Multi-Meter Display Converter Eases DMM Design

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Introduction

Dual-Slope Analog to Digital converters have enjoyed enormous popularity in the past due to such features as: auto-zero, input polarity detection, differential inputs, and excellent linearity. Although running at slower conversion speeds than SAR, and FLASH type converters, Dual-Slope converters are cost effective for digital multi-meters (DMMs), temperature systems, weigh scales, and panel meters. Current usage of dual-slope products has reached 10 million units per year. Even with this large number of parts being shipped each year, there is significant room for improvement.

At present, it requires approximately 60 external components (many precision in nature) to bring the typical 26-range, $3^1/_2$ digit DVM to market. Many of these external components are for LCD annunciator-driving, range, and function selection, AC to DC conversion, and fault protection. The ICL7139 with the addition of only 20 external components, builds a complete autoranging $3^3/_4$ digit DVM. The major features of the ICL7139 are: fast autoranging, continuity detection, low power CMOS (20mW), and LCD display drivers, including annunciators and decimal points. Add to these only one external adjustment, and the already low cost of $3^1/_2$ digit DVMs can be further decreased.

It may be beneficial to first review the concept of dual-slope conversion. It is an Analog to Digital conversion technique that is a subclass of integrating/charge-balancing conversion techniques. Some typical features are: high input impedance, excellent linearity, and excellent rejection to line-frequency noise (normal mode rejection). Two disadvantages are the slow conversion rate and the need for several external components.

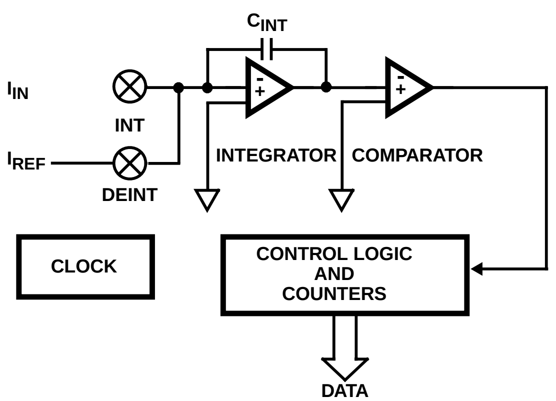

FIGURE 1. DUAL SLOPE A/D CONVERTER

The basic block diagram of a dual-slope converter is shown in Figure 1. The unknown input current (I_{IN}) is integrated across an integration capacitor (C_{INT}) for a fixed amount of time (T_{INT}), and then deintegrated with a reference current (I_{REF}) for a variable amount of time (T_{DEINT}). The ratio of I_{IN}/I_{REF} is equal to T_{DEINT}/T_{INT}. Therefore, by making Tint equal to one thousand clock cycles, T_{DEINT} is equal to $(I_{IN}/I_{REF})*1000$. A voltage-to-current converter is generally added at the input to isolate the user from the low input impedance of the system.

Figure 2 is a simplified block diagram of the ICL7139. The digital section contains the control logic, the counters, and the display decoders and drivers. The digital section is powered by V_{CC} and by Digital Common, which is about 3.1V below V_{CC}. The oscillator, normally 120kHz for measurement of 60Hz AC, is divided by two, to generate the internal master clock. The analog section Figure 3 includes the integrator, the comparator, the reference, the analog buffers, and several analog switches. The analog section is either powered from V_{CC} to V_{EE}, or from V_{CC} to Analog Common, depending on function.

Analog Common is about 3V below V_{CC} and is derived from a temperature-compensated zener diode. Its typical temperature coefficient is ±50ppm/^{o}C. It can source a large amount of current (20mA), but can only sink about 20μA.

Description of Modes and Functions

The key to lowering the overall cost of a typical DVM is to reduce the number of range-select switches and precision range resistors. To accomplish this, a system that changes range by changing the integration time instead of using range select resistors was developed (see the Autoranging Concept insert). This allowed a large reduction in cost for the average DVM by removing most of the range select resistors and the range select switches

The various modes of conversion, DC Volts, DC current, ohms, and AC to DC conversion, are now described. In the DC voltage mode, the input voltage is first converted to a current (V_{IN}/R_{INTV}) by the 100mΩ integrate resistor. It is then integrated for ten, one hundred, one thousand, or ten thousand clock-cycles by the integrator. The integrated voltage is then deintegrated by a known current V_{REF}/R_{DEINT}). The display counters are started at the beginning of the deintegration and continue to count the master clock until the integrator output has crossed zero. The digital count is then checked for underrange and if necessary, the next range is entered (see Figure 4 for timing diagram). If underrange is not detected, the count is sent to the display latches.

