Errata

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A Wide-Ranging, Automatic LCR Meter for Stand-Alone or Systems Applications

Microprocessor control broadens the capabilities of this speedy LCR meter and makes it readily adaptable to BCD or HP-IB automatic systems.

by Masahiro Yokokawa and Keiki Kanafuji

FOR AN ELECTRONIC CIRCUIT to meet performance goals, the values of the components used in assembling the circuit must fall within certain ranges, some wide, some narrow. Despite increasing sophistication in the design and manufacture of passive circuit components, differences between supposedly identical components do exist and the ranges of values encountered often exceed acceptable limits.

Thus, most electronic laboratories, quality-control labs, and receiving departments are equipped to measure the actual values of the components with which they are concerned, a process that is not only time consuming, but one that often introduces errors of its own. To speed these measurements, and reduce the human errors that arise in this activity, late-model LCR meters, such as the Model 4261A described in a recent issue of the HP Journal,[1] have been designed with a high degree of automation.

A new LCR meter, Model 4262A, uses a microprocessor to further automate procedures while increasing the instrument's capabilities without incurring significantly greater costs. To measure the value of a passive component with this instrument (Fig. 1), it is only necessary to select the measurement function and loss parameter—i.e., resistance (R), capacitance (C), or inductance (L), and dissipation factor (D) or quality factor (Q)—select the appropriate test frequency, and connect the component to the test terminals. The instrument automatically switches to the correct measurement range, selects the preferred circuit mode, and presents results on the 3½ digit displays in about 250 ms without any time-consuming balancing adjustments. The user, however, can have full manual control of the instrument at any time simply by pressing the appropriate front-panel pushbuttons.

The front-panel control arrangement is similar to manually controlled instruments (see Fig. 1) speeding familiarization with the instrument. As a further safeguard against the possibility of unintentional missettings, the RANGE and CIRCUIT MODE functions automatically revert to AUTO whenever the L, C, or R function keys are pressed after manual modes have been in use. Since most measurements made with this kind of instrument are made on capacitors, when it is first turned on the new LCR meter automatically sets itself for the CD mode using a 1-kHz test frequency.

Enhanced Capability

Besides autoranging, self-triggering, and automatic selection of the appropriate circuit mode (series or parallel), the microprocessor brings several other capabilities to the instrument at little cost. Deviation measurement is one. When the ΔLCR key is pressed,

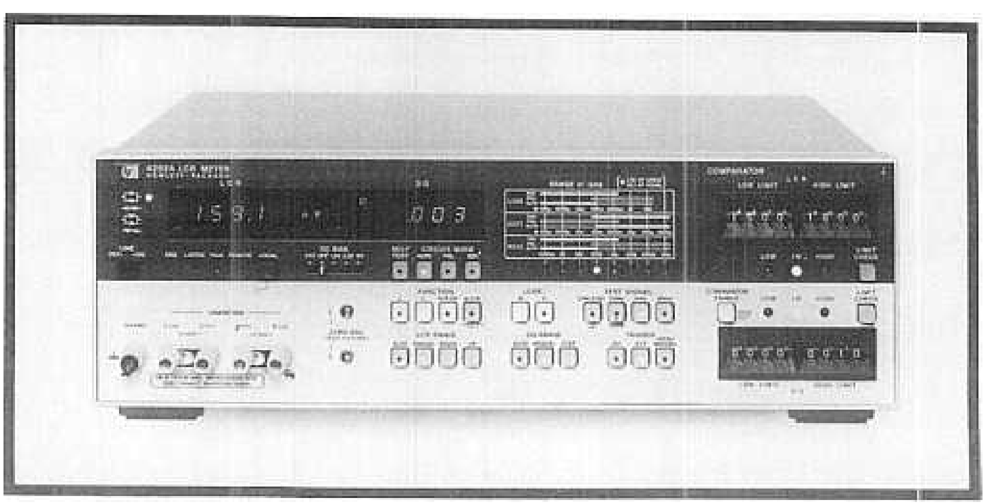

Fig. 1. *Model 4262A LCR Meter, shown here with the comparator option installed, measures the inductance (L), capacitance (C), resistance (R), dissipation factor (D), and quality factor (Q) of components with 3½ digit resolution. Three test frequencies (120 Hz, 1 kHz, and 10 kHz) enable measurements of a wide range of component values.*

the measurement value currently on display is stored, the display resets to zero, and the present measurement range is held. The result of the next measurement is then displayed as the difference between the new measurement value and the stored value. Besides checking device deviations during incoming inspection, this mode is also useful for monitoring the changes in device performance caused by variations in temperature or bias voltage.

For go/no-go measurements, a comparator option provides two pairs of thumbwheel switches on the front panel, one pair for LCR and one for DQ. Once high and low limits are established with these switches, a green light turns on when measured values are within the selected limits and a red light turns on when they are outside the limits. Electrical indications are also provided at a rear-panel connector.

