Instrument Programming That Optimizes Speed and Accuracy

When a general purpose instrument leaves the factory, it's programmed to work well in a broad range of applications, but may not have optimum settings for your specific needs. This article describes the most common programmable features of electrical measurement instruments and how you can change settings to optimize throughput and accuracy.

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FACTORS AFFECTING SPEED AND ACCURACY

The time required to take a measurement is a major factor in overall test system throughput. Understanding the parameters that affect measurement time is crucial in getting the best combination of noise immunity, accuracy, and speed, because some instruments can be programmed to optimize these tradeoffs. (The degree of control provided by the instrument determines the level of optimization.) Inside the instrument, the primary factors affecting these tradeoffs are:

- A/D conversion rate
- Ranging time
- Use of filters
- Triggering method
- Autozero effects
- Variable being measured
- Display update rate

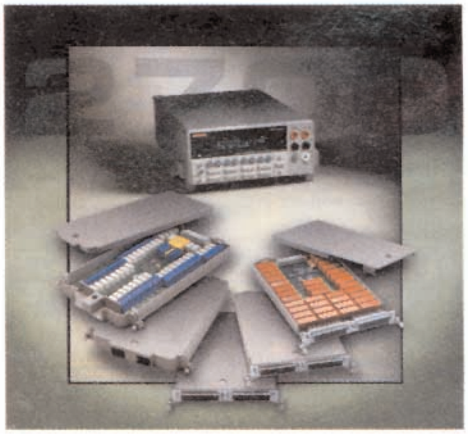
A/D Conversion Rate – Taking a real world analog signal (resistance, voltage, current, etc.) and turning it into a digital number requires an analog to digital converter (ADC). A large portion of the time required to perform a test is the time it takes the instrument's ADC to acquire data. Most measurement instruments have integrating ADCs, which "look" at the input signal for a specified time interval and integrate analog values for that period. The integration rate affects useable measurement resolution, the amount of reading noise and the ultimate reading rate of the instrument.

The optimum integration time setting for a given application depends on test requirements. If speed is the most important consideration, then the smallest integration time is used (typically, 0.01 of a power line cycle or PLC). This is done at the expense of additional noise and less useable resolution. For maximum common mode and normal mode noise rejection, the longest integration period is used. For some instruments that could be as much as 100 PLCs.

Most instruments with integrating ADCs are shipped from the factory with the integration rate set at 1 PLC as the default value. This means the ADC will integrate the input signal over a 16.667 millisecond period (for a 60 Hz power line). If the instrument allows you to program the integration period, integer PLC values (e.g., 1, 2, 5, 10) produce the best common mode and normal mode rejection of 60 Hz noise. Non-integer PLCs (e.g. 0.7, 1.5, 2.3) result in fractional integration periods that tend to allow more 60 Hz noise into the measurement. Table 1 gives measurement times and equivalent instrument reading resolutions for different PLC settings. Frequently, experimentation and judgment are needed to arrive at the optimum integration time setting.

Autoranging – A digital instrument's reading rate specification is stated for a fixed measurement range, but most have an autoranging feature that selects the appropriate range for the input's magnitude. Usually, this is a feature that can be turned on and off by the user. Although some instruments have fast autoranging features, the actual speed is not predictable.

Autoranging may create other problems in DC current and voltage sources with this autoranging feature.



Keithley Instruments Model 2700

NPDC Value	ADC time in msec at 60 Hz	ADC time in msec at 50 Hz	Typical Resolution (equivalent digits)
100	1667	2000	8 1/2
50	833.5	1000	7 1/2
10	166.67	200	6 1/2
1	16.67	20	5 1/2
0.1	1.67	2	4 1/2
0.01	0.167	0.2	3 1/2

Table 1 Typical Measurement Resolutions for Different PLC Settings

For example, when changing from one range to another it is not uncommon for a constant current source to drop to zero output for a short time (e.g. milliseconds) and then uprange or downrange to the desired value. This can cause errors when generating a family of I-V curves for an active device, such as a diode or transistor. When applying the current sweep (over a range of values), a momentary drop to zero in the output can be detrimental to the device, as well as produce unwanted measurement effects.

Autoranging is a convenience feature that is particularly valuable when first setting up a measurement and the exact signal level is unknown. The autorange feature can find the proper range, but afterward a fixed range helps fine tune the measurement for maximum resolution and accuracy. Also, a fixed range ensures data acquisition timing precision and allows the maximum speed consistent with required measurement resolution.

Filters – Some instruments have digital input filters that can be turned on to reduce random noise affects. Again, the instrument's measurement rate is usually specified with this feature turned off, but could also be stated for specific filter settings. This gives the user an idea of what to expect under different measurement conditions. While filtering stabilizes noisy measurements, it also reduces measurement speed because a selected number of A/D conversions are stored in a temporary buffer and averaged. The result is displayed or stored as a "filtered" reading.

Typically, a user can control the number of conversions averaged, and this is the largest factor affecting the instrument's filtered measurement rate. As the number of averaged conversions increases so does measurement accuracy (if significant random noise is present), but the measurement rate decreases. (For a more detailed discussion of this topic, see Part 3 in the September 2000 issue of M&C.)

