



# AUTO-RANGING ANALOG-TO-DIGITAL CONVERTER WITH 3-1/2 DIGIT AND BAR-GRAPH DISPLAYS

## TC818

### GENERAL DESCRIPTION

The TC818 is a 2-chip integrating analog-to-digital converter (ADC) with 3-1/2 digit numeric and 40-segment bar-graph LCD drivers, automatic ranging, and single 9V battery operation. The TC818 chip set (consisting of the TC818A and TC818D), combines the precision of a numeric display with the quick recognition of a bar-graph. The numeric display is driven by the TC818A, which also includes the ADC. The bar-graph display is driven by the TC818D.

The 40-segment bar-graph display provides "quick-look" perception of amplitude. Recognizing trends is also easier with a bar-graph, making TC818-based instruments valuable in nulling, tuning, calibration, and similar applications. On the other hand, the numeric display provides 0.05% resolution and a full set of annunciators that spell out the TC818's many operating modes.

Automatic range selection is provided for both voltage (DC and AC) and ohms (high and low power) measurements. Expensive and bulky mechanical range switches are not required. Five full-scale ranges are available, with automatic selection of external volt/ohm attenuators over a 1 to 10,000 range. Two current ranges, 20 mA and 200 mA, can be manually selected. The auto-range feature can be bypassed, allowing input attenuator selection through a single line input.

During manual mode operation, resolution is extended to 3000 counts full-scale. Extended resolution is also available during 2000 k $\Omega$  and 2000V full-scale auto-range operation. The extended range operation is indicated by a flashing 1 MSD and by the fully-extended bar-graph.

The TC818 includes an AC-to-DC converter for AC voltage and current measurements. Only external diodes/resistors/capacitors are required. Other features include a memory mode, low-battery detection, display HOLD input, and continuity buzzer driver.

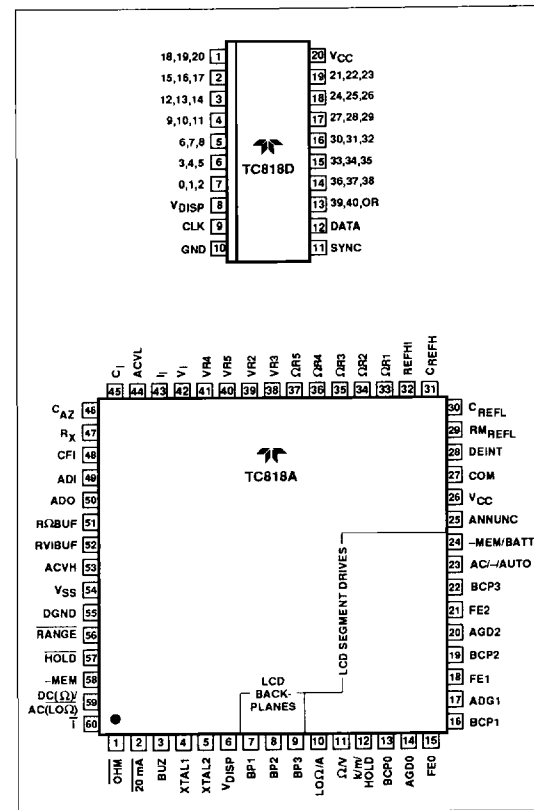
The 3-1/2 digit numeric display includes a full set of annunciators. Decimal points are adjusted as automatic or manual range changes occur, and voltage, current, and ohms operating modes are displayed. Additional annunciators are activated for manual, auto, memory, HOLD, AC, low-power ohms, and low-battery conditions.

The TC818 is available in a surface-mounted chip set, with the TC818A in a 60-pin flat package and the TC818D in a 20-pin small outline (SO) package. Combining numeric and bar-graph display drivers, single 9V battery operation, internal range switching, and compact surface mounting, the TC818 is ideal for advanced portable instruments.

### ORDERING INFORMATION

Part No.	Package	Temperature Range
TC818ACBQ	60-Pin Plastic Flat	0°C to +70°C
TC818DCOP	20-Pin SO	0°C to +70°C

### PIN CONFIGURATIONS



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## ABSOLUTE MAXIMUM RATINGS

### TC818A

Supply Voltage	+15V
Analog Input Voltage	$V_{CC}$ to $V_{SS}$
Reference Input Voltage	$V_{CC}$ to $V_{SS}$
Voltage at Pin 43	Common $\pm 0.7V$
Power Dissipation	800 mW

### TC818D

Supply Voltage	+6V
Digital Input Voltage	$V_{CC}$ to GND
Power Dissipation	500 mW

### Both Devices

Operating Temperature Range	0°C to +70°C
Storage Temperature Range	-65°C to +150°C
Lead Temperature (Soldering, 60 sec)	+300°C

Static-sensitive device. Unused devices must be stored in conductive material. Protect devices from static discharge and static fields. Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operational sections of the specifications is not implied. Exposure to Absolute Maximum Rating Conditions for extended periods may affect device reliability.

## ELECTRICAL CHARACTERISTICS: $V_S = 9V$ , $T_A = +25^\circ C$ , Figure 1 Test Circuit

Symbol	Parameter	Test Conditions	TC818A			Unit
			Min	Typ	Max	
	Zero Input Reading	200 mV Range Without 10 M $\Omega$ Resistor 200 mV Range With 10 M $\Omega$ Resistor 20 mA and 200 mA Range	-0000 -0001 -0000	0000 — 0000	+0000 +0001 +0000	Digital Reading
RE	Roll-Over Error	200 mV Range Without 10 M $\Omega$ Resistor 200 mV Range With 10 M $\Omega$ Resistor 20 mA and 200 mA Range	— — —	— — —	$\pm 1$ $\pm 3$ $\pm 1$	Counts
NL	Linearity Error	Best Case Straight Line	—	—	$\pm 1$	Count
$I_{IN}$	Input Leakage Current		—	—	10	pA
$e_N$	Input Noise	BW = 0.1 to 10 Hz	—	20	—	$\mu V_{P-P}$
	AC Frequency Response	$\pm 1\%$ Error $\pm 5\%$ Error	—	40 to 500 40 to 2000	—	Hz
	Open Circuit Voltage for Ohm Measurements	Excludes 200 $\Omega$ Range	—	570	660	mV
	Open Circuit Voltage for LO Ohm Measurements	Excludes 200 $\Omega$ Range	—	285	350	mV
$V_{COM}$	Analog Common Voltage	$(V_{CC} - V_{COM})$	2.8	3	3.3	V
$V_{CTC}$	Common Voltage Temperature Coefficient		—	—	50	ppm/ $^\circ C$
		Display Multiplex Rate	—	100	—	Hz
$V_{IL}$	Low Logic Input	20mA, AC, I, LO $\Omega$ , HOLD Range, -MEM, Ohms (Relative to DIGITAL GND, Pin 55)	—	—	1	V
	Logic 1 Pull-Up	20 mA, AC, I, LO $\Omega$ , HOLD Range, -MEM, Ohms (Relative to DIGITAL GND, Pin 55)	—	25	—	$\mu A$
$V_{OL}$	Low Logic Output	ANNUNC, DEINT; $I_L = 100 \mu A$	—	DGND+0.1	—	V
$V_{OH}$	High Logic Output	ANNUNC, DEINT; $I_L = 100 \mu A$	—	$V_{CC}-0.1$	—	V
	Buzzer Driver Frequency		—	4	—	kHz
	Low Battery Flag Voltage	$V_{CC}$ to $V_{SS}$	6.3	6.6	7	V
	Operating Supply Current		—	0.8	1.5	mA

## ELECTRICAL CHARACTERISTICS: $V_{CC} = 5V$ , GND = 0V, $T_A = +25^\circ C$

Symbol	Parameter	Test Conditions	TC818D			Unit
			Min	Typ	Max	
$V_{IH}$	High Logic Input		2.5	—	—	V
$V_{IL}$	Low Logic Input		—	—	1	V
$I_{IL}$	Logic Input Current	$V_{CC} - V_{IN} - GND$	—	0.01	10	nA
	Display Multiplex Rate		—	100	—	Hz
	Operating Supply Current		—	40	100	$\mu A$