Self test is another capability obtained at low cost with the microprocessor. At turn on, all LED indicators and all segments of the display digits light up momentarily to verify that all are functioning. Then, when the SELF TEST button is pressed while the input terminals are open (if the C measurement function is selected), or shorted (with the L or R measurement function), the instrument tests its digital section and the process amplifier and phase detector/integrator in the analog section, through five ranges. If all goes well, the word PASS appears in the LCR window and the user can be assured that the instrument is functioning correctly (this, however, is not a check on the instrument's accuracy). If there is a problem, the word FAIL is displayed, the range is held, and a code number indicating the location of the problem appears in the DQ window.

Other capabilities that the microprocessor gives the new LCR meter include low-cost HP interface bus (HP-IB)* and BCD-output options. In earlier LCR meters, an HP-IB interface very often cost more than the instrument itself but because of the microprocessor, the cost of the HP-IB interface for Model 4262A is less than one-fifth that of earlier interfaces. The new LCR meter may thus be interfaced readily to a printer for logging measurement results, or to a desktop computer and/or other instruments for programmed measurements and statistical analyses of measurement results.

When the new instrument is equipped with the HP-IB option, all functions except DC BIAS are programmable through the HP-IB. The current status of the instrument (FUNCTION, CIRCUIT MODE, AUTORANGE, etc.) is made visible by illumination of the LED indicators in the corresponding front-panel keys.

Wide-Ranging Measurements

The new instrument has a 10-kHz test frequency in addition to the customary 120-Hz and 1-kHz test frequencies. The 10-kHz test frequency extends the low-end C and L measurement ranges respectively to 10 pF and 10 μH full scale, giving the new instrument the ability to measure components over exceptionally wide ranges: inductance from 0.01 μH (the limit of resolution) to 1999 H, capacitance from 0.01 pF to 19.99 mF, resistance from 1 mΩ to 19.99 MΩ, dissipation factor from 0.001 to 19.9, and quality factor from 0.05 to 1000. With these wide ranges, the instrument may be used to measure RF coils, dielectric materials, electrolytes, the internal resistance of batteries, and the high dissipation factor of delay lines, as well as

*Hewlett-Packard's implementation of IEEE Standard 488-1975.

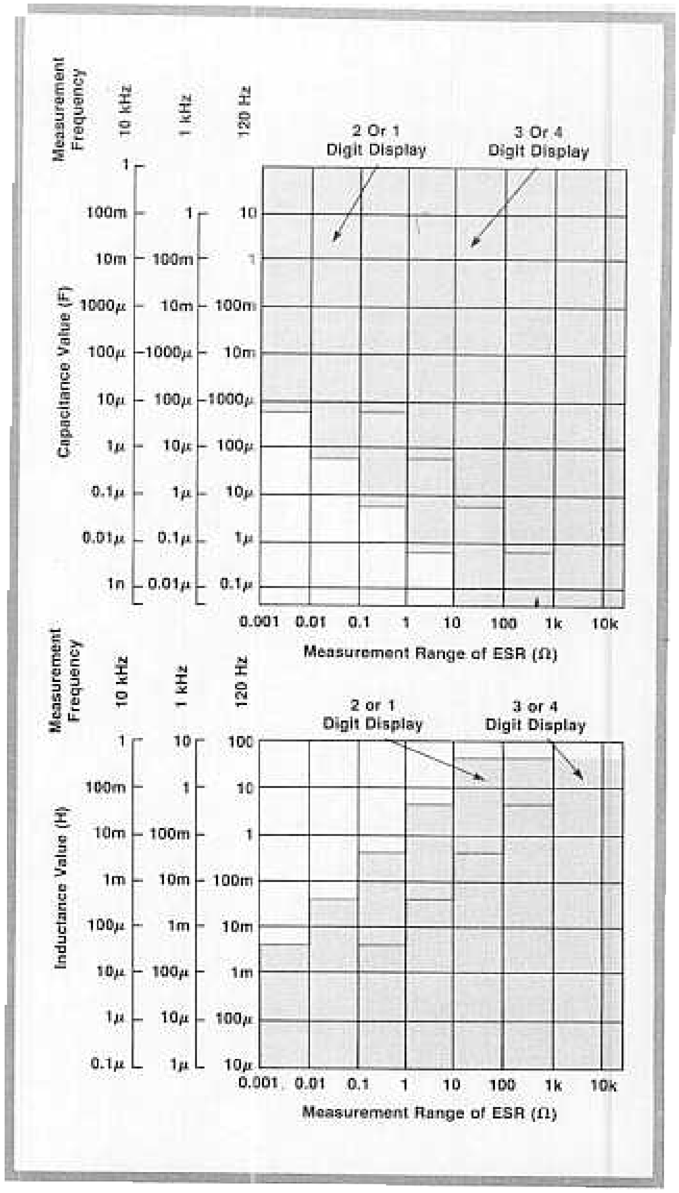

Fig. 2. *Capacitance and inductance ranges over which the equivalent series resistance (ESR) can be measured with the Model 4262A LCR Meter. The 10-kHz test frequency extends these ranges by a factor of 10 over those usually found in meters of this type.*

the values of discrete components.

