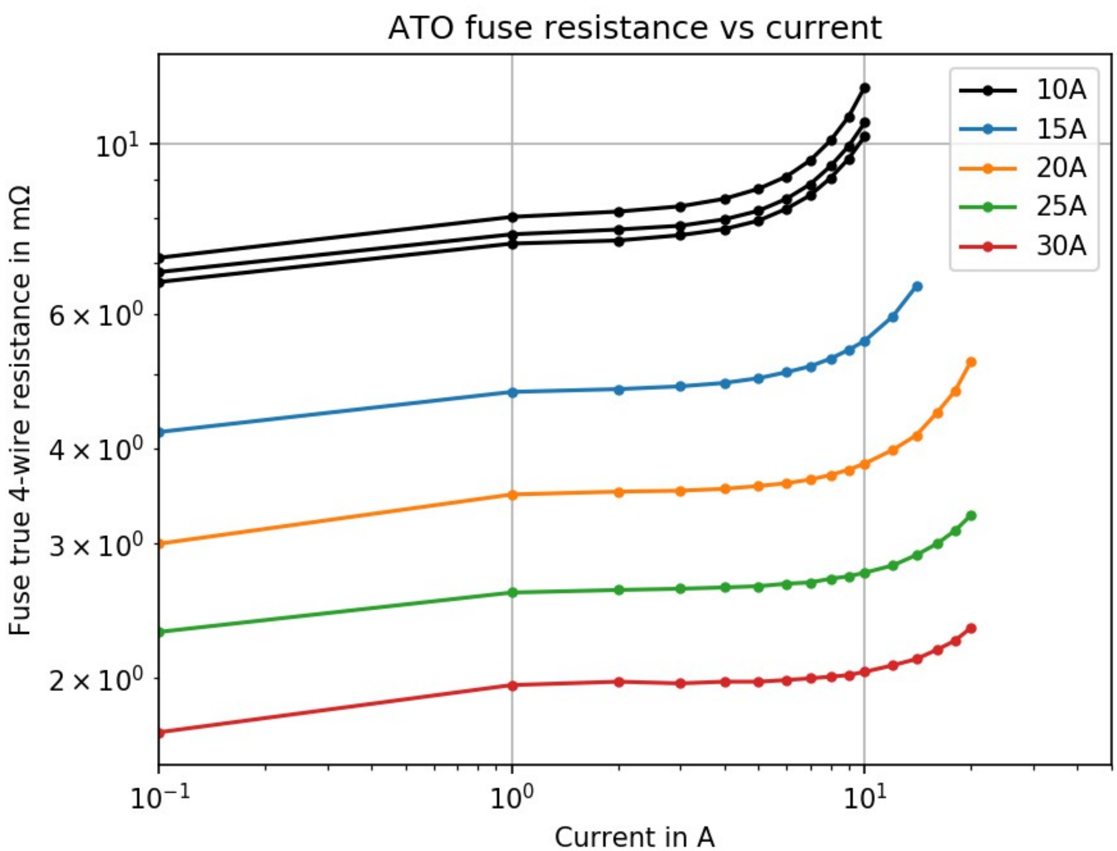
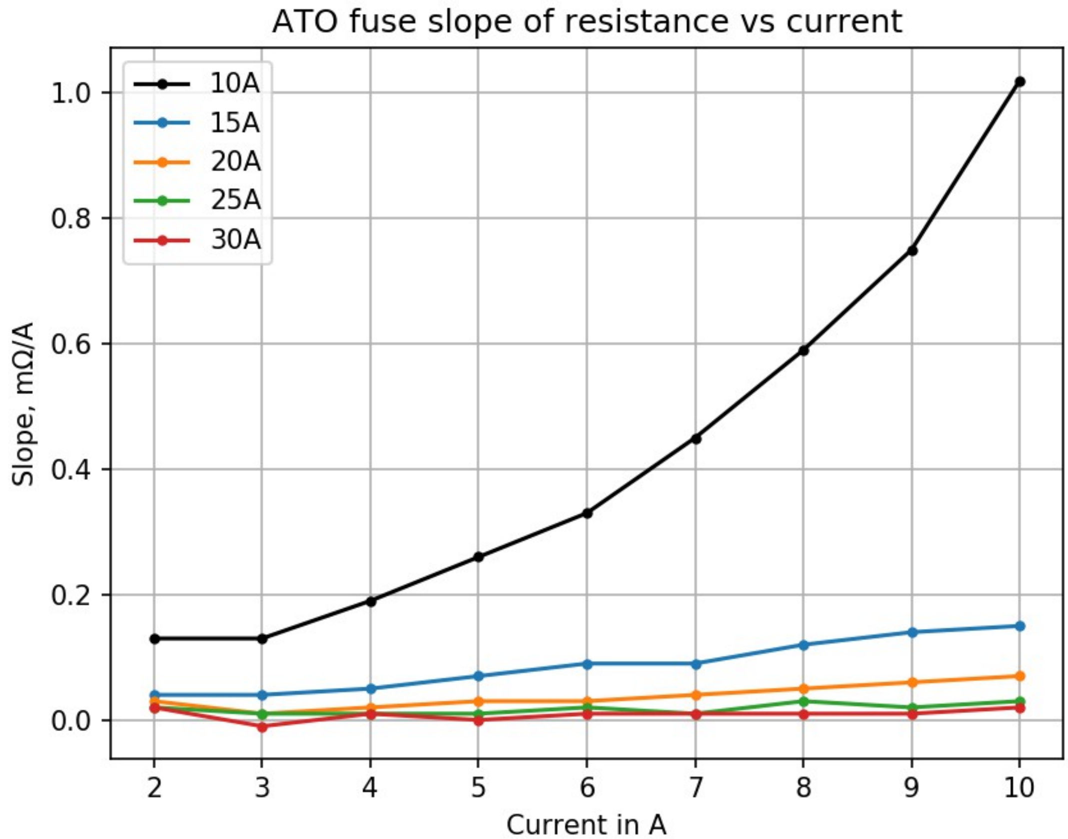
I wondered if auto ATO fuses could be used as poor man's shunts. I measured the 4-wire resistance of various fuses by putting a constant current through them and waiting until the voltage drop stabilized to a steady-state value. 1/4 inch female spade connectors made the current connection to the fuse and IC clips were used to measure the voltage drop across the fuse spade terminals' metal. Here are the measurements:



The following plot shows the slopes of the R(i) curves; a nonzero slope indicates self-heating effects:



The best shunts will be made from those fuses whose slopes are near zero. I made the following observations from these data

- ♦ The 30 A shunt would work well for a 0-10 A current range. The 25 A shunt would also be fairly good.
- ♦ The 20 A fuse would be suitable as a shunt for 0-4 A or so.
- ♦ I wouldn't use the 10 or 15 A fuses, as they are too non-ohmic. But they may work adequately for smaller current measurements.
- ♦ Note all of the shunts had non-zero slopes, so these aren't suitable for precision measurement work like a lab shunt made from Constantan or Manganin would be.

The fuse material will likely have a nonzero temperature coefficient of resistance, contributing another confounding factor for precision measurements. These measurements were made at an ambient temperature of 26 °C. Careful use of these shunts would still require corrections for use at different ambient temperatures. Also notice the within-group variation as shown by the three different 10 A measurements, so corrections would also need to be made when a shunt was replaced.

You can buy a 30 A fuse in a holder with 10 gauge copper wire connections for around $1; the fuses can be had for around $0.1. These 30 A fuses have resistances around 1 mΩ, so for a 10 A measurement, you could use a micropower op amp to condition the voltage to e.g. drive a suitable analog meter. One AA battery could power the meter for a substantial period of time.

