AUTORANGING DIGITAL MULTIMETER USING THE MC14433 CMOS A/D CONVERTER

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This article describes an autorange digital multimeter using the MC14433. The multimeter includes ac and dc voltage ranges from 200 mV to 200 V, ac and dc current from 2 mA to 2 A full scale, and resistance ranges from 2 kΩ to 2 MΩ full scale. The MC14433 DVM chip used provides a 3-1/2-digit A/D converter with autopolarity, autozero and a high input impedance. The chip has overrange and underrange information available to simplify the design of the autoranging meter. Only two input jacks are required for all ranges and functions, eliminating the need for changing leads on the instrument when changing ranges or functions. Although only four ranges are provided for each function, the technique used may be expanded to more ranges if desired.

Range switching is done with the use of mechanical relays. The relays may be replaced with solid-state analog switches; however it was felt that the mechanical relays would provide a higher degree of reliability due to the high voltage and currents being measured with the multimeter.

MC14433 A/D CONVERTER

The MC14433 is a single-chip 3-1/2-digit A/D converter using a modified dual ramp technique of A/D conversion. Housed in a 24-pin package, it features autopolarity, autozero and a high input impedance. Figure 1 shows the pin diagram of the MC14433.

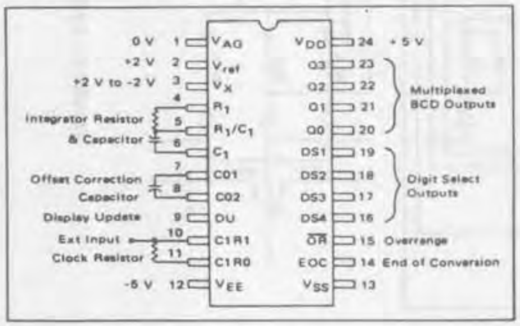

FIGURE 1 – MC14433 Pin Assignment

The output of the MC14433 is 3-1/2-digit multiplexed BCD with the MSD containing not only the half digit but also the polarity of the input, overrange and underrange information. Figure 2 shows the decoding for the MSD. The digit selects for the multiplexed BCD have interdigit blanking to ensure correct BCD data during the time that the digit select is true.

The converter is ratiometric and requires an external

TRUTH TABLE

Coded Condition of MSD	Q3	Q2	Q1	Q0	BCD to 7 Segment Decoding	
+0	1	1	1	0	Blank	
−0	1	0	1	0	Blank	
+0 UR	1	1	1	1	Blank	
−0 UR	1	0	1	1	Blank	
+1	0	1	0	0	4 → 1	Hook up
−1	0	0	0	0	0 → 1	only seg b
+1 OR	0	1	1	1	7 → 1	and c to
−1 OR	0	0	1	1	3 → 1	MSD

Notes for Truth Table

Q3 – ½ digit, low for "1", high for "0"

Q2 – Polarity: "1" = positive, "0" = negative

Q0 – Out of range condition exists if Q0 = 1. When used in conjunction with Q3 the type of out of range condition is indicated, i.e., Q3 = 0 → OR or Q3 = 1 → UR.

When only segment b and c of the decoder are connected to the ½ digit of the display, 4, 0, 7 and 3 appear as 1.

FIGURE 2 – MSD Coding

reference voltage. This voltage is 2.000 volts for the 1.999 volt range and 200 mV for the 199.9 mV full scale input. Both the unknown and reference inputs and analog ground are high-impedance inputs. External components required are two resistors and two capacitors.

The MC14433 has an End of Conversion (EOC) pin for indicating the end of one conversion and the start of the next conversion by a positive pulse 1/2 clock period long. The device also contains a display update pin which allows the data to be strobed into the output latches. If at least one positive edge is received prior to the ramp down cycle, new data is strobed to the display. Normally this pin is tied to EOC to allow a data update each conversion cycle.

The MC14433 requires two power supplies. The total voltage must not exceed 18 volts. Pin 13 is the reference level for the output of the MC14433. If this pin is tied to 0 volts, the BCD output, digit selects and EOC will swing from 0 volts to V_{DD}. If, however, pin 13 is tied to V_{EE}, the output swing will be from V_{EE} to V_{DD}.

The clock for the MC14433 is internal to the chip, requiring only a single external resistor to set the frequency. An external clock may be used by driving pin 10. The total conversion time for the MC14433 is approximately 16400 clock periods. This conversion time includes the autozero cycle and the unknown input measurement cycle.