In particular, the new LCR meter can measure the ESR (equivalent series resistance) of a capacitor to very low values, a significant measurement if the capacitor is to be used for bypass applications. With the 10-kHz test frequency, the reactance of a wide range of capacitors becomes low enough for the ESR to be a significant, and measurable, part of the total impedance, as plotted in Fig. 2. At 10 kHz, the resolution of an ESR measurement is 1 mΩ for capacitors larger than 10 μF. A five-terminal input (two for voltage, two for current, and one for a guard) is provided to minimize errors. Internally-generated bias levels of 1.5V, 2.2V and 6V are also provided, primarily for measurements on electrolytic capacitors.

Small values of capacitance, such as the junction capacitance of semiconductor devices, can be measured with the low-level (50 mV) test signal level that is available. Normally, the test signal level is 1V rms.

Typical measurement accuracy is 0.2%. On the low-end ranges, the test-fixture parasitic reactances can affect the accuracy of the measurement, so front-panel C and L offset controls are provided to null out parasitics up to 10 pF and 1 μH. The compensation technique is explained in Fig. 3.

Internal Operations

Model 4262A LCR Meter finds the values of L, C, R, D, and Q by determining the vector ratio of the voltage across the device under test (DUT) to the current flowing through the device, in the same manner as the Model 4261A LCR Meter.[1]

A block diagram is shown in Fig. 4. The voltage across the device is represented by e_1 in the diagram and the current by voltage e_2, which is proportional to the current flowing through range resistor R_R in series with the unknown. Op amp A3 assures accurate current flow by maintaining the LOW input terminal at virtual ground.

The four-phase generator supplies a signal shifted in precise increments of 90° with respect to its input for use as a reference by the phase detector. The integrator and comparator are part of a dual-slope A-to-D converter of the type widely used in digital voltmeters.

As an example of how all this fits together, assume that a capacitor is being measured in the parallel-circuit mode. Voltage e_1 is applied to the phase detector and voltage e_2, shifted 90°, serves as the phase detector reference. The output of the phase detector is applied to the integrator, which starts from the zero