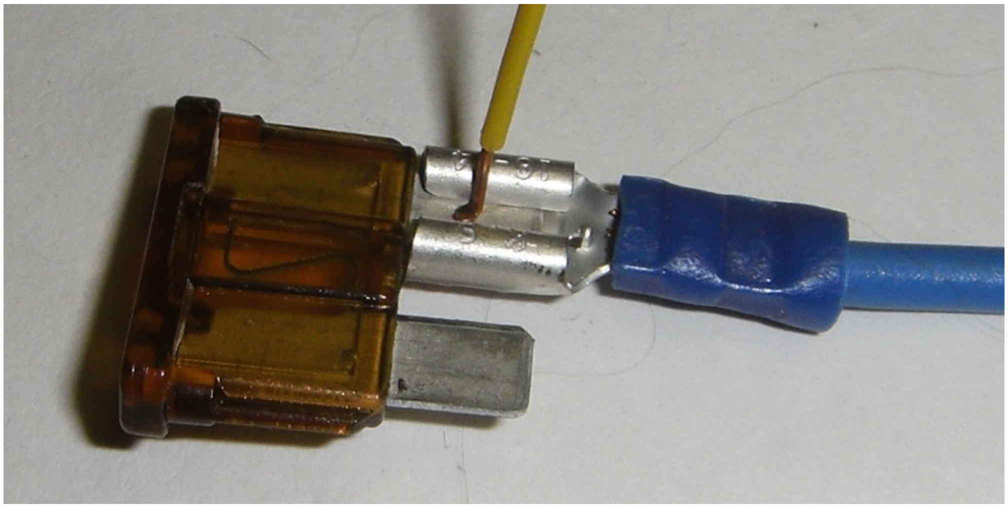
Thus, I'd conclude these fuses could be used for non-critical low-cost current measuring duty in tools that didn't need high measurement accuracy in a variety of ambient temperatures.

Inexpensive Kelvin connection to ATO fuse

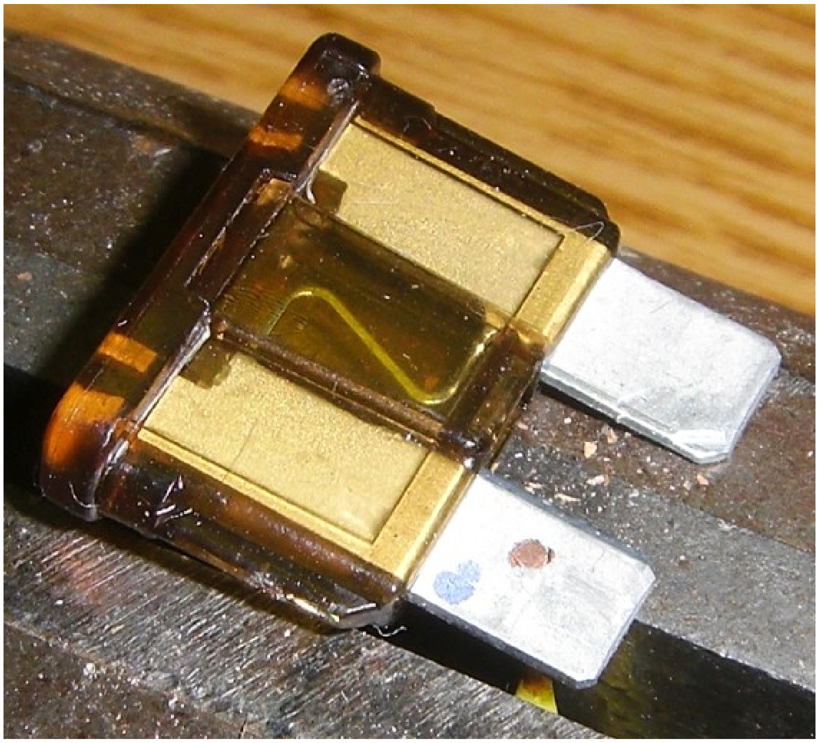
Here's a simple way to make a Kelvin connection to an ATO fuse for use in measuring circuitry. It's simple and robust. The basic idea is to attach a copper wire as if it were a rivet.

Drill a small hole in the blade that will be a close fit to a solid copper wire. Countersink each side of the hole slightly so the hole is beveled. Stick the wire through the hole, then bend it so that the insulation side is parallel to the blade. Clip off the back side's wire so that 1 or 2 mm protrude. Place the blade on e.g. the top of a vise jaw so that the side with the wire is touching the jaw. Use a small hammer to peen the protruding copper flush with the blade. You can file off any excess, but a little practice will make it so filing isn't required.