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### TC818A PIN DESCRIPTION

Pin No. (Quad Flat Package)	Symbol	Description
1	OHM	Logic input. "0" (digital ground) for resistance measurement.
2	20 mA	Logic Input. "0" (digital ground) for 20 mA full-scale current measurement.
3	BUZ	Buzzer. Audio frequency, 4 kHz, output for continuity indication during resistance measurement. A noncontinuous 4 kHz signal is output to indicate an input overrange during voltage or current measurements.
4	XTAL1	32.768 kHz crystal connection and clock output to drive TC818D.
5	XTAL2	32.768 kHz crystal connection.
6	V <sub>DISP</sub>	Sets peak LCD drive signal: V <sub>P</sub> = V <sub>CC</sub> = V <sub>DISP</sub> . V <sub>DISP</sub> may also be used to compensate for temperature variation of LCD crystal threshold voltage.
7	BP1	LCD backplane #1.
8	BP2	LCD backplane #2.
9	BP3	LCD backplane #3.
10	LOΩ/A	LCD annunciator segment drive for low ohms resistance measurement and current measurement.
11	Ω/A	LCD annunciator segment drive for resistance measurement and current measurement.
12	k/m/HOLD	LCD annunciator segment drive for k ("kilo-Ohms"), m ("milli-Amps" and "milli-Volts") and HOLD mode.
13	BCP0 (Ones Digit)	LCD segment drive for "b," "c" segments and decimal point of least significant digit (LSD).
14	ADG0	LCD segment drive for "a," "g," "d" segments of LSD.
15	FE0	LCD segment drive for "f" and "e" segments of LSD.
16	BCP1	LCD segment drive for "b," "c" segments and decimal point of second LSD.
17	ADG1	LCD segment drive for "a," "g," "d" segments of second LSD.
18	FE1	LCD segment drive for "f" and "e" segments of second LSD.
19	BCP2	LCD segment drive for "b," "c" segments and decimal point of third LSD (hundreds digit).
20	ADG2	LCD segment drive for "a," "g," "d" segments of third LSD.
21	FE2	LCD segment drive for "f" and "e" segments of third LSD.
22	BCP3	LCD segment drive for "b," "c" segments and decimal point of MSD (thousands digit).
23	AC/-AUTO	LCD annunciator segment drive for AC measurements, polarity, and auto-range operation.
24	-MEM/BATT	LCD annunciator segment drive for low-battery indication and memory (relative measurement).
25	ANNUNC	Square-wave output at the backplane frequency, synchronized to BP1. ANNUNC can be used to control display annunciators. Connecting an LCD segment to ANNUNC turns it on; connecting it to its backplane turns it off. ANNUNC is also used to synchronize the TC818A and TC818D backplanes.
26	V <sub>CC</sub>	Positive battery supply connection.
27	COM	Analog circuit ground reference point. Nominally 3V below V <sub>CC</sub> .
28	DEINT	Deintegrate output. Transmits the A/D conversion result to the bar-graph LCD driver. (See text.)
29	RM <sub>REFL</sub>	Ratiometric (resistance measurement) reference low voltage.
30	C <sub>REFL</sub>	Reference capacitor negative terminal, C <sub>REF</sub> = 0.1 μF.
31	C <sub>REFH</sub>	Reference capacitor positive terminal, C <sub>REF</sub> = 0.1 μF.
32	REFHI	Reference voltage for voltage and current measurement. Nominally 163.85 mV.
33	ΩR1	Standard resistor connection for 200Ω full-scale.
34	ΩR2	Standard resistor connection for 2000Ω full-scale.
35	ΩR3	Standard resistor connection for 20 kΩ full-scale.
36	ΩR4	Standard resistor connection for 200 kΩ full-scale.

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## TC818A PIN DESCRIPTION (Cont.)

Pin No. (Quad Flat Package)	Symbol	Description
37	$\Omega R5$	Standard resistor connection for 2000 k $\Omega$ full-scale.
38	VR3	Voltage measurement +100 attenuator.
39	VR2	Voltage measurement +10 attenuator.
40	VR5	Voltage measurement +10,000 attenuator.
41	VR4	Voltage measurement +1000 attenuator.
42	V <sub>I</sub>	Unknown voltage input + attenuator.
43	I <sub>I</sub>	Unknown current input.
44	ACVL	Low output of AC-to-DC converter.
45	C <sub>I</sub>	Integrator capacitor connection. Nominally 0.1 $\mu$ F. (Must have low dielectric absorption. Polypropylene dielectric suggested.)
46	CAZ	Auto-zero capacitor connection. Nominally 0.1 $\mu$ F.
47	R <sub>X</sub>	Unknown resistance input.
48	CFI	Input filter connection.
49	ADI	Negative input of internal AC-to-DC operational amplifier.
50	ADO	Output of internal AC-to-DC operational amplifier.
51	R $\Omega$ BUF	Active buffer output for resistance measurement. Integration resistor connection. Nominally 220 k $\Omega$ .
52	RVIBUF	Active buffer output for voltage and current measurement. Integration resistor connection. Nominally 150 k $\Omega$ .
53	ACVH	Positive output of AC-to-DC converter.
54	V <sub>SS</sub>	Negative supply connection. Connect to negative terminal of 9V battery.
55	DGND	Internal logic digital ground. Ground connection for the TC818D, and the logic "0" level. Nominally 4.7V below V <sub>CC</sub> .
56	RANGE	Input to set manual operation and change ranges.
57	HOLD	Input to hold display. Connect to DGND to "freeze" display.
58	-MEM	Input to enter memory measurement mode for relative measurements. The two LSDs are stored and subtracted from future measurements.
59	DC ( $\Omega$ )/ AC (LO $\Omega$ )	Input that selects AC or DC option during voltage/current measurements. For resistance measurements, the ohms or low power (voltage) ohms option can be selected.
60	I	Input to select measurement. Connect to logic "0" (digital ground) for current measurement.

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### TC818D PIN DESCRIPTION

Pin No. (20-Pin SO)	Symbol	Description
1	18, 19, 20	Segments 18, 19, 20 of LCD.
2	15, 16, 17	Segments 15, 16, 17 of LCD.
3	12, 13, 14	Segments 12, 13, 14 of LCD.
4	9, 10, 11	Segments 9, 10, 11 of LCD.
5	6, 7, 8	Segments 6, 7, 8 of LCD.
6	3, 4, 5	Segments 3, 4, 5 of LCD.
7	0, 1, 2	Segments 0, 1, 2 of LCD.
8	V <sub>DISP</sub>	Sets peak LCD voltage drive level. Connect to V <sub>DISP</sub> of TC818A, or to GND of TC818D.
9	CLK	Clock input. Connect to XTAL1 output of TC818A.
10	GND	Digital ground. Connect to DGND of TC818A.
11	SYNC	Display SYNC input. Synchronizes backplanes of the TC818A and TC818D. Connect to ANNUNC output of TC818A.
12	DATA	Data input. Pulses at the CLK input are counted while DATA is logic high. Connect to DEINT output of TC818A.
13	39, 40, OR	Segments 39, 40 and overrange of LCD.
14	36, 37, 38	Segments 36, 37, 38 of LCD.
15	33, 34, 35	Segments 33, 34, 35 of LCD.
16	30, 31, 32	Segments 30, 31, 32 of LCD.
17	27, 28, 29	Segments 27, 28, 29 of LCD.
18	24, 25, 26	Segments 24, 25, 26 of LCD.
19	21, 22, 23	Segments 21, 22, 23 of LCD.
20	V <sub>CC</sub>	Power supply input. Connect to V <sub>CC</sub> of TC818A.

### THEORY OF OPERATION

The TC818 consists of two CMOS integrated circuits. The TC818A incorporates an auto-ranging ADC and drivers for a 3-1/2 digit LCD, while the TC818D provides data formatting and drivers for a 40-segment bar-graph display. Both integrated circuits are required to form a complete measurement system.

During each A/D conversion cycle, data is transferred from the TC818A to the TC818D. Therefore, the bar-graph display will track the numeric (3-1/2 digit) display. The exact relationship between numeric display counts and bar-graph segments displayed is shown in Table I. Both displays are updated at the same rate. When the TC818A is in its extended resolution mode (3000 counts, maximum), the bar-graph will display all 40 bars continuously.

#### Analog-to-Digital Converter (ADC)

The TC818A includes an integrating ADC with auto-ranging resolution of 2000 counts and manual range resolution of 3000 counts. Figure 1 shows a simplified schematic of the analog section. In auto-ranging mode, internal logic

will adjust the input voltage or ohms attenuators so that measurements will always be made in the appropriate range. Measurement ranges, logic control inputs, 3-1/2 digit LCD formatting, and other features are identical to the TC815 auto-ranging A/D converter. However, the TC818A is not pin-compatible with, and is not a replacement for, the TC815.

A display annunciator output (ANNUNC) can be used to customize the LCD. ANNUNC is a square wave at the backplane frequency. Connecting an annunciator segment to the ANNUNC driver turns the segment on; connecting the segment to its backplane turns it off.

#### Bar-Graph Driver

The TC818D includes a counter and data latch, clock divider, and triplex LCD bar-graph formatting and display functions. A block diagram of the TC818D and connections between the TC818A and TC818D is shown in Figure 2. The TC818D does not require a separate power supply, since it is powered from V<sub>CC</sub> and digital ground of the TC818A.