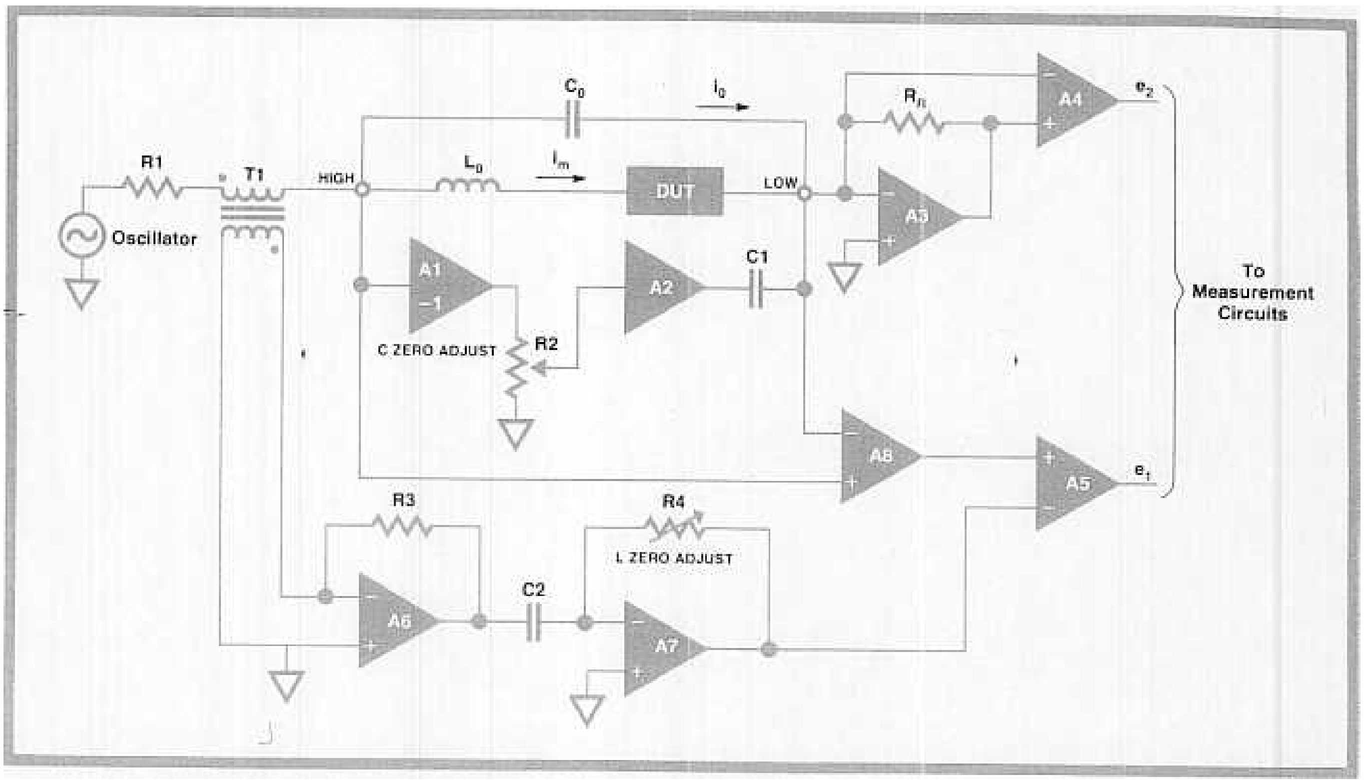

Fig. 3. *Compensating circuits neutralize the effect of the test fixture's stray capacitance (C_o) and residual inductance (L_o). Amplifier A1 inverts the test signal; the C ZERO ADJUST control allows adjustment of the current through C1 so it equals and thus cancels the current through C_o. Transformer T1 supplies a current to amplifier A6 equal to that flowing through the unknown, and the combination of C2, A7, and R4 shifts the signal 90°. R4 is adjusted so C2R3R4 = L_o, cancelling the effect of L_o at the input to amplifier A5.*

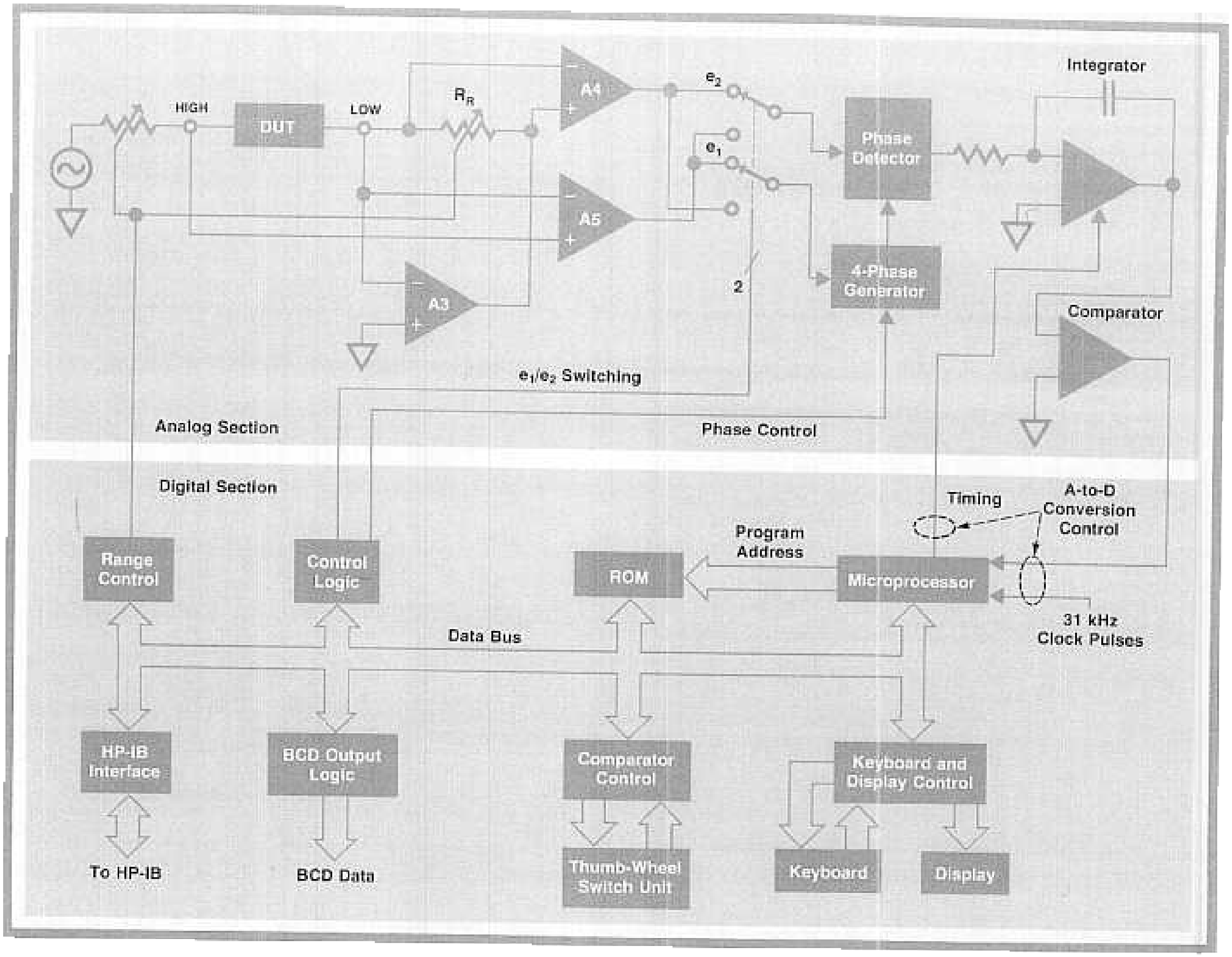

Fig. 4. *Simplified block diagram of the Model 4262A LCR Meter. Under control of the microprocessor, the circuits find the ratios of the real and imaginary parts of the voltage across the DUT with respect to the current (or vice versa), from which the device parameters can be derived.*

level and charges for a fixed period of time. Voltage e_2 is then applied to the phase detector input and it is also used as the phase reference but shifted 180° to give a negative output, which is used to discharge the integrator.

