KEITHLEY

Application Note Series

Optimizing Switch/Read Rates with Keithley Series 2000 DMMs and 7001/7002 Switch Systems

Introduction

The period of time an instrument requires to perform a specific measurement is only one factor in the overall equation of test system timing. Typical testing applications often require measuring several points of the DUT with the same instrument, such as a multimeter. A multiplexer is typically used to switch the test signals automatically from point to point. Multiplexing can be done with relays or solid-state switching devices. The switching devices are normally housed in a mainframe that provides the card cage facility, drive lines and test instruction parameters. Keithley offers a variety of flexible measurement and switching solutions for these multipoint testing applications, including the Series 2000 line of digital multimeters and Model 7001 and 7002 switch mainframes.

The rate at which a test is performed is crucial to test engineers because the faster the test is completed with reliable results, the more devices that can be tested in same period of time. Manufacturing/production facilities are always seeking optimum speed in their test systems. This application note addresses the factors that affect test system speed. These factors are generally additive, but their effect on total system speed varies.

Test engineers use the word "throughput" to define overall system speed. Throughput encompasses a variety of factors, including measurement source and sense times, and switch settling, actuation, and trigger actuation times.

Test System Configuration

Although test systems may be configured with many devices, for the purposes of this application note, we will consider a test system consisting of a digital multimeter and a switching device. The system may connect these devices through several ports, such as external trigger lines, input/output signals, and remote control connections (GPIB, RS-232, etc.) *Figure 1* illustrates a typical DMM/Switch-based test system.

DMM Configuration

The time required to make the measurement itself is the first major factor in overall system throughput. When using a multimeter, several parameters can affect the measurement speed. While most multimeters have control over many of these parameters, some of the more "basic" units do not. However, the factors are the same for the simplest meter or for the most complicated one. It is the level of control of these parameters that is important for exact measurement timing.
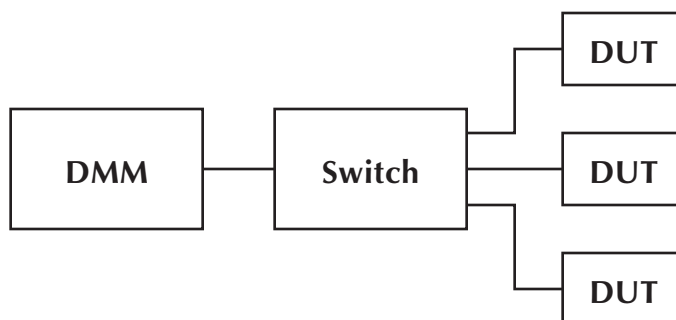

Figure 1. DMM/Switch Configuration

Integration rate—The integration rate is the time it takes the A/D converter to "look" at the input signal. The integration time affects the usable resolution, the amount of reading noise, and the ultimate reading rate of the measurement. The optimum integration time setting for a given application depends on the measurement requirements. If speed is the most important consideration, then the smallest integration rate would be used (0.01 power line cycles or PLCs) at the expense of additional reading noise and less usable resolution. For maximum common mode and normal mode rejection, the larger integration rate would be used (up to 50 PLCs). This would produce the most stable, accurate and highest resolution readings. See *Tables 1 and 2* for integration selections for Series 2000 DMMs.

Table 1. Model 2000 and 2010 Integration Selections

Model	Fast (Front Panel)	Medium (Front Panel)	Slow (Front Panel)	Settings (Remote)
2000	0.1	1.0	10	0.01 — 10.00
2010	0.1	1.0	5	0.01 — 10.00

Table 2. Model 2001 and 2002 Integration Selections

Model*	Fast	Medium	Normal	HI Accuracy	Settings
2001	0.01	0.1	1.0	10	0.01 — 10.00
2002	0.01	0.1	1.0	10	0.01 — 50.00

*All settings available on front panel and remote

Ranging—All published measurement rates are stated with a fixed measurement range. Autoranging should not be used when optimum speed is required. While some meters have fast autoranging features, the actual speed is not predictable. Fixed range is the only way to ensure timing precision.

Filter—All rates are stated with all filters turned off. Although filtering stabilizes noisy measurements, it also slows the rate of measurement. The Keithley 2000 Series meters all have digital filters, which are based on reading conversions. With a digital

filter, a DMM takes a number of conversions and averages them before displaying the result. The number of conversions is the largest factor affecting rate when using filters. As the number of conversion averaged increases, the rate decreases.

DMMs typically offer two types of filters (*Figure 2*):

Repeating Filter—A repeating filter takes a selected number of reading conversions, averages them, and yields a reading. The filter is then cleared and starts collecting conversions all over again.

Moving Filter—A moving filter is a first-in/first-out stack; in other words, the newest reading conversion replaces the oldest. An average of the stacked reading conversions yields a reading. Therefore, after a selected number of conversions, a moving filter gives a new reading for every new conversion.

The time to the first reading is the same for both types of filters. After the first reading, the moving average filter produces a faster rate than the repeating filter.