Triggering – Some instruments allow only one method of triggering. Typically, that method is continuous triggering from an internal source after the instrument powers up. Most handheld DMMs operate in this manner. More sophisticated instruments allow a choice of methods and trigger signal sources, each one having advantages and disadvantages.

Internal Triggering. This method continually updates data acquisition; the update rate may or may not be adjustable. The main advantages of this method are its simplicity (i.e., no set-up required) and no need to manually trigger a reading with a pushbutton. For applications that require precise timing for accurate measurements, internal triggering may not be appropriate. (See Part 1 in the April 2000 issue of M&C for more information on trigger timing issues.)

External Triggering. External triggering avoids latencies that are inherent with internal triggering circuits. There are two modes for this type of triggering: single and continuous. Typically, the single mode is used for "one shot" measurements (one reading per trigger), which keeps the instrument ready to update on receipt of the next external trigger signal. The continuous mode requires one external trigger to start but then continually updates based on the instrument's internal trigger rate.

A common external trigger signal is a pulse that originates in the process, experiment or equipment being monitored. Each instrument has a trigger input specification, which frequently calls for a TTL level pulse. Depending on the source, additional circuitry may be needed to condition the trigger signal to meet input specifications. If the voltage level is too high or too low, then amplification or division of the trigger pulse is required. If the pulse duration is too short, then a pulse stretching circuit is required. When the instrument has an external trigger link port, this type of triggering allows the most precise control of the measurement.

In computer controlled measurement applications, the trigger signal can originate inside the PC. Sources include digital I/O signals from data acquisition cards that are routed to the external trigger input of the instrument or placed on the external General Purpose Interface Bus (GPIB). In the latter case, the application program is written to call for a trigger signal under appropriate conditions. This program typically uses GPIB commands, such as GET (Group Execute Trigger) and the Talk Command (to send data), or simply sends an ASCII character string, such as "X". In any case, an instrument with a GPIB interface can be set up to interpret these as a trigger signal and initiate a measurement. The downside to this triggering method is the latency created by the PC's software and operating system.

Timer. A timer, either internal or external, can also be used as a trigger. Many instruments have internal timers as a standard feature. This is useful in situations when a measurement application only runs periodically and there is no external trigger available. In any event, the timer can be set from the fastest measurement rate of the instrument to as high as 999,999.999 seconds.
The value of a timer as a trigger source depends a great deal on instrument design. Ideally, the instrument should allow programming that triggers a reading, or series of readings, at specified intervals corresponding to application needs. With this capability, you could, for example, measure both the temperature and R-T coefficient of a resistive device as it is cycled every few minutes in a temperature chamber. In this type of application, a timer allows automatic data acquisition and storage at flexible intervals. When the experiment or process is complete, data can be downloaded from the instrument to a computer and processed.

Autozero – As discussed in an earlier article, an instrument's autozero feature minimizes errors due to thermal drift in electronic circuits. If the instrument has been running long enough (at least 20 minutes) and is at thermal equilibrium, then drift error normally is minimal. Nevertheless, many manufacturers provide programmable autozero features that allow you to adjust this function for application requirements.

Typical autozero programming options are ON, OFF and PERIODIC. The (always) ON option results in the most stable and reliable readings by performing an autozero adjustment before each measurement. Turning autozero OFF allows faster measurement rates at the expense of more drift error. The PERIODIC option permits autozero adjustments at user selected intervals. This level of control allows you to optimize tradeoffs between speed and accuracy based on measurement conditions.

Measurement Function – The type of measurement (DCV, ACI, resistance, etc.) has a major effect on instrument throughput because each function uses a different data acquisition and calculation technique. Although each application dictates the type of measurements required, there may be cases where measurement sequence makes a difference in overall system speed.

For example, changing from one measurement function to another takes a certain amount of time. The longest times are associated with AC functions, which typically take several hundred milliseconds to change and settle before the AC measurement can be taken. This is due to extra time consumed in signal conditioning before ADC processing. Temperature measurements using thermocouples also are slow because of cold junction comparison readings and calculations converting voltages to temperature. Measurements with RTDs and thermistors are not much faster because a resistance reader requires several A/D conversions for one measurement. (See sidebar.)

The key point here is that a test algorithm can be written so that other system functions are performed while slower measurements take place. Examples include sending data over the GPIB and cycling an automatic test fixture. This may mean making the slowest measurement the last one in a test sequence.