AUTORANGING CIRCUITRY

Figure 3 shows the autoranging DMM. The heart of the autoranging circuitry is an MC14035B CMOS shift

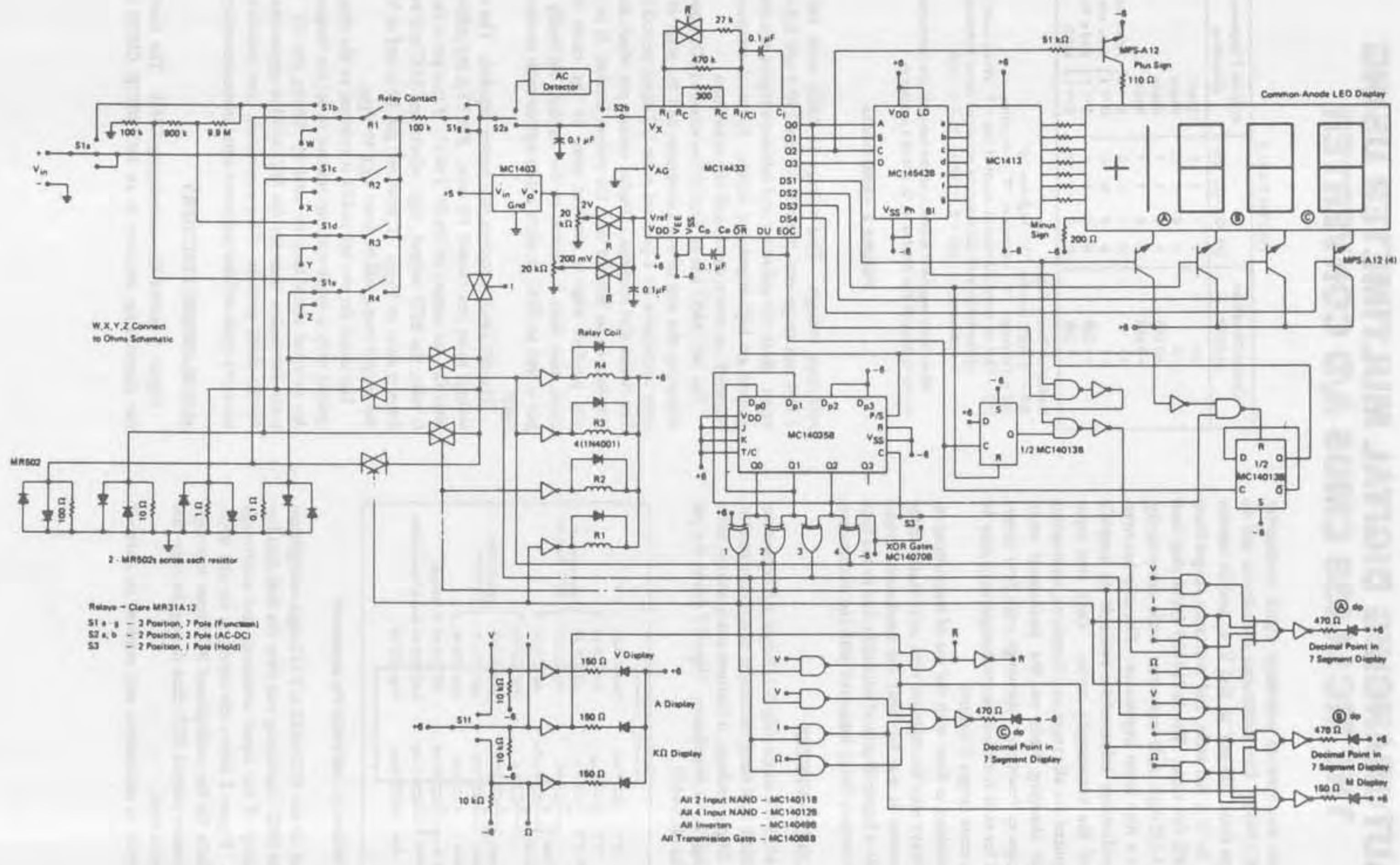

FIGURE 3 – 3-1/2-Digit Autoranging Multimeter

register which can be configured to shift either right or left. The direction of the shift is dependent upon whether an overrange or underrange signal is received at the end of each conversion. If the meter is in range, no shift signal is received. For an overrange condition, a high level is clocked to the right, and for an underrange condition the high level is clocked to the left (see Figure 4). The Exclusive OR gates decode the shift register output to produce only one output high. This output is used to turn on the corresponding range relays.