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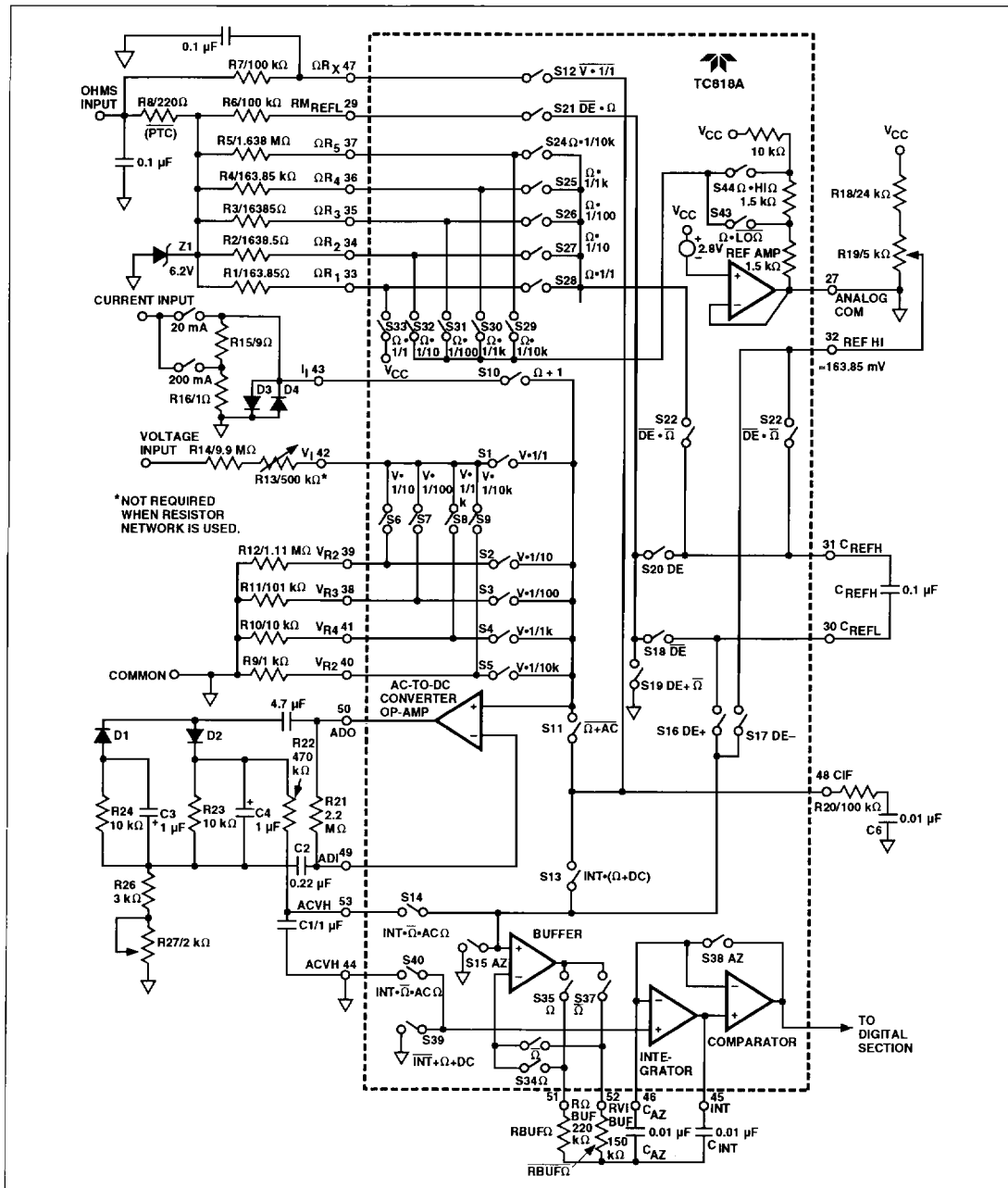


Figure 1 TC818A Analog Section

## AUTO-RANGING ANALOG-TO-DIGITAL CONVERTER WITH 3-1/2 DIGIT AND BAR-GRAPH DISPLAYS

### TC818

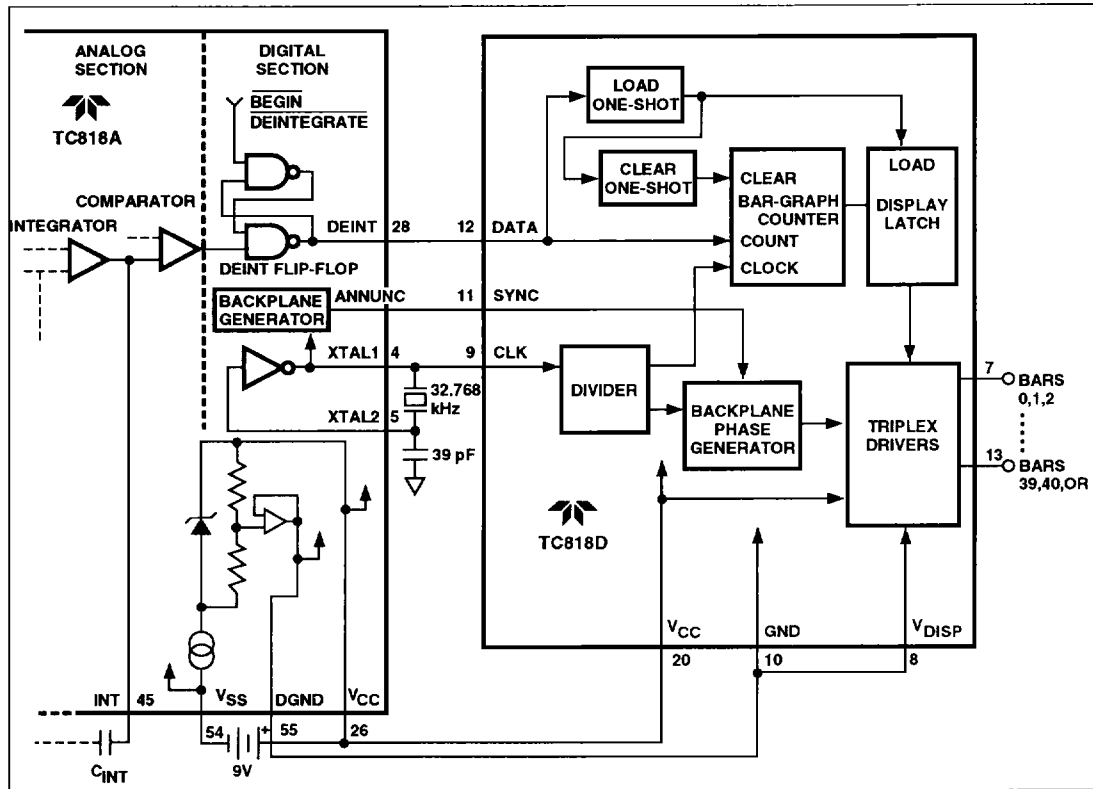


Figure 2 Interface Between TC818A and TC818D

When the TC818D DATA input goes to a logic high, pulses are counted at the CLK input. A clock divider scales clock pulses so that the number of LCD bar-graph segments is proportional to the numeric display (see Table I).

When the DATA input goes low, the counter contents are transferred to a display latch. Then the bar-graph counter is reset to zero in preparation for the next A/D conversion cycle.

The CLK input is also used to produce the triplex LCD drivers. The backplane and segment driver waveforms are the same voltage levels as the TC818A. However, the TC818D segment driver waveforms are less complicated than those of the TC818A, because adjacent bar-graph segments are either on or off.

The SYNC input permits synchronizing display backplanes. By connecting the ANNUNC output of the TC818A to the SYNC input of the TC818D, the two sets of LCD

drivers will be synchronized. This feature permits the use of an LCD with only one set of backplane drivers and saves three pin connections to the display.

LCD backplane and segment drive voltages are set by the voltage between  $V_{CC}$  and  $V_{DISP}$  pins. In most cases,  $V_{DISP}$  will be connected to GND and the LCD drive voltage will be about 5V. If  $V_{DISP}$  is not connected to GND, then  $V_{DISP}$  of the TC818D must be connected to  $V_{DISP}$  of the TC818A.

### Data Transfer

Analog conversion results are transferred from the TC818A to the TC818D via two pins, DEINT and XTAL1. DEINT is a TC818A output with a pulse width proportional to the analog voltage being measured. DEINT goes to a logic high at the beginning of the TC818A deintegrate cycle, and goes low at the comparator zero-crossing (end of conversion).

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Timing of the DEINT pulse width is derived from the TC818A's XTAL1 output, which provides a 32.768 kHz clock. The number of clock pulses occurring while DEINT is high determines the number of bar-graph segments displayed. The relationship between numeric display counts and bar-graph segments is shown in Table I.

## Resistance, Voltage, Current Measurement Selection

The TC818 is designed to measure voltage, current, and resistance. Auto-ranging is available for resistance and voltage measurements. The OHM (pin 1) and  $\bar{I}$  (pin 60) input controls are normally pulled internally to  $V_{CC}$ .

By tying these pins to DGND (pin 55), the TC818 is configured internally to measure resistance, voltage, or current. The required signal combinations are shown in Table II.

**Table I. TC818A Numeric Display vs TC818D Bar-Graph Segments**

Numeric Reading	Bar-Graph Segments
0–24	0
25–74	1
75–124	2
•	•
•	•
•	•
((50*N)–25) to ((50*N)+24) (where 1 ≤ N ≤ 40)	N
•	•
•	•
•	•
1975–2024*	40
>2024*	OVR

\*Readings >1999 will only occur in manual or expanded resolution modes.

**Table II. TC818 Measurement Selection Logic**

Function Select Pin		Selected Measurement
OHM (Pin 1)	$\bar{I}$ (Pin 60)	
0	0	Voltage
0	1	Resistance
1	0	Current
1	1	Voltage

0 = Digital Ground    1 = Floating or Tied to  $V_{CC}$

**NOTES:** 1. OHM and  $\bar{I}$  are normally pulled internally high to  $V_{CC}$  (pin 26). This is considered a logic "1".  
2. Logic "0" is the potential at digital ground (pin 55).

## Resistance Measurements — Ohms and Low Power Ohms

The TC818 can be configured to reliably measure in-circuit resistances shunted by semiconductor junctions. The TC818 low-power ohms measurement mode limits the probe open circuit voltage. This prevents semiconductor junctions in the measured system from turning on.

In the resistance measurement mode, the  $\Omega/\overline{LO\Omega}$  (pin 59) input selects the low-power ohms measurement mode. For low-power ohms measurements,  $\Omega/\overline{LO\Omega}$  (pin 59) is momentarily brought low to digital ground potential. The TC818 sets up for a low-power ohms measurement with a maximum open circuit probe voltage of 0.35V above analog common. In the low-power ohms mode, an LCD annunciator,  $\overline{LO\Omega}$ , will be activated. On power-up, the low-power ohms mode is not active.