Though I haven't used this method yet, here are some photos of my first try. The method worked well. I used a piece of 22 gauge solid copper wire (0.64 mm diameter) and a #73 PC board carbide drill (0.61 mm diameter) to make the hole. A small watchmaker's broach was used to widen the hole enough so that the wire was a push fit in the hole. A sharp machinist's scraper made from an old 3-corner file was used to put the bevel on both sides of the hole. Here's how this connection would be used with a female spade connector:



Here's a closeup of the wire's end side pounded flat:



Here's the insulation side of the wire:

You can see where the copper was flattened by the hammer.

If you have the requisite tools, you'll find this surprisingly easy to do and quite secure because the copper has been inelastically deformed into the hole and locked in place by the bevels.

Caution: the pounded copper will break easily because of work-hardening if you bend it a few times, so only bend it once after peening.

Experimental data

Here are the notes on the experiment stuff I did to investigate this use of fuses as shunts.

I used an HP 6033A power supply to feed current through various ATX fuses and used an HP 3456A voltmeter (default state, 4 digits) to measure the voltage drop across the fuse. The first tests used Popper clips to connect to the fuses' blades and IC clips connected to the Popper clips to measure the voltage drop.

I later fixed the connection method to use 1/4" female spade connectors to a 90 mm long piece of 12 gauge (2 mm diameter) solid copper wire to the 12 gauge wires from the power supply to minimize voltage drops; the IC clips were then physically connected to the ATX fuses' blades to avoid the spade connections' resistance.

All voltage drops in mV, current in A, resistance in mΩ, time in minutes.

10 A (red)

Here's how the following data were taken. Two alligator clips connected to a BNC to dual-banana plug were connected to my Popper clips cable; the Popper clips were connected to the fuse and some IC clips connected the fuse's blades connected to the voltmeter. A dual banana with a chunk of 12 gauge copper wire as a short was used to short out the power supply connection to allow setting of the test current; at 1 A, there was some current flowing through the fuse which resulted in a 1.1 mV drop across the fuse (about 0.1 A current, which is negligible); at 10 A from the supply, there was 10 mV across a 10 A fuse, indicating 1 A through the fuse. This means the 12 gauge short works fine for setting the current without having to disconnect wires.

The current leads were shorted and the power supply was set to the desired current. Then the leads were connected to the fuse and the initial voltage drop was read as V0. A stopwatch was started at the start of current flow through the fuse and the maximum voltage drop across the fuse was read as Vt after Δt seconds; the criterion for the reading was when the voltage drop stabilized.

After testing at a particular current, the fuse was allowed to cool until the 100 mA voltage drop was within 20% of the cold value.

Here are the columns' data

i = current through fuse in A
ΔV = voltage drop across fuse in mV
R = fuse resistance at this current in mΩ
V0 = initial voltage drop in mV at t = 0
Vt = final voltage drop in mV (stabilized)
Δt = time to stabilize in minutes

RT = 79 °F

i	V0	Vt	R	Δt
0.1	0.73	0.73	7.30	-
1	8.21	8.22	8.22	1.5
2	16.59	16.69	8.35	4.0
5	43.87	45.77	9.15	8.0
10	104	130.1	13.01	8.0

At 10 A, the Popper clips were noticeably warm; this probably contributed to the last digit of the voltage at the 10 μV level because of thermoelectric voltages.

Alternative connections: I crimped some 10-12 gauge solderless connectors with 1/4" female spade connectors onto solid 12 gauge wire about 90 mm long, then soldered them to the wire. This let me connect to the power supply's cables with wire nuts; the female spade connectors connect to the ATX fuse blades OK. This is a better connection than the Popper clips cable -- and it's suitable for circuit construction if e.g. some vinyl tape is put between the connectors to avoid an accidental short (this is a cheap method of construction and doesn't require buying an ATX fuse holder).

With the 10 A current again, the initial voltage was 109 mV. At 30 sec it was 113 mV and 1 minute was 114.8 mV, so self-heating is definitely taking place. But the connectors and wire are cool and I can feel the fuse is warm with my finger, so this is a more legitimate connection method than the Popper clips.