MC14035 Output

Q0	Q1	Q2	Q3
0	0	0	Not Used
1	0	0	
1	1	0	
1	1	1	

Lowest Range ↕ Highest Range

Underrange Shift ← → Overrange Shift

FIGURE 4 – Shift Register Operation for Autoranging DMM

If at the end of the next conversion the MC14433 is still either overrange or underrange, the shift register receives another clock pulse and thus the next range is selected. When an extreme overrange or underrange condition occurs the register is filled with all "ones" or all "zeros" which selects continuously either the highest or lowest range. Input voltages that exceed 200 volts as well as complete overrange conditions for the other functions cause the display to blink on and off. This feature is provided by the second half of the MC14013 flip-flop. The blinking rate is at half the conversion rate.

Figure 5 describes the functional operation for each range and function for the multimeter. The 2-volt reference is used for the ohms function, which means that 2 volts are developed across the unknown resistors at full scale. All current ranges use the 200-mV reference, while for voltage both the 200-mV and the 2-volt reference are used.

MC14066B transmission gates are used to switch between the 2-volt reference and the 200-mV reference. A transmission gate is also used to reduce the integrator resistor for the 200-mV range. In the current mode, transmission gates are used to switch the input of the MC14433 to the appropriate current-measuring resistor. This is necessary to eliminate the problem of measuring the voltage across the contact resistance of the function switch and relays in addition to the voltage across the current resistor. MR501 rectifiers are placed across the current resistors to limit the power dissipation during overrange conditions.

A ±6-volt power supply is used for the multimeter, with the logic sections referenced to the -6-volt level. This power supply is shown in Figure 6 and uses the MC7806 and MC7906 three-terminal regulators.

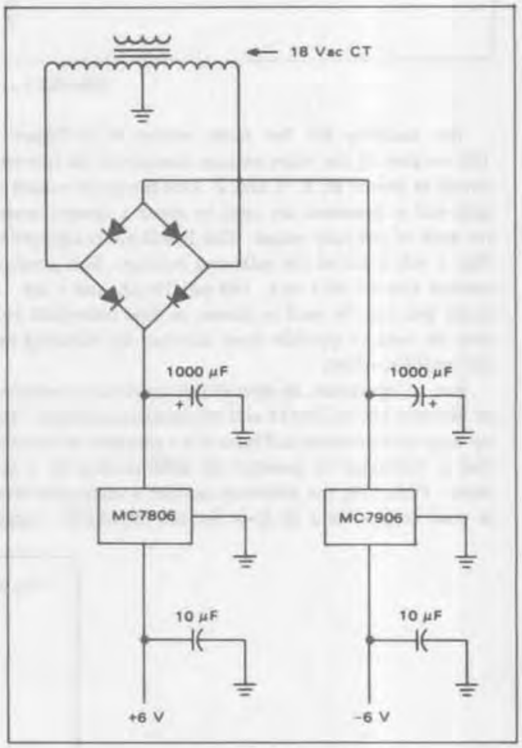

FIGURE 6 – ±6-Volt Power Supply

Relay	Voltage					Current					Resistance				
	Range	dp	Ref Used	Function Display	Resistor Divider	Range	dp	Ref Used	Function Display	Measurement Resistor	Range	dp	Ref Used	Function Display	Current Source
R1	200 mV	199.9	200 mV	mV	1:1	2 mA	1.999	200 mV	mA	100 Ω	2 kΩ	1.999	2 V	kΩ	1 mA
R2	2 V	1.999	2 V	V	1:1	20 mA	19.99	200 mV	mA	10 Ω	20 kΩ	19.99	2 V	kΩ	100 µA
R3	20 V	19.99	2 V	V	10:1	200 mA	199.9	200 mV	mA	1 Ω	200 kΩ	199.9	2 V	kΩ	10 µA
R4	200 V	199.9	2 V	V	100:1	2 A	1.999	200 mV	A	0.1 Ω	2000 kΩ	1999	2 V	kΩ	1 µA