As shown in the flow chart of Fig. 5, the microprocessor determines the time of discharge by accumulating clock pulses during the discharge interval, the end of discharge being indicated by the comparator when it senses the return to the zero level. The discharge time is proportional to the quadrature part of the vector ratio e_2/e_1, which is proportional to the capacitance.

The counts accumulated during the discharge time are stored in a register within the microprocessor. The stored count can be used directly as the displayed quantity in a capacitance measurement because of the choice of the range resistor R_R and the clock frequency (31 kHz), which eliminates the need for any computation.

Similarly, by suitable choice of e_1 or e_2 as the phase reference, and proper choice of the phase shift, time periods proportional to the other measurement quantities can be obtained.

Digital Design

The microprocessor reads the keyboard, operates the displays, the comparator and the HP-IB option, performs the self test, and controls the many operations of the measurement cycle, such as autoranging and the A-to-D conversion. The various measurement routines, the comparator algorithm, the self-test program, and other instrument programs are stored in a 4K-byte ROM. The microprocessor is the same control-oriented type as that used in the HP Models 3455A and 3437A Digital Voltmeters.[2] It uses parallel architecture to achieve high speed but does not have a great deal of computation capability. What little

SPECIFICATIONS
HP Model 4262A LCR Meter

PARAMETERS MEASURED: C-D* or C-Q; L-D or L-Q; R/ESR.
*Loss measurement may be disabled by switch on internal PC board.
DISPLAY: Dual 3½ digit displays; maximum reading 1999.
MEASUREMENT CIRCUIT MODES: Series, parallel, auto (automatic selection of appropriate equivalent circuit mode).
MEASUREMENT TERMINALS: 5 terminal (H_{CUR}, H_{POT}, L_{CUR}, L_{POT}, GUARD).
RANGE MODES:
LCR: Autorange and manual (up-down).
DQ: Autorange and manual (step).
MEASUREMENT FREQUENCIES: 120 Hz (100 Hz optional), 1 kHz, and 10 kHz ±3%.
TRIGGER: Internal, external, or manual.
DEVIATION MEASUREMENT: When ΔLCR switch is depressed, measurement value is stored in memory, range is set to "Hold", and display is offset to zero. Deviation is displayed as difference between stored value and subsequent measurement data.
OFFSET ADJUSTMENTS (Front-panel adjustments to compensate for stray capacitance and residual inductance of test fixtures):
C: 0 to 10 pF; L: 0 to 1 µH
SELF/TEST INDICATORS: When SELF TEST function is selected, results of test are displayed in LCR and DQ windows. Results are indicated by PASS, FAIL 1, FAIL 2, or FAIL 3.
DC BIAS:
INTERNAL: 1.5 V, 2.2 V and 6 V ±5%, selectable on front panel.
EXTERNAL: Rear-panel input for external dc bias (0 to +40 V).
ESR MEASUREMENTS: (See Fig. 2, page 19).

ACCURACY: (All accuracies apply over temperature range of 23°C±5°C; at 0°C to 55°C, error doubles):

L-D and L-Q Measurement

Range	L	120 (100) Hz 1 kHz 10 kHz	1000 µH 100.0 µH 10.00 µH	10.00 mH 1000 µH 100.0 µH	100.0 mH 10.00 mH 1000 µH	1000 mH 100.0 mH 10.00 mH	10.00 H 1000 mH 100.0 mH	100.0 H 10.00 H 1000 mH	1000 H 100.0 H 10.00 H
	D		.001 - 19.9 (2 Ranges)						
	Q	(Note 1)	.050 - 1000 (4 Ranges)						
Test Signal Level (Note 2)	Parallel		————			1 V			
	Series		40 mA	10 mA	1 mA	100 µA	10 µA	————	
	AUTO		Same as Series Mode				Same as Parallel Mode		
L Accuracy (Note 3)	Parallel		At 120 (100) Hz, 1 kHz			0.2% + 2 counts		1% + 2 counts	
			At 10 kHz					1% + 2 counts	5% + 2 counts
	Series		0.2% + 2 counts					At 120 (100) Hz, 1 kHz	
			0.3% + 2 counts	0.2% + 2 counts				At 10 kHz	
	AUTO		Same as Series Mode				Same as Parallel Mode		
D (1/Q) Accuracy (Note 3)	Parallel		At 120 (100) Hz, 1 kHz			0.2% + (3 + Lx/500) counts		1% + (3 + Lx/500) counts	
			At 10 kHz			0.5% + (3 + Lx/500) counts		1% + (3 + Lx/500) counts	5% + (5 + Lx/500) counts
	Series		0.2% + (3 + 200/Lx) counts					At 120 (100) Hz, 1 kHz	
			0.5% + (3 + 200/Lx) counts					At 10 kHz	
	AUTO		Same as Series Mode				Same as Parallel Mode		

1. Calculated from D value as a reciprocal number.
2. Typical data, varies with value of D and number of counts.
3. ±(% of reading + counts). Lx is inductance readout in counts. Accuracies in this table apply when D ≤1.999.