DC current is handled by forcing the input current through one of two selected current shunts (R_{S1} or R_{S2}). The voltage that is developed across the current shunt is integrated as in the voltage mode. The integration resistor (R_{INTI}) is smaller than R_{INTV} to allow the least possible voltage across the current shunts. The ICL7139 allows a maximum of 400mV across the current shunts. There are eight current ranges (four DC and four AC). The ranges are split into two sets (high and low) of two ranges each. The ICL7139 autoranges between the two ranges in each set.

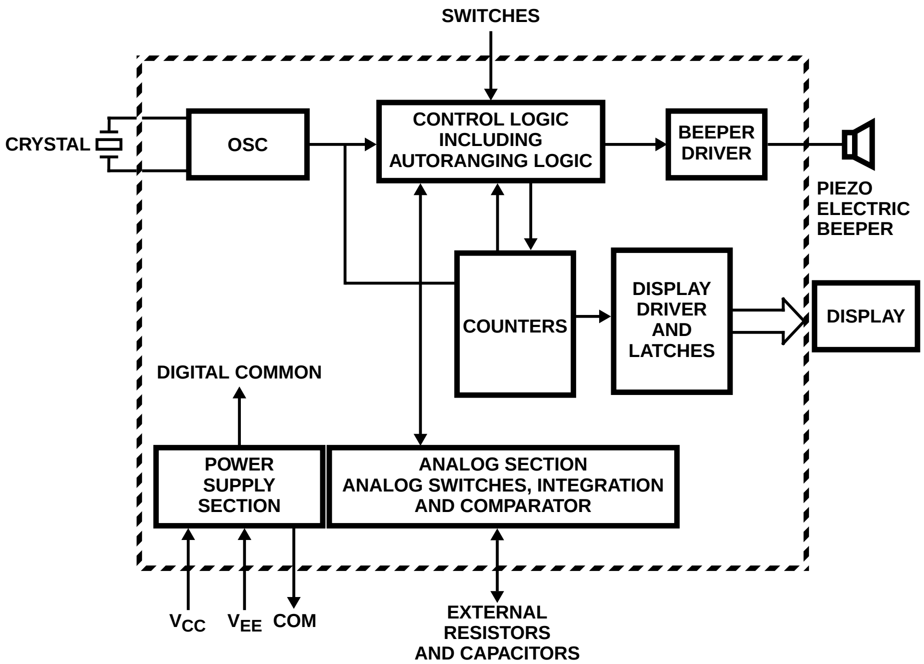

FIGURE 2. ICL7139 BLOCK DIAGRAM

The ohms mode is a slight modification of the standard ratiometric technique. The standard ratiometric measurement is accomplished by first forcing the same current through a known and an unknown resistor. Then, by integrating the voltage across the unknown resistor (effectively the input voltage), and deintegrating with the voltage across the known resistor (effectively the reference voltage), the converter can measure the ratio of unknown/known. This is the technique that most $3^1/_2$ digit meters use. The ICL7139 cannot integrate voltages without drawing some input current. Fortunately, this input current (the integrate and deintegrate currents) has no effect on the accuracy of the reading, as it exactly cancels between the integrate and deintegrate phases. The ICL7139 has four ohm ranges that are split into two sets of two ranges. Again, the ICL7139 autoranges between the two ranges in each set.

AC to DC conversion is limited to line-frequency/sine-wave measurements only. The ICL7139 starts the AC measurement by disconnecting the integrator capacitor and using the integrator as an auto-zeroed comparator. Once synchronized to the AC input, the ICL7139 closes two autozero loops and begins a normal integrate/deintegrate cycle. Since diode D4 is in series with the integrator capacitor (C_{INT}). The timing is similar to the DC voltage mode, except that the integration period is doubled and the ICL7139. resynchronizes to the AC input before each range's reading. Since the voltage across C_{INT} is proportional to the average AC input voltage, the ICL7139 modifies the deintegration clock to scale the reading to RMS.

