THE BENEFITS OF AUTOCALIBRATION

Jonathan Miller, Founder and President

INTRODUCTION

Every analog circuit exhibits fluctuations in performance due to changes in temperature. An analog component's datasheet will list this error as a temperature coefficient. The total error of an analog circuit is the sum of the temperature coefficients of all the components in the signal path. A simple analog circuit containing just an A/D converter chip may have an acceptable error that can be ignored for many applications. But today's complex A/D circuits, containing input multiplexor chips, a programmable gain circuit, a unipolar / bipolar shifting circuit, a single-ended / differential switching circuit, a voltage reference, and finally the A/D chip, may exhibit errors that become significant in comparison to the signal being measured. The problem becomes even worse with today's boards, which are rated for operation over a range of -40 to +85^{o}C, a total range of 125 degrees.

If the A/D circuit does not have some method to compensate for these built-in errors, the A/D reading will be unreliable. In simple terms, the effective resolution of the circuit will be substantially lower than the resolution listed on the product's datasheet. It is not uncommon for an A/D board with a 16-bit A/D converter to yield measurements with only 9-bit or 10-bit accuracy. Why pay a 16-bit price for a 9-bit measurement?

CALIBRATION METHODS

Analog potentiometers are used on low-cost A/D boards to calibrate the analog circuitry. This method works well *at a given temperature*, typically room temperature at which the board was initially calibrated. However as the temperature changes, the above-noted temperature coefficients take effect again, causing errors which increase as the temperature increases or decreases. In addition, calibrating the board again requires physical access to the potentiometers, which usually means disassembling the system, an inconvenient and time-consuming process.

Autocalibration solves these two problems by enabling the board to be calibrated under software control at any time. No physical access is required, so the process can be done as often as desired with essentially zero cost and zero time required. Since the calibration can be done at any time, the application program may perform calibration on a frequent basis, such as once a day or once an hour, limiting any effects of temperature changes on the system. Autocalibration still requires direct intervention of the application program. The program has to know that calibration is required, and it has to control the process, which can be quite complex. Diamond Systems' Universal Driver software, included free with all our A/D boards, provides built-in autocalibration code to simplify the process. A simple function call, addressing the board to be calibrated, is all that is required to initiate autocalibration.

Auto-autocalibration takes this process one step further by eliminating the need for application software intervention. In the technique patented by Diamond Systems, the A/D board contains a built-in temperature sensor and microcontroller. The microcontroller continuously monitors the temperature sensor. When the board's temperature changes by a specified amount, the microcontroller will initiate and control the autocalibration process automatically, without any need for involvement by the system in which it is embedded.

HOW IT WORKS

In the Diamond Systems approach, a precision low-drift voltage reference is used as the starting point. A series of voltage dividers provide two measurement points near the endpoints of each input voltage range on the board. For example, for the 0-1.25V input range, values of approximately 2mV and 1.24V are used. During autocalibration, these two voltages are read by the A/D circuit, and the resulting A/D readings are compared to correct readings stored in an EEPROM on the board. Note that the absolute values of these voltages are not important, only their stability and the difference between the current reading compared to the stored value.

To correct these reference A/D readings, small voltages are applied to the A/D circuit via dedicated D/A converters to adjust the A/D offset and gain until the A/D readings are within a specified tolerance, usually +/-2LSB. The fineness of these adjustments is in the range of a fractional LSB of the A/D converter, assuring precise correction of the A/D circuit. Once the optimal offset and gain adjustments are found, the corresponding D/A codes are stored in the same EEPROM for later recall. In most situations the actual calibration results will be better than +/-1LSB, although a wider tolerance is specified in the calibration software to assure success in all circumstances.

This autocalibration process is repeated for each individual input range, because each range has its own particular offset and gain errors. On power-up, the board recalls the "default" A/D range calibration values, instantly bringing the board into calibration. The default A/D range is selectable using Diamond Systems' Universal Driver application software. The application program may, by means of an option in the driver software, recall the correct calibration settings for any input range each time the input range is changed.

The calibration process may be triggered by several events, the most common of which is a change in temperature. Since the analog error is directly proportional to temperature change, reducing the size of the temperature change that triggers autocalibration will result in lower maximum error. Diamond Systems sets a default value of 5 degrees for the autocalibration trigger point. Whenever the board's temperature changes by more than 5 degrees from the previous calibration temperature, the calibration process will start again.