ACCURACY FOR LARGE D: Typical accuracies for large D (≥ 2 on range 10.00):

Circuit Mode	Accuracy ±(% of reading + counts)
C_p Parallel	5% + (2 + $1000/C_x$) counts
C_s Series	5% + (5 + $C_x/500$) counts
L_p Parallel	5% + (5 + $L_x/500$) counts
L_s Series	5% + (3 + $200/L_x$) counts

C_x is capacitance readout in counts.
L_x is inductance readout in counts.

C-D and C-Q Measurement

Ranges	C	120 (100) Hz 1 kHz 10 kHz	1000 pF 100.0 pF 10.00 pF	10.00 nF 1000 pF 100.0 pF	100.0 nF 10.00 nF 1000 pF	1000 nF 100.0 nF 10.00 nF	10.00 µF 1000 nF 100.0 nF	100.0 µF 10.00 µF 1000 nF	1000 µF 100.0 µF 10.00 µF	10.00 mF 1000 µF 100.0 µF
	D		.001-19.9 (2 Ranges)							
	Q	(Note 1)	.050-1000 (4 Ranges)							
Test Signal Level (Note 2)	Parallel		1 V or 50 mV					————		
	Series		————			10 µA	100 µA	1 mA	10 mA	40 mA
	AUTO		Same as Parallel Mode				Same as Series Mode			
C Accuracy (Note 3)	Parallel		0.2% + 1 count					(Test signal level: 1 V)		
			0.5% + 3 Counts	0.3% + 2 counts				(Test signal level: 50 mV)		
	Series		At 120 (100) Hz, 1 kHz			0.2% + 2 counts			0.5% + 2 counts	1% + 2 counts (Note 4)
			At 10 kHz						1% + 2 counts	5% + 2 counts
	AUTO		Same as Parallel Mode				Same as Series Mode			
D (1/Q) Accuracy (Note 3)	Parallel		0.2% + (2 + 200/Cx) counts					At 120 (100) Hz, 1 kHz (Test signal level: 1 V) At 10 kHz		
			0.5% + (2 + 200/Cx) counts							
			————	0.3% + (2 + 1000/Cx) counts				At 120 (100) Hz, 1 kHz (Test signal level: 50 mV) At 10 kHz		
			————	1.0% + (2 + 1000/Cx) counts						
	Series		At 120 (100) Hz, 1 kHz			0.2% + (2 + Cx/500) counts				1% + (5 + Cx/500) counts
			At 10 kHz			0.5% + (2 + Cx/500) counts			1% + (3 + Cx/500) counts	5% + (5 + Cx/500) counts
	AUTO		Same as Parallel Mode				Same as Series Mode			

1. Calculated from D value as a reciprocal number.
2. Typical data, varies with value of D and number of counts.
3. ±(% of reading + counts). C_x is capacitance readout in counts. Accuracies in this table apply when D ≤1.999.
4. 5% + 2 counts at 1 kHz.

R/ESR* Measurement

Range		120 (100) Hz 1 kHz 10 kHz	1000 mΩ	10.00 Ω	100.0 Ω	1000 Ω	10.00 kΩ	100.0 kΩ	1000 kΩ	10.00 MΩ
Test Signal Level (Note 1)	Parallel		————			1V				
	Series		40 mA	10 mA	1 mA	100 µA	10 µA	————		
	AUTO		Same as Series Mode				Same as Parallel Mode			
Accuracy (Note 2)	Parallel		————			0.5% + 2 counts (Note 3)				
	Series		0.2% + 2 counts					————		
	AUTO		Same as Series Mode				Same as Parallel Mode			

1. Typical data, varies with number of counts.
2. ±(% of reading + counts)
3. ±(5% + 2 counts) on 10.00 MΩ range at 10 kHz test frequency

*Measurement range for ESR is from 1 mΩ to 19 kΩ (typical). These values vary depending on series capacitance or inductance value of device under test. Refer to Fig. 2, page for actual ranges.