Additional Features

Although the line-frequency/sine-wave limitation for AC measurements seems severe, most measurements are line-frequency oriented. An alternative is to use an external RMS converter such as an AD536 or an AD636. This technique could extend measurements of arbitrary inputs from 40Hz to 20kHz.

Continuity detection is enabled on the lowest ohms range. When the voltage across the unknown resistor (R_X) is less than approximately 100mV, the beeper output will drive a 2kHz square wave. Since continuity detection is independent of the state of the conversion, it appears instantaneous to the user. The beeper output is designed to drive a piezoelectric transducer.

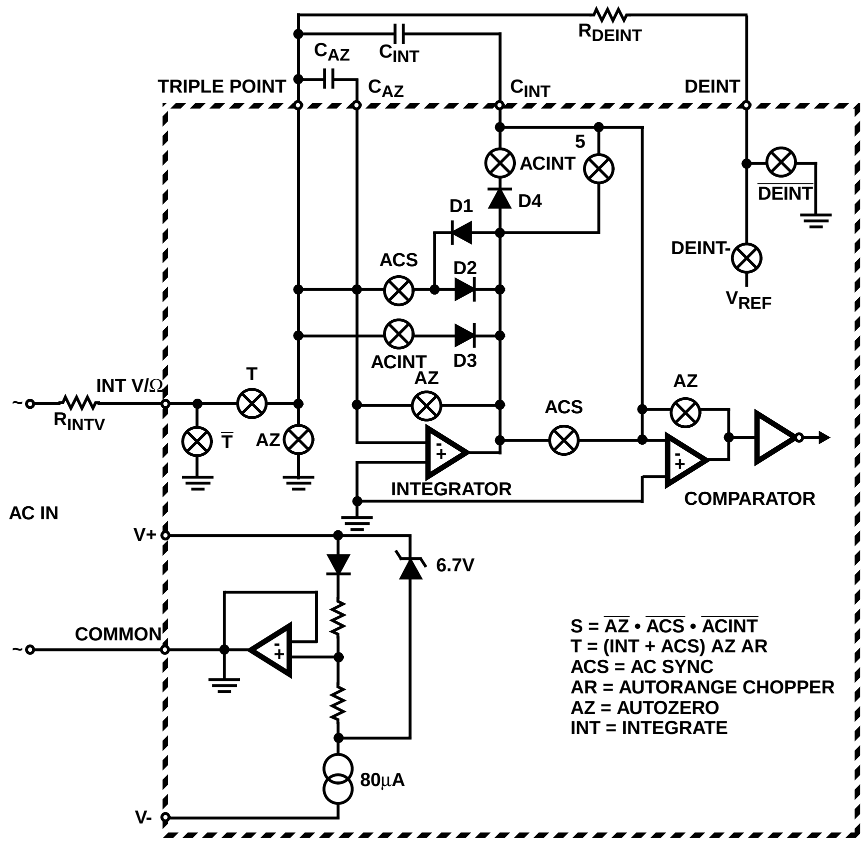

FIGURE 3. ANALOG BLOCK DIAGRAM

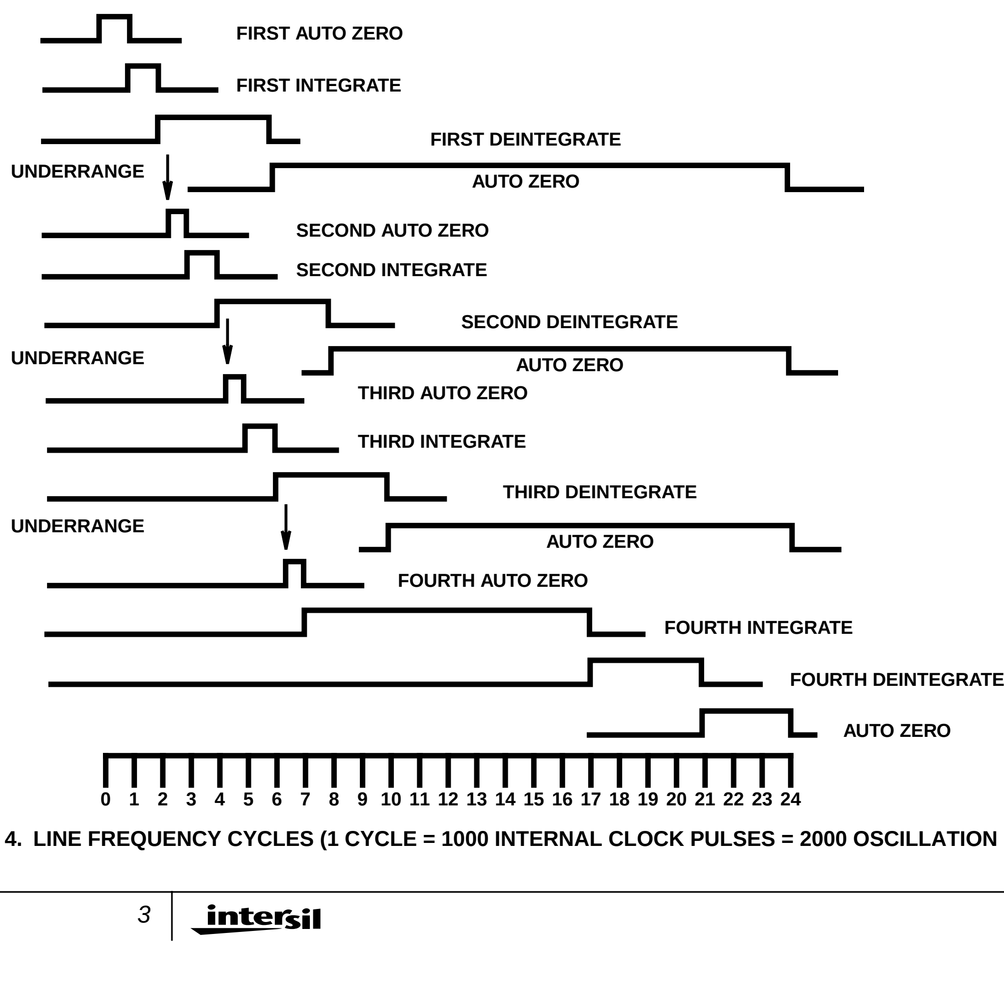

FIGURE 4. LINE FREQUENCY CYCLES (1 CYCLE = 1000 INTERNAL CLOCK PULSES = 2000 OSCILLATION CYCLES)

Range jumping is a common problem in autoranging DVMs. This phenomenon occurs when the DVM is unable to lock into on range due to noise near the range entry/exit point. A small amount of digital hystersis was added to keep the ICL7139 from range jumping.

The duplexed display-driver section has 2 backplane drivers and 21 segments drivers. The typical display has 3 decimal points, 11 annunciators, and $3^3/_4$ digits (up to 3999) of seven segment digits. The display-driver section is powered from V_{CC} to Digital Common. The ICL7139 is designed to use a standard 9V battery. When the supply voltage drops below 7V, the low battery annunicator is turned on. This is approximately 200mV before the internal reference (Analog Common) drops out of regulation.

Design Trade-offs and System Considerations

The ICL7139 retains many of the features of the popular ICL7106, but some new design constraints must now be dealt with. The reference capacitor has been removed from the ICL7139, thus lowering the system cost and improving the response speed in the ohms mode. However, this also requires the internal amplifiers to have high common-mode rejection, causing parasitic capacitances to play a more important role in the determination of offset errors.

The output impedance of the reference must also be looked at more carefully than in previous designs. During the voltage and current modes, the ICL7139 draws the deintegration current (V_{REF}/R_{DEINT}) directly from the reference for negative voltage inputs, but not for positive voltage inputs. To eliminate rollover error (the difference between a positive voltage reading and the same negative voltage reading), the output impedance of the reference should be smaller than $R_{DEINT}/4000$.

The ratiometric ohms can be modified to read Siemens (the inverse of ohms). By reversing the roles of the reference resistor and the unknown resistor, the display will read Siemens. This extends the upper limit of resistance from 4mΩ to well beyond 10MΩ.

Putting the ICL7139 to Work

The real advantage of the ICL7139 is the simplicity and low cost of building a DVM. Three applications are discussed.