If the manual operating mode has been selected, toggling  $\Omega/\overline{LO\Omega}$  resets the TC818 back to auto-range mode. In manual mode, the decision to make a normal or low-power ohms measurement should be made before selecting the desired range.

The low-power ohms measurement is not available on the 200 $\Omega$  full-scale range. Open-circuit voltage on this range is below 2.8V.

The standard resistance values are listed in Table III.

**Table III. Ohms Range Ladder Network**

Full-Scale Range	Standard Resistance	Low-Power Ohms Mode
200 $\Omega$	163.85 $\Omega$ (R1)	No
2000 $\Omega$	1638.5 $\Omega$ (R2)	Yes
20 k $\Omega$	16,385 $\Omega$ (R3)	Yes
200 k $\Omega$	163,850 $\Omega$ (R4)	Yes
2000 k $\Omega$	1,638,500 $\Omega$ (R5)	Yes

R8, a positive temperature coefficient resistor, and the 6.2V zener, Z1, provide input voltage protection during ohms measurement.

## Ratiometric Resistance Measurements

The TC818 measures resistance ratiometrically. Accuracy is set by the external standard resistors connected to pins 33 through 37. A low-power ohms mode may be selected on all but the 200 $\Omega$  full-scale range. The low-power ohms mode limits the voltage applied to the measured system. This allows accurate "in-circuit" measurements when a resistor is shunted by semiconductor junctions.

Full auto-ranging is provided. External precision standard resistors are automatically switched to provide the proper range.

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Figure 3 is a detailed block diagram of the TC818 configured for ratiometric resistance measurements. During the signal integrate phase the reference capacitor charges to a voltage inversely proportional to the measured resistance,  $R_x$ . Figure 4 shows that the conversion accuracy relies only on the accuracy of the external standard resistors.

Normally, the required accuracy of the standard resistances will be dictated by the accuracy specifications of the user's end product. Table IV gives the equivalent ohms per count for various full-scale ranges to allow users to judge the required resistor accuracy.

Table IV. Reference Resistors

Full-Scale Range ( $\Omega$ )	Reference Resistor	$\Omega$ /Count
200	163.85	0.1
2k	1638.5	1
20k	16385	10
200k	163,850	100
2M	1,638,500	1000

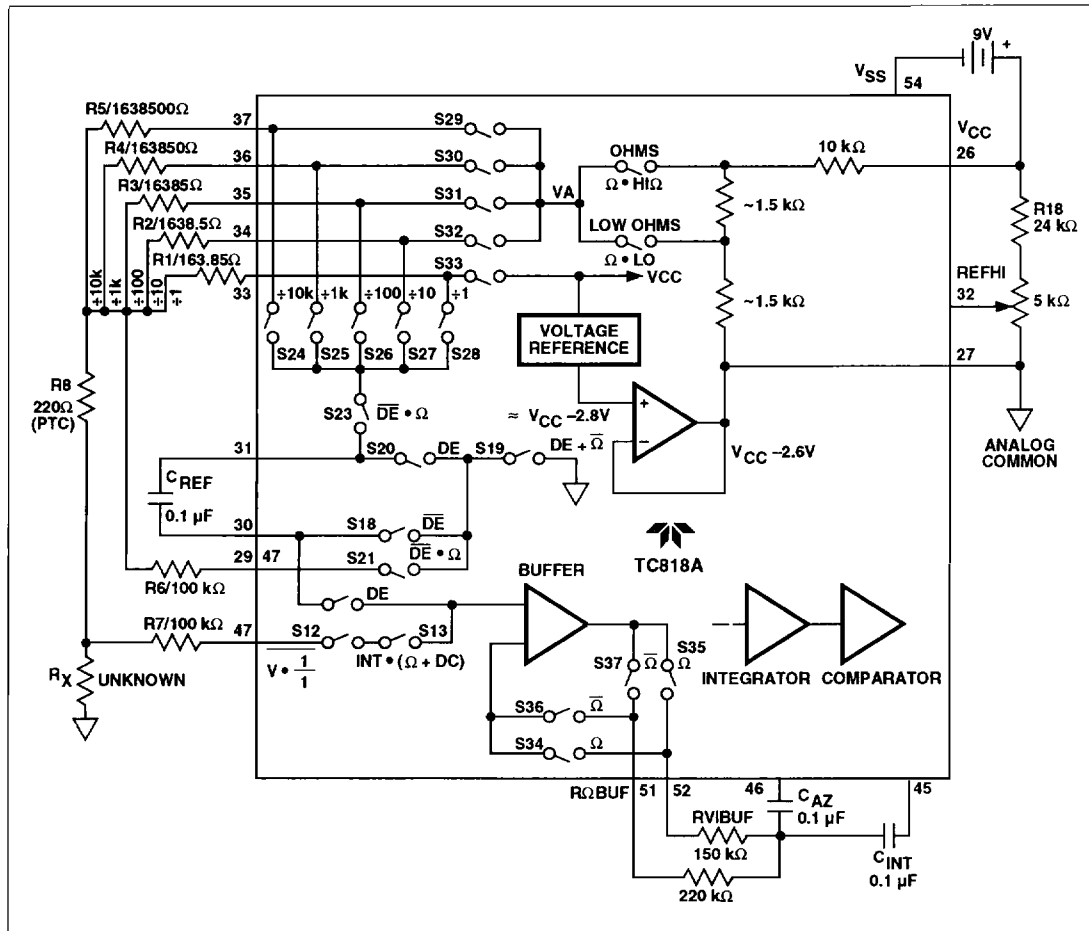
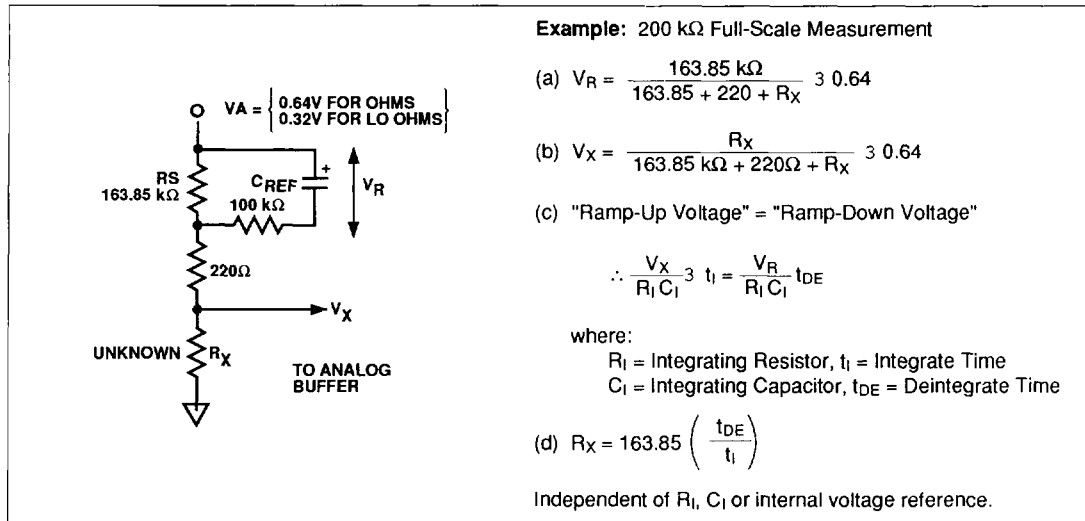


Figure 3 Ratiometric Resistance Measurement Functional Diagram



**Figure 4 Resistance Measurement Accuracy Set by External Standard Resistor**

**Voltage Measurement**

Resistive dividers are automatically changed to provide in-range readings for 200 mV to 2000V full-scale readings (Figure 1). The input resistance is set by external resistors R14/R13. The divider leg resistors are R9–R12. The divider leg resistors give a 200 mV signal at  $V_1$  (pin 42) for full-scale voltages from 200 mV to 2000V.

For applications that do not require a 10 MW input impedance, the divider network impedances may be lowered. This will reduce voltage offset errors induced by switch leakage currents.

**Current Measurement**

The TC818 measures current only under manual range operation. The two user-selectable, full-scale ranges are 20 mA and 200 mA. Select the current measurement mode by holding the I input (pin 60) low at digital ground potential. The OHM input (pin 1) is left floating or tied to the positive supply.

Two ranges are possible. The 200 mA full-scale range is selected by connecting the 20 mA input (pin 2) to digital ground. If left floating, the 200 mA full-scale range is selected.

External current-to-voltage conversion resistors are used

at the current input ( $I_1$ , pin 43). For 20 mA measurements, a 10Ω resistor is used. The 200 mA range requires a 1Ω resistor. Full scale is 200 mV

Printed circuit board trace resistance between analog common and R16 must be minimized. In the 200 mA range, for example, a 0.05Ω trace resistance causes a 5% current-to-voltage conversion error at  $I_1$  (pin 43).

The extended resolution measurement option operates during current measurements.

To minimize roll-over error, the potential difference between ANALOG COM (pin 27) and system common must be minimized.

**AC-to-DC Measurements**

In voltage and current measurements, the TC818 can be configured for AC measurements. An on-chip operational amplifier and external rectifier components perform the AC-to-DC conversion.

When power is first applied, the TC818 enters the DC measurement mode. For AC measurements (current or voltage), AC/DC (pin 59) is momentarily brought low to digital ground potential; the TC818 sets-up for AC measurements and the AC liquid crystal display annunciator activates. Toggling AC/DC low again returns the TC818 to DC operation.

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If manual operating mode has been selected, toggling AC/DC resets the TC818 back to auto-range mode. In manual mode operation, AC or DC should be selected first, then the desired range.