MEASUREMENT TIME (typical): For 1000-count measurement on low-loss component with range fixed:
1 kHz, 10 kHz: C/L, 220-260 ms. R, 120-160 ms.
120 (100) Hz: C/L, 900 ms. R, 700 ms.
When autorange is selected, the following must be added to the above:
1 kHz, 10 kHz: 45 ms/160 ms per range step.
120 (100) Hz: 150 ms/670 ms per range step.
When UNCAL lamp is lit, the faster ranging time is selected.
READING RATE:
INT (Internal trigger): approximately 30 ms between end of one measurement cycle and start of next.
EXT (External trigger): measurement cycle is initiated by remote trigger input.
DIMENSIONS: 426 W × 147 H × 345 D mm (16¾ in × 5¾ in × 13¾ in).
WEIGHT: approximately 8 kg (17.5 lbs).
POWER: 100/120/220 Vac ±10%, 240 Vac +5%-10%; 48-66 Hz, ≤55 VA with any option.
OPTIONS:
001: Simultaneous BCD output of LCR and DQ data. 1-2-4-8 BCD code, TTL logic level, "1" state positive. Alternate BCD output may be selected by switch on internal PC board.
004: Digital Comparator. Compares measured value with high and low limit switch settings for both LCR and DQ and provides High, In, Low comparison outputs. Cannot be used with Option 101. Comparison outputs: visual, relay contact closure and TTL level output.
010: 100-Hz Test Frequency instead of 120 Hz.
101: HP-IB data output and remote control.
PRICES IN U.S.A.: Model 4262A, $2335. Opt. 001, $240. Opt. 004, $580. Opt. 010, no charge. Opt. 101, $395.
MANUFACTURING DIVISION: YOKOGAWA-HEWLETT-PACKARD LTD.
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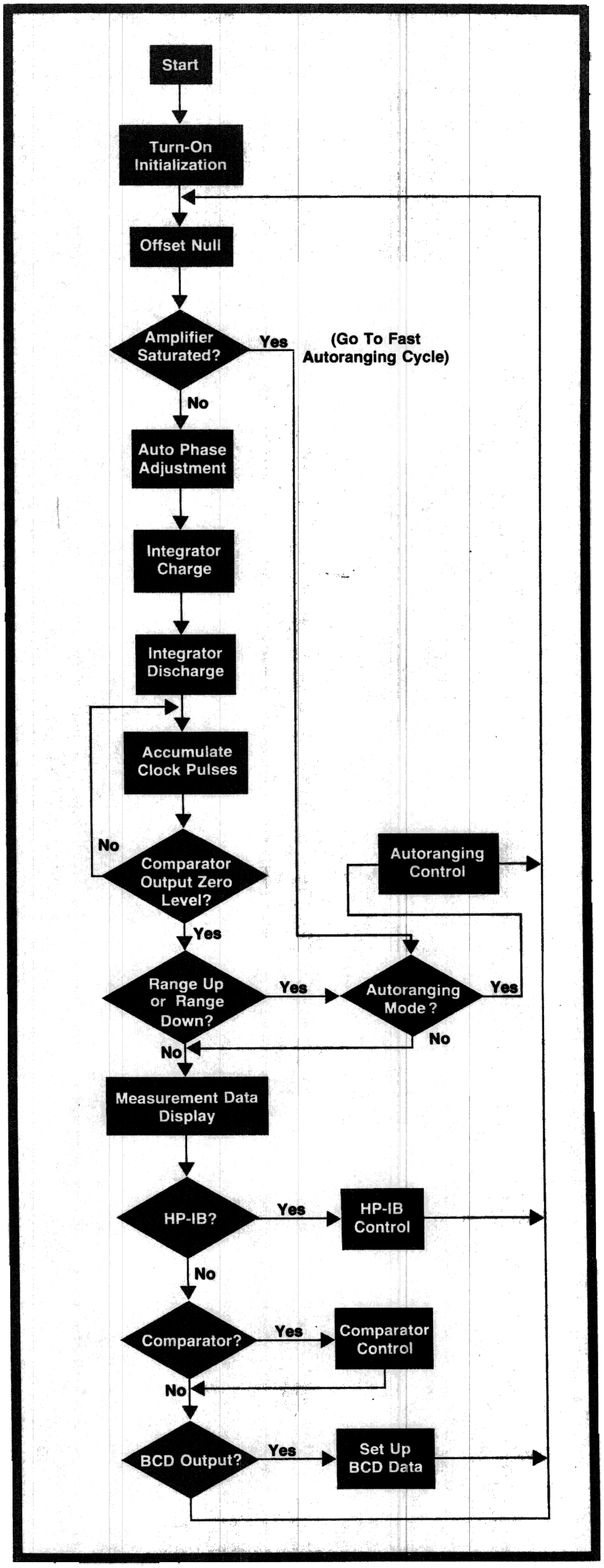

