During the development of various technologies, many engineers encounter and must deal with inrush currents to their devices. This application brief addresses the reality of inrush current and the meaning of an $I^2t$ measurement, and then presents an actual $I^2t$ measurement and results from that measurement.

Many appliances draw a very large current for a brief period when they’re first switched on. This can cause problems in circuitry and hardware components. The shape and transient time of the inrush current depends on the particular device. Unless something is done to limit the magnitude of the inrush, a peak of 5 to 10 times the operating current would not be surprising. The reality of this large turn-on current makes it paramount to be able to measure and characterize the inrush in the development and verification of a device.

At first glance, the term $I^2t$ is not intuitive. However, it is simple and can be measured easily using modern instrumentation. An $I^2t$ measurement is an energy measurement and is derived from the power equation $P = I^2R$. The result of this measurement is quite often used to size fuses. Because a fuse manufacturer knows the fuse resistance and that it is fairly constant, the $R$ term of the power falls out of the equation. The physical meaning of this number said in words is “the energy delivered by an inrush current.” It is tempting to try to come up with a peak-current, transient-time multiplication of sorts to simplify this calculation; however, an inrush current can come in any shape and size. So it really is necessary to sum up the area under the full current inrush curve over the transient time.

Problems that users may encounter if fuses are not properly sized can range from annoying to quite unacceptable. An improperly sized fuse can potentially blow every time a user turns on the device due to the inrush current. If the fuse is readily available, the users can replace the fuse. In many cases, however, the fuse is buried down in the depths of other hardware or can be quite small and integrated into a printed circuit board or ASIC. In the latter case, replacing the fuse can be time-consuming and costly.
Inrush current measurement and characterization

The basics of doing an I^2t measurement are as follows. You must first capture the inrush current. Then you must decide where the inrush current transient starts and where the inrush ends. No exact equation exists to determine the start and end point of the inrush transient. The engineer designing the device should know what is considered the steady-state current in the device and use that point as the end of the transient. At that point, you should calculate the square of the inrush. The final step is to integrate the squared current values across the entire transient. The resulting number is the I^2t value. With this number, you can properly size a fuse or verify that it can indeed handle the inrush current.

To demonstrate this process, we will verify the 312 Series 1A fast-acting fuse by Littelfuse using the above steps for an I^2t measurement. To capture the inrush current, we used the Keysight IntegraVision PA2203 power analyzer. To source the inrush, we used the N6705B DC power analyzer with a N6784A module, both from Keysight Technologies.

The purpose of this test is to verify that the fuse will not blow when it encounters an inrush meeting the I^2t value on the fuse’s datasheet. The test setup is fairly simple. We set up the N6705B to source a square inrush pulse into the fuse and then connected an external current probe to one of the channels of the PA2203A. To find out what amplitude inrush is needed, we had to make a few simple calculations. We arbitrarily selected a transient time of 100 ms. The amplitude of the inrush is calculated as follows:

$$A_{pk} = \sqrt{\frac{I^2t \times 0.95}{t}}$$

where I^2t = 0.76 from the fuse's datasheet and t = 100 ms. Putting these values into the equation, we get an inrush amplitude of 2.68 amps. Also, it is necessary to measure the resistance of the fuse before and after the test to ensure that the fuse isn’t melting partially, thus changing its resistance. The resistance before the test was 0.3 ohms.

The IntegraVision PA2203A includes a handy I^2t applet that simplifies this test. To get to the applet, you press the Analyze button on the PA2203A and touch the I^2t application. Figure 1 shows the setup of the test parameters. For this test, we chose 2.60 amps for the trigger point of the inrush. We set the acquisition time to 150.0 ms to fully capture our 100 ms pulse. And then we simply pressed Start. The PA2203A then prompted us to turn off the power supply and hit Next, then to turn on the power supply. These steps are necessary to ensure that the analyzer captures the inrush.

Figure 1. The Keysight IntegraVision PA2203A screen shows the test parameter setup.
Figure 2 shows the captured pulse. Hitting Next, Figure 3 shows a math waveform of the current inrush squared and another math waveform showing the integral of the inrush squared. The sidebar is populated with the results of the test. We can see an inrush of 726.8 mA²s, which is close to the data sheet value. The fuse indeed did not blow. The resistance of the fuse after the test remained at 0.3 ohms, verifying the fuse did not partially melt.

**Figure 2.** The Keysight IntegraVision PA2203A captured the inrush pulse sourced from the N6750B DC power analyzer with N6784A module.

**Figure 3.** The Keysight PA2203A shows math waveforms of the current inrush squared and another math waveform showing the integral of the inrush squared, plus a sidebar with test results.

**Conclusion**

An I²t test measures the energy delivered by an inrush current pulse. You can use the resulting number to size or verify fuses to ensure a device is protected and that it will not blow the fuse every time the device is turned on. This test can be done manually, but it is much easier to use a modern power analyzer for an easy and accurate way to measure I²t.
From Hewlett-Packard through Agilent to Keysight

For more than 75 years, we’ve been helping you unlock measurement insights. Our unique combination of hardware, software and people can help you reach your next breakthrough. Unlocking measurement insights since 1939.

myKeysight
www.keysight.com/find/mykeysight
A personalized view into the information most relevant to you.

Three-Year Warranty
www.keysight.com/find/ThreeYearWarranty
Keysight’s committed to superior product quality and lower total cost of ownership. Keysight is the only test and measurement company with three-year warranty standard on all instruments, worldwide. And, we provide a one-year warranty on many accessories, calibration devices, systems and custom products.

Keysight Assurance Plans
www.keysight.com/find/AssurancePlans
Up to ten years of protection and no budgetary surprises to ensure your instruments are operating to specification, so you can rely on accurate measurements.

Keysight Infoline
www.keysight.com/find/service
Keysight’s insight to best in class information management. Free access to your Keysight equipment company reports and e-library.

Keysight Channel Partners
www.keysight.com/find/channelpartners
Get the best of both worlds: Keysight’s measurement expertise and product breadth, combined with channel partner convenience.

www.keysight.com/find/PA2203A

For more information on Keysight Technologies’ products, applications or services, please contact your local Keysight office. The complete list is available at:
www.keysight.com/find/contactus

Americas
Canada (877) 894 4414
Brazil 55 11 3351 7010
Mexico 01 800 254 2440
United States (800) 829 4444

Asia Pacific
Australia 1 800 629 485
China 800 810 0189
Hong Kong 800 983 693
India 1 800 11 2626
Japan 0120 (421) 345
Korea 080 769 0800
Malaysia 1 800 888 848
Singapore 1 800 375 8100
Taiwan 0800 047 866
Other AP Countries (65) 6375 8100

Europe & Middle East
Austria 0800 001122
Belgium 0800 58580
Finland 0800 523252
France 0805 980333
Germany 0800 6270999
Ireland 1800 832700
Israel 1 809 343051
Italy 800 599100
Luxembourg +32 800 58580
Netherlands 0800 0233200
Russia 8800 5009286
Spain 800 001015
Sweden 0200 882255
Switzerland 0800 805353
Opt. 1 (DE)
Opt. 2 (FR)
Opt. 3 (IT)
United Kingdom 0800 0280637

For other unlisted countries:
www.keysight.com/find/contactus
(BP-02-10-16)

DEKRA Certified
ISO9001 Quality Management System

www.keysight.com/go/quality
Keysight Technologies, Inc.
DEKRA Certified ISO 9001:2015 Quality Management System