The minimum AC full-scale voltage range is 2V. The DC full-scale minimum voltage is 200 mV.

AC current measurements are available on the 20 mA and 200 mA full-scale ranges.

### Conversion Timing

The TC818 uses the conventional dual-slope integrating conversion technique with an added phase that automatically eliminates zero offset errors. The TC818 gives a zero reading with a 0V input.

This device is designed to operate with a low-cost, readily-available 32.768 kHz crystal. It serves as a time-base oscillator crystal in many digital clocks. (See external crystal sources, page 18.)

The external clock is divided by two. The internal clock frequency is 16.348 kHz, giving a clock period of 61.04  $\mu$ s. The total conversion — auto-zero phase, signal integrate, and reference deintegrate — requires 8000 clock periods (or 488.3 ms). There are approximately two complete conversions per second.

The integration time is fixed at 1638.5 clock periods (or 100 ms), giving a rejection of 50/60 Hz AC line noise.

The maximum reference deintegrate time, representing a full-scale analog input, is 3000 clock periods (or 183.1 ms) during manual extended resolution operation. The 3000 counts are available in manual mode, extended resolution operation only. In auto-ranging mode, the maximum deintegrate time is 2000 clock periods. The 1000 clock periods are added to the auto-zero phase. An auto-ranging or manual conversion takes 8000 clock periods. After a zero crossing is detected in the reference deintegrate mode, the auto-zero phase is entered.

Figure 5 shows the basic TC818 timing relationships.

### Manual Range Selection

The TC818's voltage and resistance auto-ranging feature can be disabled by momentarily bringing RANGE (pin 56) to digital ground potential (pin 55). When the change from auto to manual ranging occurs, the first manual range selected is the last range in the auto-ranging mode.

The TC818's power-up circuit initially selects auto-range operation. Once the manual-range option is entered, range changes are made by momentarily grounding the RANGE control input. The TC818 remains in the manual-range mode until the measurement function (voltage or resistance) or measurement option (AC/DC,  $\Omega$ /LO $\Omega$ ) changes, causing the TC818 to return to auto-ranging operation.

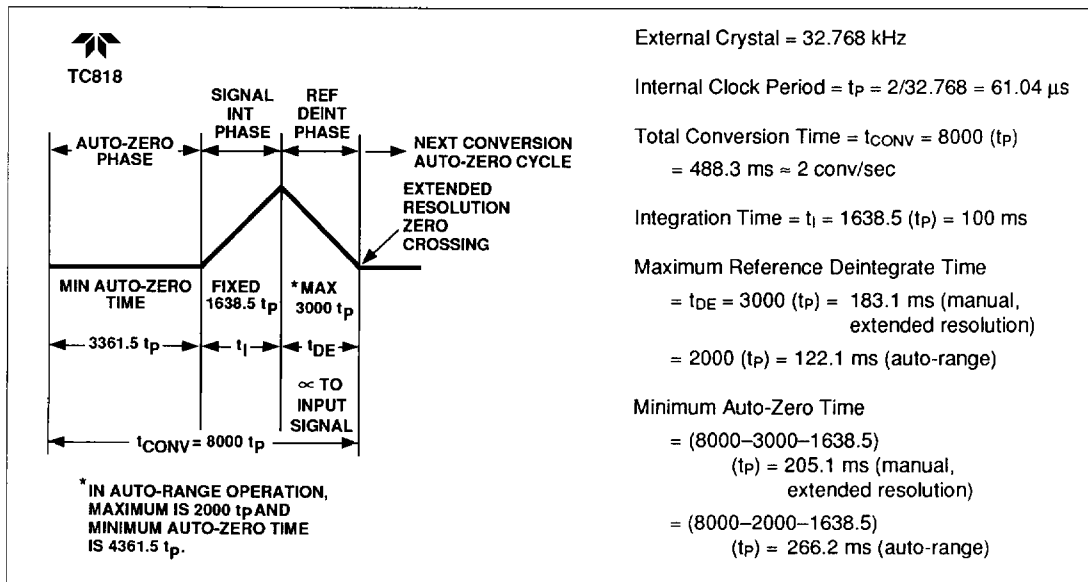


Figure 5 Basic TC818 Conversion Timing

# AUTO-RANGING ANALOG-TO-DIGITAL CONVERTER WITH 3-1/2 DIGIT AND BAR-GRAPH DISPLAYS

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TC818

The "Auto" LCD annunciator driver is active only in the auto-range mode.

Figure 6 shows typical operation where the manual range selection option is used. Also shown is the extended resolution display format.

## Extended Resolution Manual Operation

When operated in the manual-range mode, the TC818 extends resolution by 50% for current, voltage, and resistance measurements. Resolution increases to 3000 counts from 2000 counts. The extended resolution feature operates only in the 2000 k $\Omega$  and 2000V ranges during auto-range operation.

In the extended resolution operating mode, readings above 1999 are displayed with a blinking "1" most significant digit. The blinking "1" should be interpreted as the digit 2. The three least significant digits display data normally. The bar-graph LCD will be fully extended.

An input overrange condition causes the most significant digit (MSD) to blink and sets the three least significant digits (LSDs) to display "000." The buzzer output is enabled for input voltage and current signals with readings greater than 2000 counts in both manual- and auto-range operations.

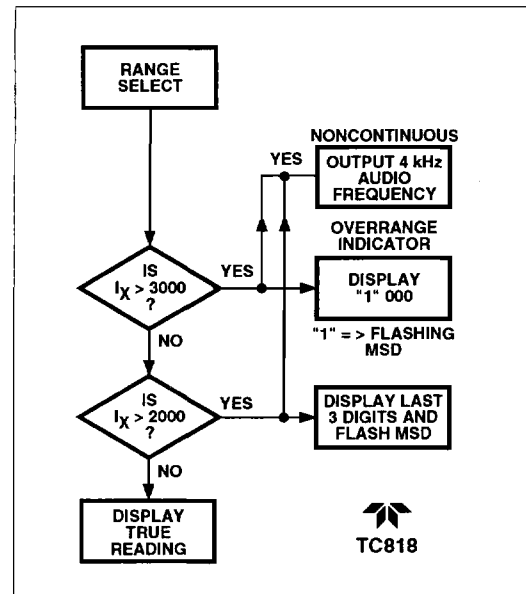


Figure 7 Manual Range Selection; Current Measurement

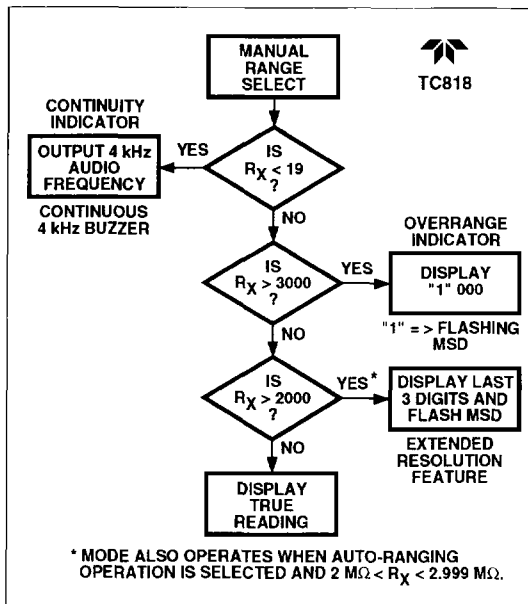


Figure 6 Manual Range Selection; Resistance Measurement

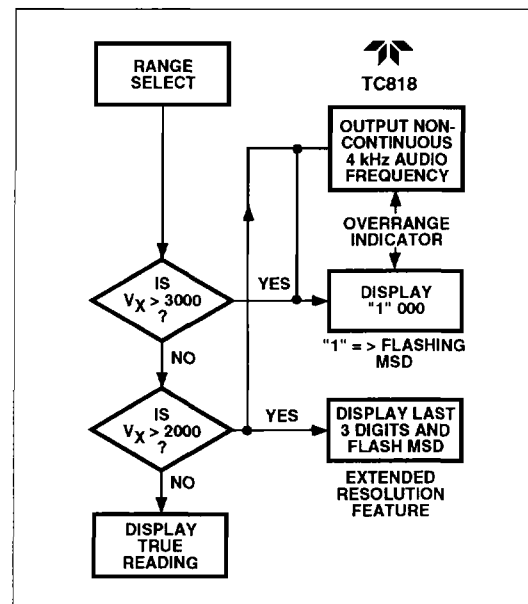


Figure 8 Manual Range Selection; Voltage Measurement

# AUTO-RANGING ANALOG-TO-DIGITAL CONVERTER WITH 3-1/2 DIGIT AND BAR-GRAPH DISPLAYS

## TC818

For resistance measurements, the buzzer signal does not indicate an overrange condition. The buzzer is used to indicate continuity. Continuity is defined as a resistance reading less than 19 counts.

### –MEM Operating Mode

Bringing –MEM (Pin 58) momentarily low configures the “–MEM” operating mode. The –MEM LCD annunciator becomes active. In this operating mode subsequent measurements are made relative to the last two digits ( $\leq 99$ ) displayed at the time MEM is low. This represents 5% of full-scale. The last two significant digits are stored and subtracted from all the following input conversions.