Display – Updating an instrument's front panel display is a relatively slow process particularly for those that have multiple functions and several layers of menus to program. In an automated system where

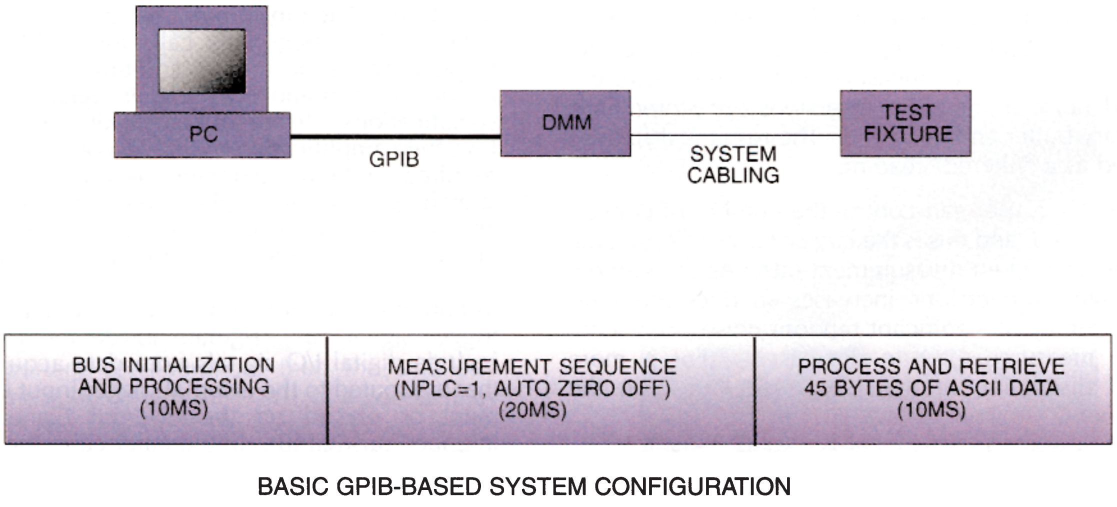


Figure 2. GPIB-based measurements potentially add trigger latencies if measurement programs are not carefully written.

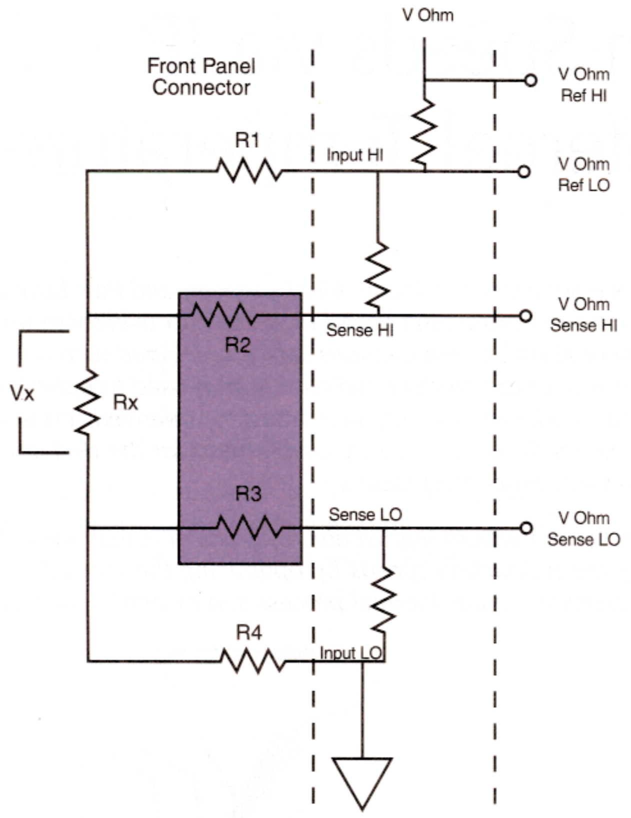


Figure 3. Input configuration during 2 and 4 terminal resistance measurement

instrument data is being streamed to a computer for storage or immediate processing, a display probably is not required; speed will be more important. Therefore, if the option is available, turn off the display. This can increase measurement speed by up to 10%.

If an operator really needs to see the display to make a decision, this probably will not occur during the period of an automated measurement. If so, the following sequence can be used to optimize speed:

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

For a given set of test conditions, the instrument programming techniques described in this article can help improve both measurement accuracy and throughput. In the next and final part of this series, additional programming techniques will be described that further enhance measurement quality and productivity. These will include ways to minimize system overhead with proper use of the GPIB; using instrument memory for test configurations; taking advantage of an instrument's compliance and pass/fail features; application of instrument math functions; and selection of output modes.

SIDEBAR

WHAT'S SO TOUGH ABOUT RESISTANCE MEASUREMENTS?

Most resistance measuring instruments use the ratio-metric technique. When the resistance function is selected, a series circuit is formed between an ohms measurment current source, a reference resistor (for range calibration) and the external unknown resistance. A known current is forced through both the reference resistor and the unknown resistance. Since this current is common to both resistances, the value of the unknown resistance can be calculated using Ohm's law by measuring the voltages across the reference resistor and the unknown resistance. Because a resistance measurement requires two voltage measurements and a calculation, it takes much longer than a standard DCV reading, which requires only one measurement and a direct display of results. A four-wire (Kelvin) resistance measurement, which is often used for improved accuracy, would take even longer because it requires four voltage measurements (see Figure 3).

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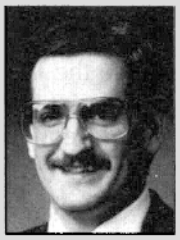

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