The autocalibration process lasts about 0.5 second. In order to prevent the process from interrupting a time-sensitive data acquisition sequence (i.e. one in which the sample rate is faster than 2Hz), auto-autocalibration can be disabled via the Universal Driver software. Once the sensitive operation is complete, the autocalibration process can be re-enabled. If calibration is then required it will begin immediately. Calibration can also be terminated mid-process if needed, and the board will automatically return to its previous state. Standard autocalibration is controlled by the driver software, so there is no risk of it interrupting a data acquisition sequence.

On Diamond Systems A/D products that feature “autocalibration”, the entire calibration process is managed by software included in Universal Driver and triggered as desired by the application program. On products that feature “auto-autocalibration”, the process is managed by an on-board microcontroller and triggered automatically, eliminating all application software overhead.

ALTERNATIVE METHODS OFFER INFERIOR PERFORMANCE

Some A/D board vendors offer “autocalibration” techniques which require intensive computation by the application program. The software must select coefficients from a table of data stored on the board and apply them to the raw A/D value in a complex formula to arrive at the correct numerical value. This *digital domain* technique consumes valuable processor bandwidth, not to mention requiring significant software development and debugging time. In addition, by adding or subtracting offsets to the A/D value, the values at each end of the A/D range may become unusable, limiting the effective input voltage range of the A/D circuit.

In contrast, Diamond Systems' autocalibration occurs in the *analog domain*, meaning that all corrections are made directly to the analog circuit before the A/D conversion is done, rather than to the digital A/D code afterwards. With analog domain correction, each A/D value read from the board is already accurate and requires no further manipulation by software. The A/D value is instantly usable, and the full input voltage range of the A/D converter can be used with confidence.

ILLUSTRATION OF THE BENEFITS

Figure 1 shows total error of two PC/104 A/D boards over their full advertised operating temperature range of -40 to +85^{o}C. The blue line shows the error for a competitor's A/D board with manual calibration, and the red line shows a Diamond Systems DMM-32X-AT board with auto-autocalibration. The two boards were installed on a PC/104 CPU and placed inside a temperature chamber. Each board's input was connected to a voltage source outside the chamber. The voltage source was also connected to a digital multimeter, which was connected to the CPU via a serial port. As the temperature inside the chamber swept from -40 to +85^{o}C, at 5 degree intervals the CPU read the measurement from each A/D board and compared it to the reading from the multimeter. The resulting errors are shown in the graph. Note that the maximum error of the blue line (competitor's board) is 0.3%. For a 16-bit A/D converter, this error amounts to 197 A/D counts, reducing the accuracy to between 8 and 9 bits. In comparison, the red line (DMM-32X-AT) shows that the maximum error of the DMM-32X-AT board across the entire rated operating temperature range is only .014%, or 9 A/D counts. This represents a 20x reduction in measurement error. From this result it can be seen that autocalibration enables an embedded A/D board to achieve far better performance than manual calibration.

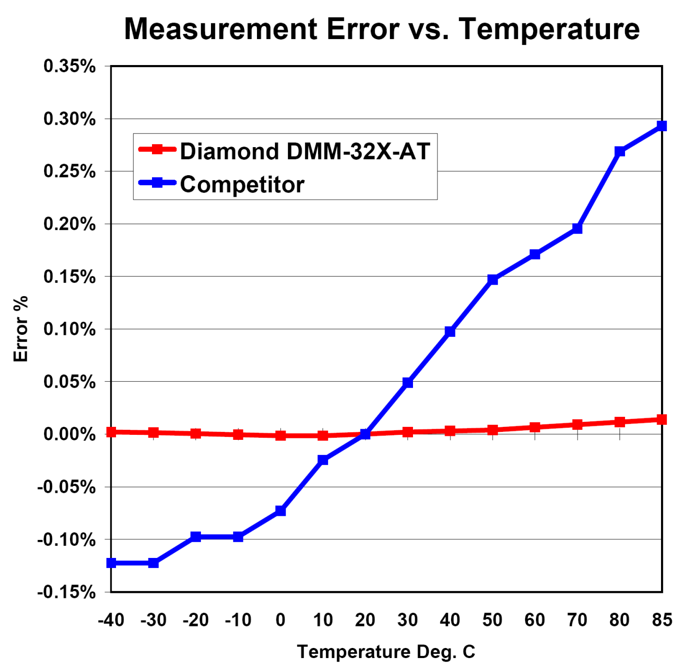

Figure 1: Comparison between auto-autocalibrated and manually-calibrated A/D board accuracy

For more information on Diamond Systems' embedded CPU and A/D boards featuring autocalibration and auto-autocalibration, please visit:

www.diamondsystems.com/products

DIAMOND SYSTEMS CORPORATION
Tel: (800) 367-2104 / (650) 810-2500
www.diamondsystems.com