A. Type: Moving Average, readings = 10
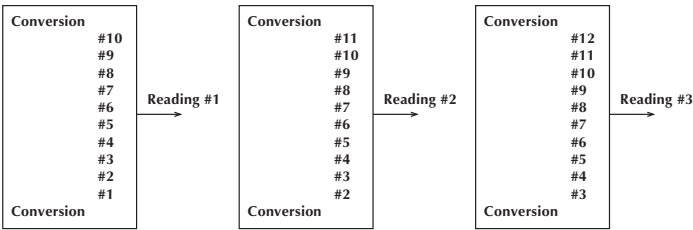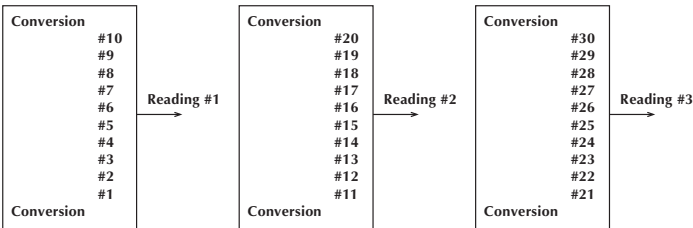
B. Type: Repeating, readings = 10

Figure 2. Filter Types

Autozero—Normally, every A/D conversion has four distinct periods, as described below. Disabling the Autozero function eliminates two of these four periods, enhancing measurement speed.

Signal Integrate   During this period, the A/D converter "looks" at the input signal. The signal integrate period is essentially the PLC setting.

Reference Integrate   This is the length of time that the meter "looks" at the internal reference signal. This allows a reference to compare the input signal with a known level.
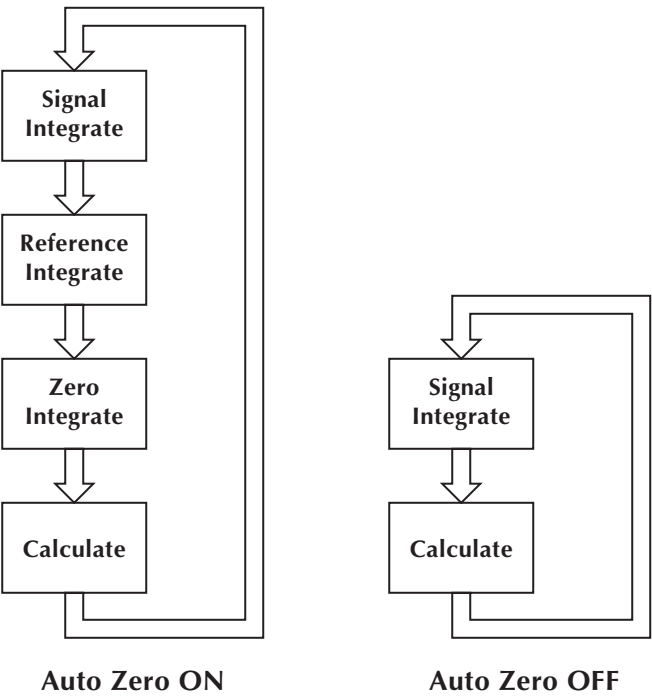

Auto Zero ON   **Auto Zero OFF**

Figure 3. Typical A/D Conversion Period

Zero Integrate   This is how long the meter "looks" at the internal zero. This allows re-zeroing the input amplifier. This is designed to keep the signal from drifting over the course of several conversions.

Calculate   This is the period in which the meter firmware calculates the measurement. It is normally a very small portion of the overall conversion.

With Autozero enabled, the A/D conversion sequence includes all four periods. With Autozero disabled, the A/D conversion does not go through the zero integrate or reference integrate periods. Therefore, the conversion period is much shorter and the measurement speed is increased. However, it also means the meter is not checking reference or zero in the A/D conversion, so the reading could drift slightly after a period of time. The actual drift is a result of small changes in the temperature of the measurement circuitry. To avoid this drift, keep Autozero enabled until just before the actual measurement sequence is performed. Re-enable Autozero once the measurement sequence is completed. This technique keeps the measurement circuitry on track before and after the measurement. As long as the measurement does not last too long, e.g. longer than ten minutes (depending on the meter used), the readings shouldn't drift enough to affect the accuracy of the measurement.

Trigger Delay—In a multiple channel test system, a relay is used to make the connection to various signals. Relays normally have bounce or settle times of several milliseconds. Starting the A/D conversion before the signal is settled could result in a noisy measurement. The trigger delay is the period from when a trigger is received to the time the meter starts the A/D conversion (*Figure 4*). This delay is generally used to allow the input signal to settle before starting the A/D conversion. Keithley's Series 2000 meters have settable trigger delays, which, if applied carefully, can help optimize measurement integrity and speed.
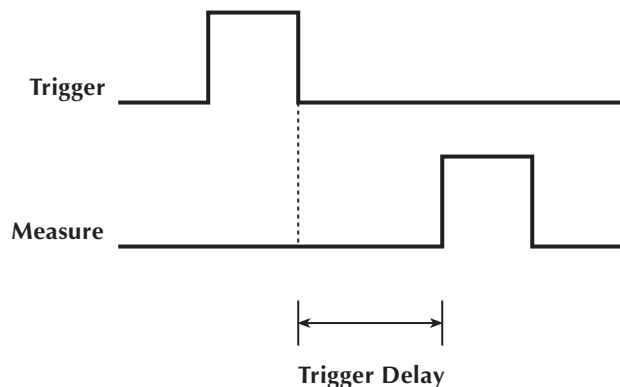
Figure 4. Trigger Delay