A few examples clarify operation:

#### Example 1: In Auto-Ranging

$$R_I(N) = 18.21 \text{ k}\Omega \text{ (20 k}\Omega \text{ Range)} \geq \text{Display } 18.21 \text{ k}\Omega \\ \text{MEM} \geq \text{Store } 0.21 \text{ k}\Omega$$

$$R_I(N+1) = 19.87 \text{ k}\Omega \text{ (20 k}\Omega \text{ Range)} \\ \geq \text{Display } 19.87 - 0.21 = 19.66 \text{ k}\Omega$$

$$R_I(N+2) = 22.65 \text{ k}\Omega \text{ (200 k}\Omega \text{ Range)} \\ \geq \text{Display } 22.7 \text{ k}\Omega \text{ and MEM Disappears}$$

#### Example 2: In Fixed Range 200 $\Omega$ Full Scale

$$R_I(N) = 18.2\Omega \geq \text{Display } 18.2\Omega \\ \text{MEM} \geq \text{Store } 8.2\Omega$$

$$R_I(N+1) = 36.7\Omega \\ \geq \text{Display } 36.7 - 8.2 = 28.5\Omega$$

$$R_I(N+2) = 5.8\Omega \\ \geq \text{Display } 5.8 - 8.2 = -2.4\Omega^*$$

\*Will display minus resistance if following input is less than offset stored at fixed range.

#### Example 3: In Fixed Range 20V Full Scale

$$V_I(N) = 0.51V \geq \text{Display } 0.51V \\ \text{MEM} \geq \text{Store } 0.51V$$

$$V_I(N+1) = 3.68V \\ \geq \text{Display } 3.68 - 0.51 = 3.17V$$

$$V_I(N+2) = 0.23V \\ \geq \text{Display } 0.23 - 0.51 = -0.28V$$

$$V_I(N+3) = -5.21V \\ \geq \text{Display } -5.21 - 0.51 = -5.72V$$

On power-up the, –MEM mode is not active. Once the –MEM is entered, bringing MEM low again returns the TC818 to normal operation.

The –MEM mode is also cancelled whenever the measurement type (resistance, voltage, current, AC/DC,  $\Omega/\overline{LO}\Omega$ ) or range is changed. The LCD –MEM annunciator will be off in normal operation.

In auto-range operation, if the following input signal cannot be converted on the same range as the stored value, the –MEM mode is cancelled. The LCD annunciator is turned off.

The –MEM operating mode can be very useful in resistance measurements where lead length resistance would cause measurement errors.

### Automatic Range Selection Operation

When power is first applied, the TC818 enters the auto-range operating state. The auto-range mode may be entered from manual mode by changing the measurement function (resistance or voltage) or by changing the measurement option (AC/DC,  $\Omega/\overline{LO}\Omega$ ).

The automatic voltage range selection begins on the most sensitive scale first: 200 mV for DC or 2V for AC measurements. The voltage range selection flow chart is given in Figure 9.

Internal input protection diodes to  $V_{CC}$  (pin 26) and  $V_{SS}$  (pin 54) clamp the input voltage. The external 10 M $\Omega$  input resistance (see R14 and R13, Functional Diagram) limits current safely in an overrange condition.

The voltage range selection is designed to maximize resolution. For input signals less than 9% of full scale (count reading  $<180$ ), the next most sensitive range is selected.

An overrange voltage input condition is flagged, whenever the internal count exceeds 2000, by activating the buzzer output (pin 3). This 4 kHz signal can directly drive a piezoelectric acoustic transducer. An out-of-range input signal causes the 4 kHz signal to be on for 122 ms, off for 122 ms, on for 122 ms, and off for 610 ms (see Figure 15).

During voltage auto-range operation, the extended resolution feature operates on the 2000V range only. (See extended resolution operating mode discussion.)

The resistance auto-range selection procedure is shown in Figure 10. The 200 $\Omega$  range is the first range selected unless the low ohms resistance measurement option is selected. In low ohms operation, the first full-scale range tried is 2 k $\Omega$ .

The resistance range selected maximizes sensitivity. If the conversion results in a reading less than 180, the next most sensitive full-scale range is tried.

If the conversion is less than 19 in auto-range operation, a continuous 4 kHz signal is output at BUZ (pin 3). An overrange input does not activate the buzzer.

# AUTO-RANGING ANALOG-TO-DIGITAL CONVERTER WITH 3-1/2 DIGIT AND BAR-GRAPH DISPLAYS

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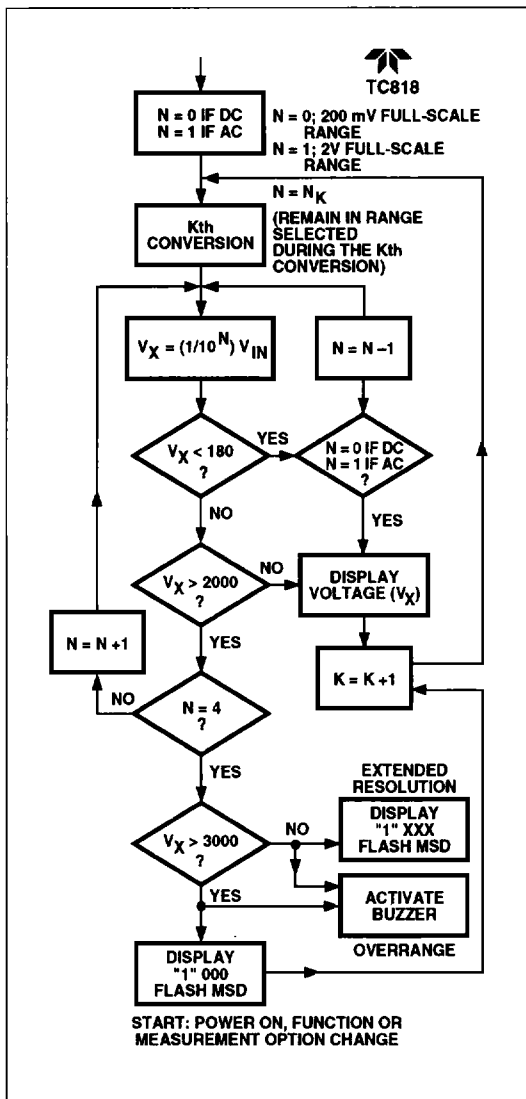


Figure 9 Auto-Range Operation; Voltage Measurement

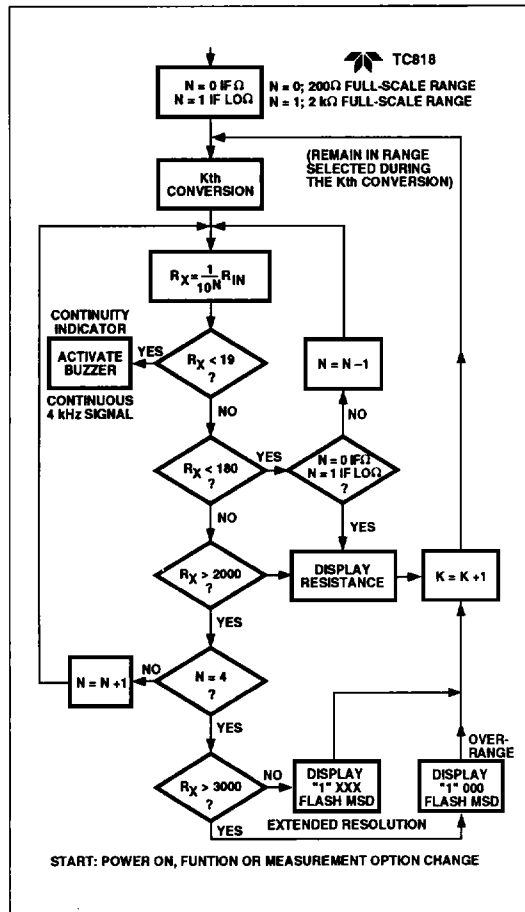


Figure 10 Auto-Range Operation; Resistance Measurement

Out-of-range input conditions are displayed by a blinking MSD with the three LSDs set to "000," and by the fully extended bar-graph.

The extended resolution feature operates only on the 200 kΩ and 2000V full-scale ranges during auto-range operation. A blinking "1" most significant digit is interpreted as the digit 2. The three LSDs display data normally.

# AUTO-RANGING ANALOG-TO-DIGITAL CONVERTER WITH 3-1/2 DIGIT AND BAR-GRAPH DISPLAYS

## TC818

### Low-Battery Detection Circuit

The TC818 contains a low-battery detector. When the 9V battery supply has been depleted to a 7V nominal value, the LCD low-battery annunciator is activated.

The low-battery detector is shown in Figure 11. The low-battery annunciator is guaranteed to remain OFF with the battery supply greater than 7V. The annunciator is guaranteed to be ON before the supply battery has reached 6.3V.

### Triplex Liquid Crystal Display (LCD) Drive

The TC818 directly drives a triplexed LCD using 1/3 bias drive. All numeric data, decimal point, polarity, and function annunciator drive signals are developed by the TC818A. The bar-graph data are developed to the TC818D. A direct connection to a triplex LCD is possible without external drive electronics. Standard and custom LCDs are readily available from LCD manufacturers.