At 5 minutes, the change rate was about 0.08% per second.

10 minutes: 118.90 mV. Definitely warm to the touch and my < 1 second finger touch dropped the voltage drop by about 100 μV. Contrast this 119 mV to the 130 mV with the Popper clips.

OK, this measurement method is adequate. I'll characterize three 10 A fuses at 1 A steps to get a feel for within-fuse variability. There appears to be no hysteresis, as when I set the current back to 0.1 A, the voltage on the first fuse always went back to 0.72 to 0.73 mV within a minute or two. Thus, I'll just increase the current setting for each measurement and take the reading when it seems stable to me.

RT = 79 °F		10 A ATX fuses				
	mV across fuse			**R fuse, mΩ**		
i	**1**	**2**	**3**	**1**	**2**	**3**
0.1	0.71	0.66	0.68	7.10	6.60	6.80
1	8.03	7.41	7.62	8.03	7.41	7.62
2	16.32	14.96	15.45	8.16	7.48	7.73
3	24.86	22.79	23.45	8.29	7.60	7.82
4	33.90	30.94	31.86	8.48	7.74	7.97
5	43.69	39.69	40.91	8.74	7.94	8.18
6	54.40	49.40	50.90	9.07	8.23	8.48
7	66.65	60.00	62.05	9.52	8.57	8.86
8	80.89	72.22	74.91	10.11	9.03	9.36
9	97.75	86.10	89.50	10.86	9.57	9.94
10	118.8	102.4	106.7	11.88	10.24	10.67

For the higher currents, I'd typically set the current to about 1 A more for a short time to allow self-heating to occur enough to see the voltage drop fall after I adjusted it to the set current (this speeded the measurements).

Note: when the 6033A was turned back to 0 A, the display read 0.02 A. If this was a true offset current, then the 0.1 A readings would probably be closer for the different fuses.

15 A (blue)

RT = 79 °F   15 A ATX fuse

i	mV across fuse	R fuse, mΩ
0.1	0.42	4.20
1	4.74	4.74
2	9.55	4.78
3	14.47	4.82
4	19.47	4.87
5	24.68	4.94
6	30.15	5.03
7	35.82	5.12
8	41.88	5.24
9	48.41	5.38
10	55.3	5.53
11	63.0	5.72
12	71.4	5.95
13	80.8	6.22
14	91.3	6.52
15	103.3	6.89

20 A (yellow)

RT = 79 °F   20 A ATX fuse

i	mV across fuse	R fuse, mΩ
0.1	0.30	3.00
1	3.48	3.48
2	7.02	3.51
3	10.55	3.52
4	14.14	3.54
5	17.84	3.57
6	21.60	3.60
7	25.48	3.64
8	29.53	3.69
9	33.77	3.75
10	38.2	3.82
12	47.7	3.98
14	58.3	4.16
16	71.2	4.45
18	85.5	4.75
20	104	5.20

25 A (clear)

I won't test this fuse past 20 A.

RT = 79 °F 25 A ATX fuse

i	mV across fuse	R fuse, mΩ
0.1	0.23	2.30
1	2.59	2.59
2	5.21	2.61
3	7.86	2.62
4	10.51	2.63
5	13.21	2.64
6	15.93	2.66
7	18.70	2.67
8	21.56	2.70
9	24.50	2.72
10	27.5	2.75
12	33.8	2.81
14	40.6	2.90
16	48.0	3.00
18	56.1	3.12
20	65	3.27

30 A (green)

I won't test this fuse past 20 A.

RT = 80 °F 30 A ATX fuse

i	mV across fuse	R fuse, mΩ
0.1	0.17	1.70
1	1.96	1.96
2	3.95	1.98
3	5.92	1.97
4	7.91	1.98
5	9.90	1.98
6	11.93	1.99
7	13.98	2.00
8	16.08	2.01
9	18.22	2.02
10	20.4	2.04
12	24.9	2.08
14	29.7	2.12
16	34.8	2.18
18	40.4	2.24
20	46.6	2.33