The first application is a 20-range DVM (see Figure 5). There are 4 AC/DC voltage ranges, 4 AC/DC current ranges, and 4 resistance ranges. The maximum voltage/current/resistance that can be measured is 400V, 4A, and 4MΩ, respectively. The minimum resolution of each range (voltage/current/resistance) is 100µV, 1µA, and 1Ω, respectively. The only external components are; 2 switches, 2 capacitors, 7 precision resistors, 1 trimpot, 1 beeper, 1 fuse, 1 crystal, and a display. This system should only be used in an environment where minimal fault protection is needed.

The second application is shown in Figure 6. This configuration has the same 20 ranges as the first application, but includes a few extra features.

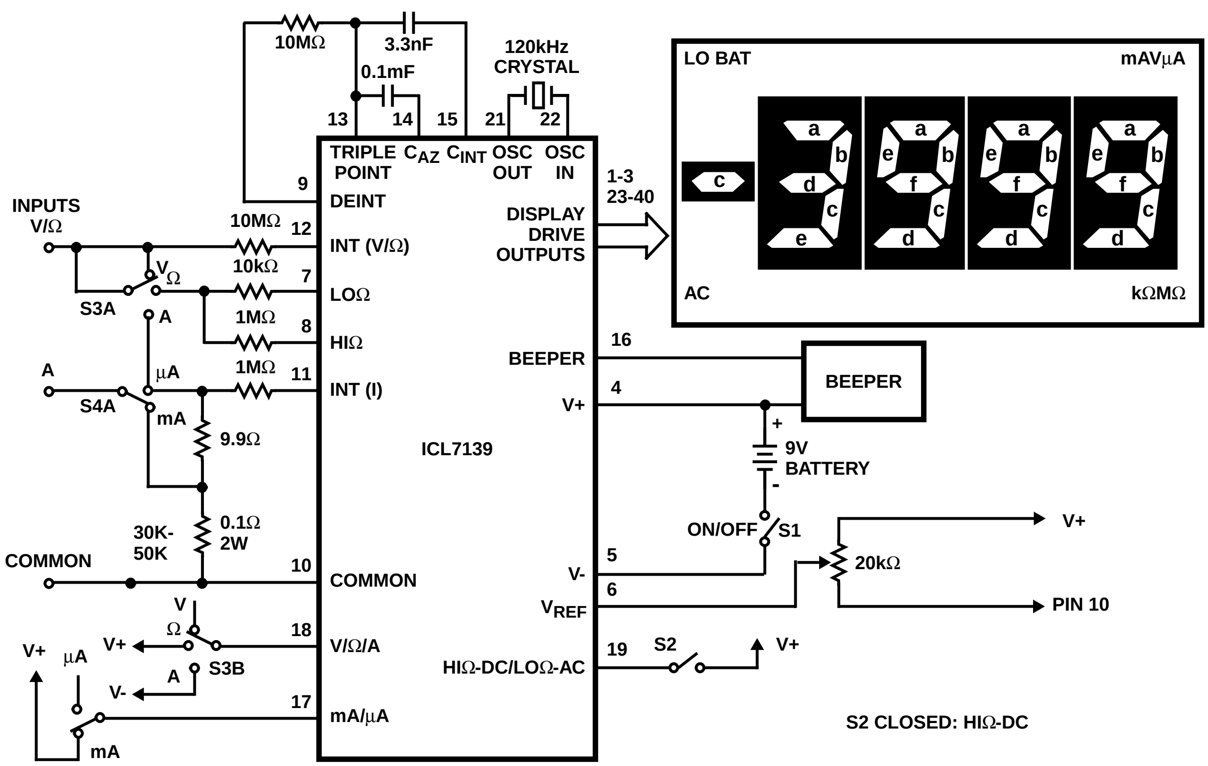

FIGURE 5. MINIMUM SYSTEM CONFIGURATION

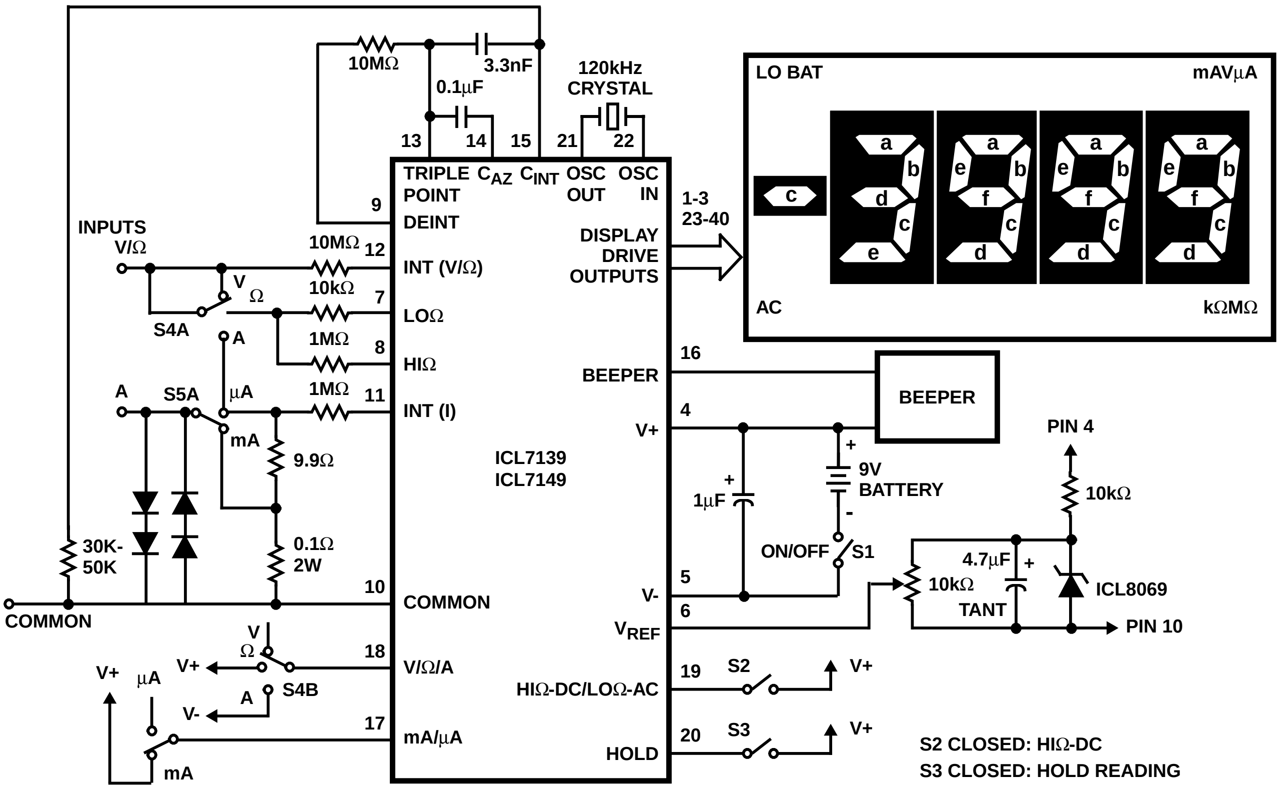

FIGURE 6. HIGH PERFORMANCE CONFIGURATION

Fault protection is significantly improved. This protection could easily provide ±250V protection for both the external components and the ICL7139. An external reference was added for improved performance over temperature. Note that the voltage reference or the deintegration resistor can be trimmed for initial accuracy. AC coupling is used on the AC ranges to isolate any DC voltage from affecting the accuracy of the AC reading. The HOLD Feature is switch accessible. The duplexed LCD display has two extra segments. These are used for the DC segment and to separate mA/V segments.

The third application Figure 7 shows a bridge circuit for measurement of pressure or temperature. Also note that the integrator capacitor from 3.3nF to 3.9nF. The voltage range has been changed to include a maximum of 1000V. A simple current-divider was all that was necessary to simultaneously maintain an input impedance of 10MΩ and a maximum of ±40µA of input integration current. The ICL8069's biasing resistor was decreased to 3.3kΩ to force more current into Analog Common (Analog Common has only 20µA of pullup current).

Customization

The internal design of the ICL7139 is set up to facilitate custom versions. A number of features (the annunciators, the ranges, the overrange trip-points, and the beeper frequency) of the ICL7139 are mask programmable.

Conclusion

An inexpensive system can now be integrated or customized for a large number of applications that were too expensive before.