The LCDs must be driven with an AC signal having a zero DC component, for long display life. The liquid crystal polarization is a function of the RMS voltage appearing across the backplane and segment driver. The peak drive signal applied to the LCD is:

$$V_{CC} - V_{DISP}$$

For example, if  $V_{DISP}$  is set at a potential 3V below  $V_{CC}$ , the peak drive signal is:

$$V_P = V_{CC} - V_{DISP} = 3V$$

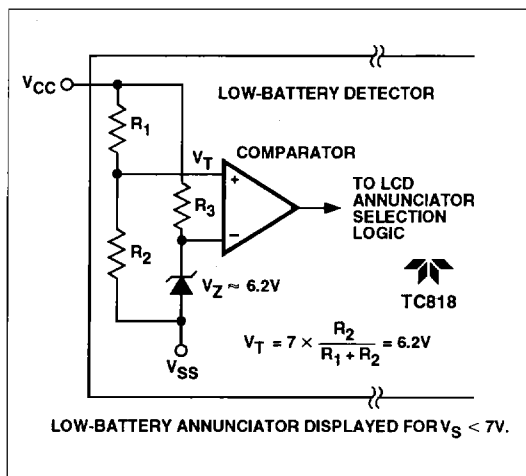


Figure 11 Low-Battery Detector

An "OFF" LCD segment has an RMS voltage of  $V_P/3$  across it or 1V. An "ON" segment has a  $0.63 V_P$  signal across it or 1.92V for  $V_{CC} - V_{DISP} = 3V$ .

Since the  $V_{DISP}$  pin is available, the user may adjust the "ON" and "OFF" LCD levels for various manufacturer's displays by changing  $V_P$  signal across it or 1.92V for  $V_{CC} - V_{DISP} = 3V$ .

"OFF" segments may become visible at high LCD operating temperatures. A voltage with a  $-5$  to  $-20$  mV/°C temperature coefficient can be applied to  $V_{DISP}$  to accommodate the liquid crystal temperature operating characteristics, if necessary.

The TC818A and TC818D internally generate two intermediate LCD drive potentials ( $V_H$  and  $V_L$ ) from resistive dividers (Figure 12) between  $V_{CC}$  and  $V_{DISP}$ . The ladder impedance is approximately 150 kΩ. This drive method is commonly known as 1/3 bias. With  $V_{DISP}$  connected to digital ground,  $V_P \approx 5V$ .

The intermediate levels are needed so that drive signals giving RMS "ON" and "OFF" levels can be generated. Figure 13 shows a typical drive signal and the resulting waveforms for "ON" and "OFF" RMS voltage levels across a selected numeric LCD element.

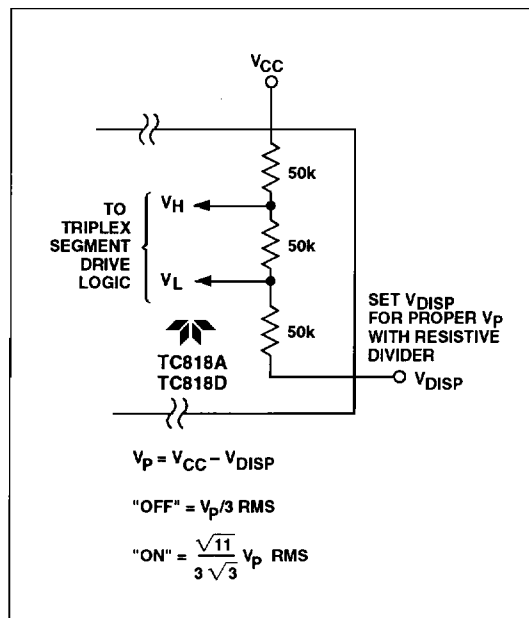


Figure 12 1/3 Bias LCD Drive

# AUTO-RANGING ANALOG-TO-DIGITAL CONVERTER WITH 3-1/2 DIGIT AND BAR-GRAPH DISPLAYS

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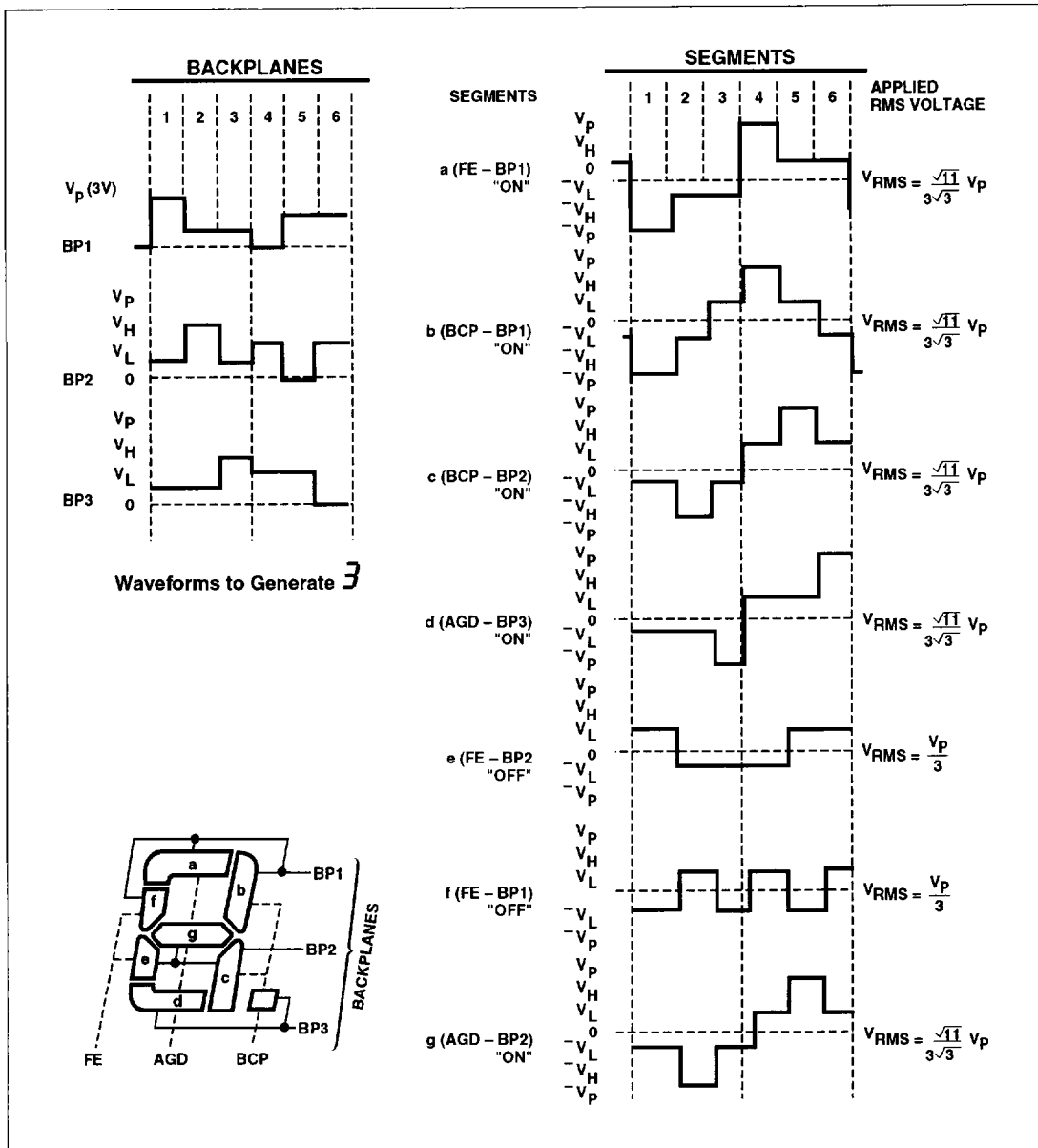


Figure 13 Triplex LCD Drive Waveforms

# AUTO-RANGING ANALOG-TO-DIGITAL CONVERTER WITH 3-1/2 DIGIT AND BAR-GRAPH DISPLAYS

## TC818

### Liquid Crystal Displays (LCDs)

Most users design their own custom LCD. However, for prototyping purposes, a standard display is available from Varitronix, Ltd. The prototype display configuration is shown in Figure 14.

- Varitronix Ltd.  
9/F Liven House, 61-63, King Yip Street  
Kwun Tjong, Hong Kong  
Tel: 3-410286  
Telex: 36643 VTRAX HX  
FAX: 852-3-439555  
  
Part No. VIM-328-DP
- USA Office:  
VL Electronics Inc.  
3171 Los Feliz Blvd, #303  
Los Angeles, CA 0039  
Tel: (213) 738-8700

### External Crystal

The TC818 is designed to operate with a 32,768 Hz crystal. This frequency is internally divided by two to give a 61.04  $\mu$ s clock period. One conversion takes 8000 clock periods or 488.3 ms ( $\approx$ 2 conversions/second). Integration time is 1638.5 clock periods or 100 ms.

The 32 kHz quartz crystal is readily available and inexpensive. The 32 kHz crystal is commonly used in digital clocks and counters.

Several crystal sources exist. A partial listing is:

- Statek Corporation  
512 N. Main  
Orange, CA 92668  
(714) 639-7810  
TWX: 910-593-1355  
Telex: 67-8394
- Daiwa Sinku Corporation  
1389, Shinzaike – AZA-Kono  
Hirakacho, Kakogawa Hyogo, Japan  
Tel: 0794-26-3211
- International Piezo LTD  
24-26 Sze Shan Street  
Yau Ton, Hong Kong  
TLX: 35454 XTAL HZ  
Tel: 3-3501151

Contact manufacturer for full specifications.