Function—The measurement function to be performed (DCV, ACV, etc.) is a factor in the measurement rate because each function is measured using a different technique. In general, the resistance function takes longer to complete a measurement than the DCV function, which is simply a single A/D conversion sequence per measurement. In contrast, the Resistance function could require several A/D conversion sequences per measurement. If a meter measures temperatures using RTDs or thermistors as temperature sensors, that temperature measurement function is usually the meter's slowest function. Typically, DCV measurement is usually the meter's fastest function.

Display—Updating the meter's front panel display takes time, so turning off the display allows the meter to complete the measurement task faster, particularly meters with information-intensive displays. These meters typically take up to 5% more time to update the display. In systems where speed is critical, the display should be disabled.

In applications where it's necessary to see the display, the following technique can be used to optimize speed.

- Enable the display before measurement.
- Disable the display during measurement.
- Re-enable the display after measurement.

The actual measurement is not viewed during the test.

Switch configuration

The next factor affecting test system speed is the switching time. The switching time is the time it takes to disconnect one signal and connect another one to the measurement instrument. Three factors affect switching time (*Figure 5*). All three factors are additive in the switch configuration calculation of switch speed.

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Settle Time	The time it takes for the switching device to settle. A relay, for example, has a settle time specification of ≈3ms.
Actuation Time	The time required for the switching mainframe to start closing the switch. The Model 7001 and 7002 have actuation times of ≈6ms.
Trigger Execution Time (Trigger Latency)	The maximum time from activation of Trigger Source to start of switch open or close. In general, this is several hundred microseconds.
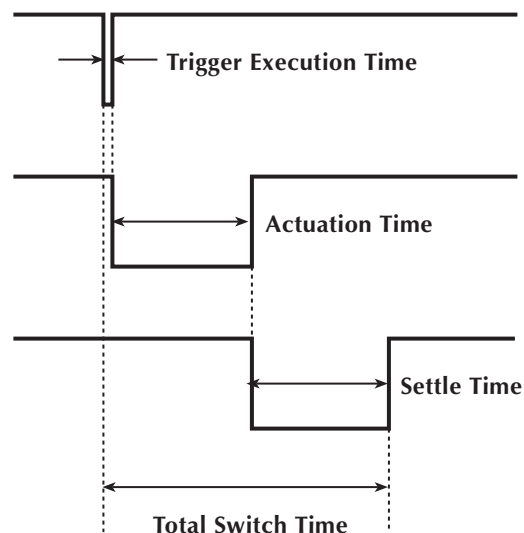
Figure 5. Switching Times

Total system speed is equal to the DMM configuration factors plus the Switch configuration factors. For example, to switch and measure six DC voltages:

Model 2001

- 1 PLC
- 1V range
- No filter
- Autozero Off
- No delay
- DCV function
- Display ON   24 ms

Model 7001/7011*

Settle Time =	3ms
Actuation time =	6 ms
Trigger Actuation Time =	0.1ms
	33.1ms
	per switch/read

*Break-before-make off

For the parameters listed above for the Model 2001 and 7001/7011-S units, the switch/read rate is 33.1 ms per switch/read. This is about 30 switch/reads per second. The times for the multimeter and switching equipment were quoted from the published specifications.

Alternative Solutions

Test systems can be configured with a variety of instrumentation. The Series 2000 Multimeters are just one choice for setting up the measurement portion of the system. The Series 2400 SourceMeter® instruments and the Model 236/7/8 SMUs include the source and measure function in one unit. These instruments allow greater flexibility and, therefore, tighter control of the measurement parameters. These instruments also offer programmable test current and voltage levels, which some test parameters require.

If a voltage or current sweep is required, then the Series 2400 and Model 236/7/8 instruments may prove better suited for the test system. If significantly more resolution and accuracy are required, then the multimeters will be the better choice of equipment.

The configuration of the switching part of the system depends on the signal parameters. Many different switch topologies could be used — single pole, double pole, four pole, high/low current, high/low voltage, matrix, multiplex, high frequency, etc. Keithley has a wide variety of switching cards to accommodate almost any application or combination of signals.

Equipment List

A typical test set-up would include the following equipment:

1. Keithley Model 2000 Multimeter

2. Keithley Model 7001 Switching Mainframe

3. Keithley Model 7011-S 40-channel switching card

4. PC with Keithley Model KPC-488.2AT IEEE-488 interface card

5. Keithley Model 7007-2 IEEE-488 Interface Cable (2)

6. Test leads to connect the Model 7011-S switch card to the input of the Model 2000

Conclusion

Measurement and the switch time are major factors in determining the throughput of a test system. Both factors must be optimized in order to attain the best overall system throughput.