Autoranging Concept Insert

In the ICL7106, the 200mV input is normally used, while the voltage applied to it is converted from higher voltages by resistive dividers, to obtain a variety of ranges. The ICL7139, on the other hand, changes the integration time to scale the input voltage. The first range to be integrated has only ten clock-cycles of integration time. For all but large input voltages, this produces a small voltage across the integration capacitor (C_{INT}). Next, a deintegration current of V_{REF}/R_{DEINT} allows the integrator to ramp back toward ground. If the digital count is larger than 360 counts, the display latches are updated, and an autozero cycle is entered for the remainder of the conversion. If the digital count is smaller than 360 counts, a short auto-zero cycle is entered, after which range-two integration begins.

Figure 4 is a timing diagram showing the various phases. Range-two integration lasts for ten times longer than range-one integration or one hundred clock cycles. Again, if the digital count is larger than 360 counts, the display latches are updated and an autozero cycle is entered. If the digital count is less than 360 counts, the short autozero cycle is entered and a range-three integration of one thousand clock cycles is started. The digital count from range three deintegration is again checked for underrange and if necessary, range four integration is begun. The fourth range deintegration count is always sent to the display drivers. All of this happens each reading (normally every 400ms), making the ICL7139 one of the fastest autoranging meters available.

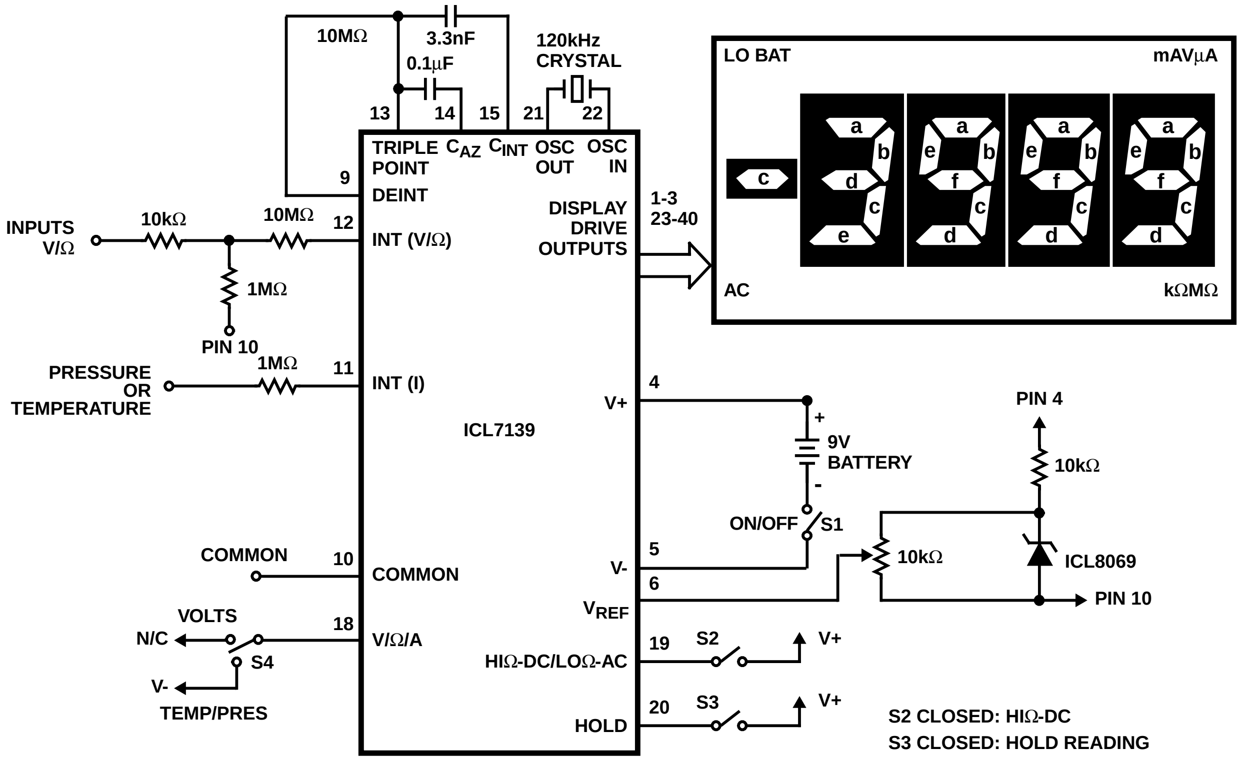

FIGURE 7. TEMPERATURE AND PRESSURE CONFIGURATION

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