FIGURE 5 – Functional Operation

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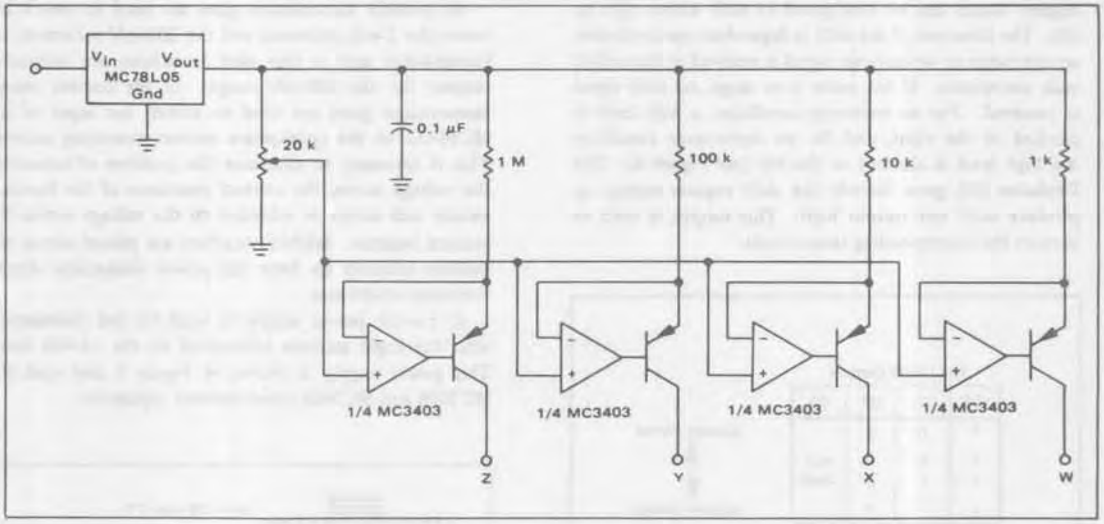


FIGURE 7 – Ohms Section Circuitry

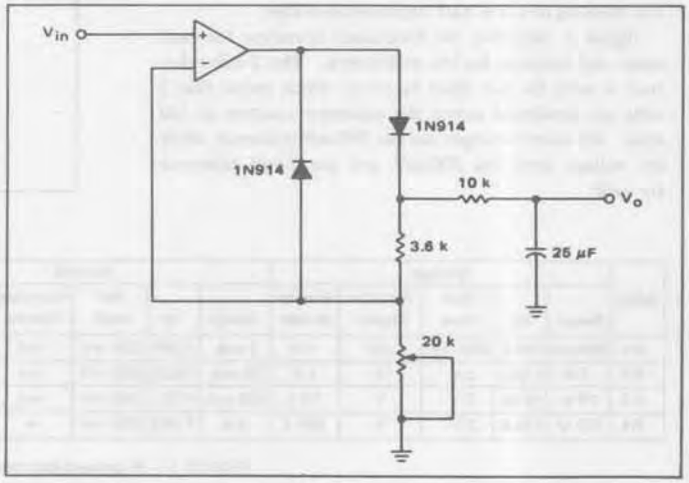
The circuitry for the ohms section is in Figure 7. The outputs of the ohms section connect to the function switch at points W, X, Y and Z. One-fourth of a quad op amp and a transistor are used to create a current source for each of the four ranges. The 20-kΩ pot is adjusted so that 1 volt is across the reference resistor. This provides current sources of 1 mA, 100 μA, 10 μA, and 1 μA. A single pot may be used as shown, or four individual pots may be used to provide more accuracy by adjusting out the amplifier offset.

For ac operation, an operational amplifier is switched in between the MC14433 and its preceding circuitry. The op amp configuration in Figure 8 is a precision ac rectifier that is calibrated to produce the RMS reading for a sine wave. Following the precision rectifier a single-pole filter is used to provide a dc level for the MC14433. Upper and lower frequency limits for ac operation are 30 kHz and 20 Hz.

A switch is placed in the clock line for a range hold switch. When in the hold mode, clock pulses are prevented from clocking the MC14035B shift register. This feature allows several measurements to be made on a high range without the multimeter switching back to the low range between measurements.

The meter must not only be protected from destroying itself during overrange conditions but must also continue to make proper overrange measurements so that the next range may be selected. The analog input to the MC14433 is internally diode protected. The multimeter has a 100-kΩ resistor in series with this input to limit the current during overvoltage measurements.

FIGURE 8 – AC Circuitry



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