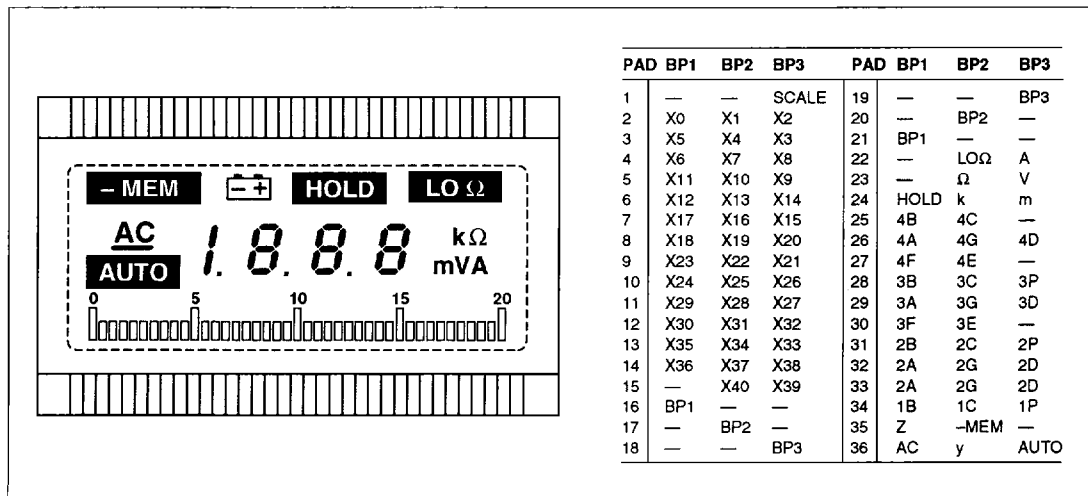


Figure 14 Typical LCD Configuration, TC818 Triplex



# AUTO-RANGING ANALOG-TO-DIGITAL CONVERTER WITH 3-1/2 DIGIT AND BAR-GRAPH DISPLAYS

## TC818

Vendors for piezoelectric audio transducers are:

- Gulton Industries  
Piezo Products Division  
212 Durham Avenue  
Metuchen, New Jersey 08840  
(201) 548-2800  
Typical P/Ns: 102-95NS, 101-FB-00
- Taiyo Yuden (USA) Inc.  
Arlington Center  
714 West Algonquin Road  
Arlington Heights, Illinois 60005  
Typical P/Ns: CB27BB, CB20BB, CB355BB

### Display Decimal Point Selection

The TC818 provides a decimal point LCD drive signal. The decimal point position is a function of the selected full-scale range, as shown in Table V.

**Table V. Decimal Point Selection**

Full-Scale Range	1	*	9	*	9	*	9
	DP3			DP2			DP1
2000V, 2000 kΩ	OFF			OFF			OFF
200V, 200 kΩ	OFF			OFF			ON
20V, 20 kΩ	OFF			ON			OFF
2V, 2 kΩ	ON			OFF			OFF
200V, 200Ω	OFF			OFF			ON
200 mV, 200Ω	OFF			OFF			ON
20 mA	OFF			ON			OFF
200 mA	OFF			OFF			ON

### AC-to-DC Converter Operational Amplifier

The TC818 contains an on-chip operational amplifier that may be connected as a rectifier for AC-to-DC voltage and current measurements. Typical operational amplifier characteristics are:

- Slew Rate: 1 V/μs
- Unity-Gain Bandwidth: 0.4 MHz
- Open-Loop Gain: 44 dB
- Output Voltage Swing (Load = 10 kΩ) ±1.5V (Referenced to Analog Common)

When the AC measurement option is selected, the input buffer receives an input signal through switch S14 rather than switch S11 (see Figure 1). With external circuits, the AC operating mode can be used to perform other types of functions within the constraints of the internal operational amplifier. External circuits that perform true RMS conversion or a peak hold function are typical examples.

### Component Selection

#### Integration Resistor Selection

The TC818 automatically selects one of two external integration resistors. RVIBUF (pin 52) is selected for voltage and current measurement. RWBUF (pin 51) is selected for resistance measurements.

#### RVIBUF Selection (Pin 52)

In auto-range operation, the TC818 operates with a 200 mV maximum full-scale potential at  $V_I$  (pin 42). Resistive dividers at VR2 (pin 39), VR3 (pin 38), VR4 (pin 41), and VR5 (pin 40) are automatically switched to maintain the 200 mV full-scale potential.

In manual mode, the extended operating mode is activated giving a 300 mV full-scale potential at  $V_I$  (pin 42).

The integrator output swing should be maximized, but saturations must be avoided. The integrator will swing within 0.45V of  $V_{CC}$  (pin 26) and 0.5V of  $V_{SS}$  (pin 54) without saturating. A ±2V swing is suggested. The value of RVIBUF is easily calculated, assuming a worst-case extended resolution input signal:

$$RVIBUF = \frac{V_{MAX}(t_i)}{V_{INT}(C_i)} \approx 150 \text{ k}\Omega$$

where:

$$\begin{aligned} V_{INT} &= \text{Integrator swing} = \pm 2V \\ t_i &= \text{Integration time} = 100 \text{ ms} \\ C_i &= \text{Integration capacitor} = 0.1 \mu\text{F} \\ V_{MAX} &= \text{Maximum input at } V_I = 300 \text{ mV} \end{aligned}$$

#### RWBUF Selection (Pin 51)

In ratiometric resistance measurements, the signal at  $R_X$  (pin 47) is always positive with respect to analog common. The integrator swings negative.

The worst-case integrator swing is for the 200Ω range with the manual, extended resolution option.

The input voltage,  $V_X$  (pin 47) is easily calculated (Figure 16):

$$R_{\Omega}BUF = \frac{(V_{CC} - V_{ANCOM}) R_X}{(R_X + R_S + R_1 + R_S)} = 0.63V$$

where:

$$\begin{aligned} V_{ANCOM} &= \text{Potential at analog common} \approx 2.7V \\ R_S &= 220\Omega \\ R_1 &= 163.85\Omega \\ R_X &= 300\Omega \\ R_S &= \text{Internal switch 33 resistance} \approx 600\Omega \end{aligned}$$

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For a 3.1V integrator swing, the value of  $R_{\Omega}BUF$  is easily calculated:

$$R_{\Omega}BUF = \frac{(V_X \text{ Max}) (t_i)}{C_1 (V_{INT})} \approx 220 \text{ k}\Omega$$

where:

- $V_{INT}$  = Integrator swing = 3.1V
- $t_i$  = Integration time = 100 ms
- $C_1$  = Integration capacitor = 0.1  $\mu$ F
- $R_X \text{ Max}$  = 300 $\Omega$
- $V_X \text{ Max}$  = 700 mV

With a low battery voltage of 6.6V, analog common will be approximately 3.6V above the negative supply terminal. With the integrator swinging down from analog common toward the negative supply, a 3.1V swing will set the integrator output to 0.5V above the negative supply.

## Capacitors — $C_{INT}$ , $C_{AZ}$ and $C_{REF}$

The integration capacitor,  $C_{INT}$ , must have low dielectric absorption. A 0.1  $\mu$ F polypropylene capacitor is suggested. The auto-zero capacitor,  $C_{AZ}$ , and reference capacitor,  $C_{REF}$ , should be selected for low leakage and dielectric absorption. Polystyrene capacitors are good choices.

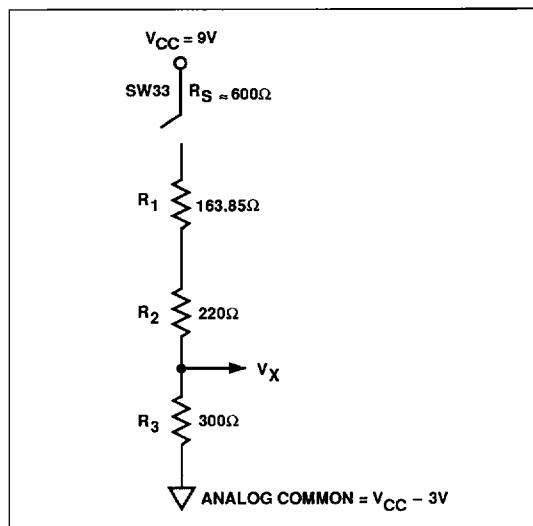


Figure 16  $R_{\Omega}BUF$  Calculation (200 $\Omega$  Manual Operation)

## Reference Voltage Adjustment

The TC818 contains a low temperature drift internal voltage reference. The analog common potential (pin 27) is established by this reference. Maximum drift is a low 75 ppm/ $^{\circ}$ C. Analog common is designed to be approximately 2.6V below  $V_{CC}$  (pin 26). A resistive divider ( $R_{18}/R_{19}$ , Functional Diagram) sets the TC818 reference input voltage ( $REF_{HI}$ , pin 32) to approximately 163.85 mV.

With an input voltage near full scale on the 200 mV range,  $R_{19}$  is adjusted for the proper reading.

## Display Hold Feature

The LCD will not be updated when  $\overline{HOLD}$  (pin 57) is connected to GND (pin 55). Conversions are made, but the display is not updated. A HOLD mode LCD annunciator is activated when  $\overline{HOLD}$  is low.

The LCD HOLD annunciator is activated through the triplex LCD driver signal at pin 12.

## Flat Package Socket

Sockets suitable for prototype work are available. A USA source is:

- Nepenthe Distribution  
2471 East Bayshore, Suite 520  
Palo Alto, CA 94303  
(415) 856-9332  
TWX: 910-373-2060  
"CBQ" Socket, Part No. IC51-064-042

## Resistive Ladder Networks

Resistor attenuator networks for voltage and resistance measurements are available from:

- Caddock Electronics  
1717 Chicago Avenue  
Riverside, CA 92507  
Tel: (714) 788-1700  
TWX: 910-332-6108

Attenuator Accuracy	Attenuator Type	Caddock Part Number
0.1%	Voltage	1776-C441
0.25%	Voltage	1776-C44
0.25%	Resistance	T1794-204-1