Fig. 5. *Flow chart of measurement routine.*

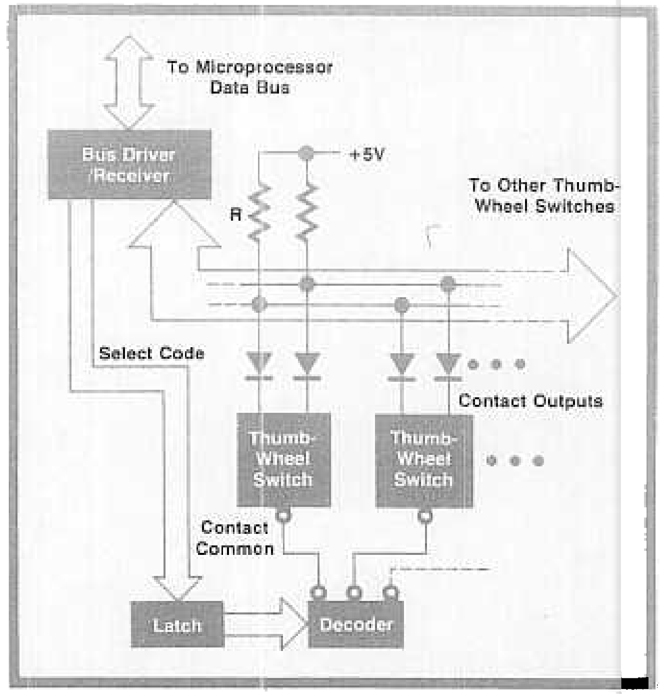

Fig. 6. *Comparator option requires little hardware because of the capabilities provided by the microprocessor.*

arithmetic there is to be done is accomplished mostly by incrementing or decrementing counts stored in registers.

The manner in which this microprocessor system enables operating features to be added at little cost is illustrated by the comparator option, diagrammed in Fig. 6. Each digit of each thumbwheel connects to one of the ten lines of the comparator data bus by means of a diode. The diode cathodes for each switch are tied in common to the switch contact. When the front-panel COMPARATOR ENABLE key is pressed, the microprocessor initiates a stored program that sequentially grounds the common contacts of the thumbwheels, and for each one senses which line of the data bus is grounded. The comparator settings can thus be stored for use during subsequent measurement comparisons. This technique minimizes the amount of hardware needed to implement the comparator function.

Acknowledgments

Special thanks are due to Hiroshi Sakayori, who evaluated the 10-kHz C standard, Shigeo Kamiya for much help, and Dave Okuyama, who developed the microcomputer cross-assembler to be run on an HP 2100 Computer. Yoshimasa Shibata contributed to the mechanical design, and industrial design was done by Kazunori Shibata. Thanks are due R and D group manager Shiro Kito and marketing manager Shigeki Mori who provided significant suggestions and encouragement throughout the project.

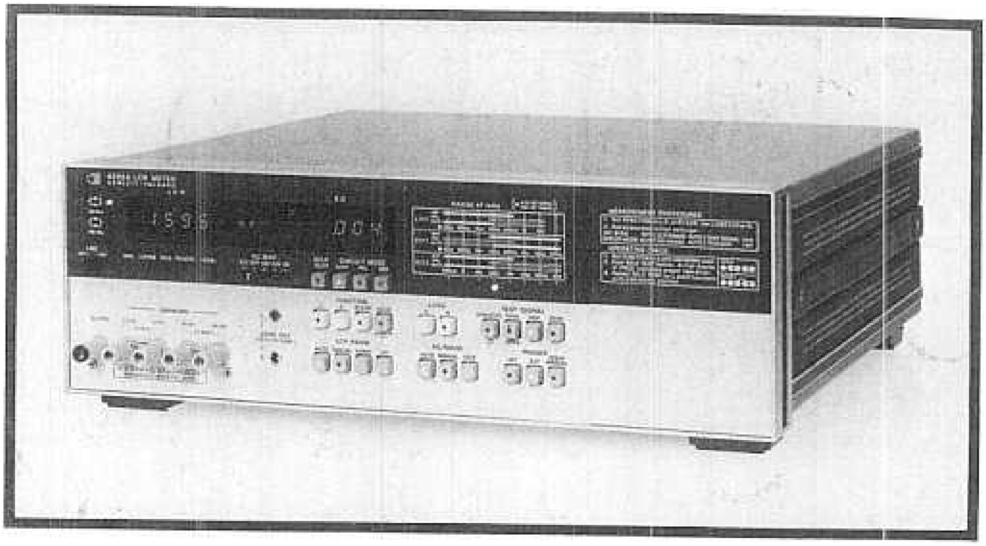

Fig. 7. *Model 4262A LCR Meter, shown here without options, has a front panel arrangement that facilitates manual control when manual control is preferred to automatic operation. With the HP-IB option installed, all pushbutton functions are programmable through the HP interface bus (all options are field installable).*

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Masahiro Yokokawa

Masahiro Yokokawa earned a BSEE degree from Nagoya University in 1971 and worked on the hardware design of computer peripherals before joining Yokogawa-Hewlett-Packard in 1973. After developing an HP-IB coupler for LCR meters, Masahiro became project leader for Model 4262A, contributing the digital design. In his spare time he enjoys swimming and traveling and he likes to listen to jazz.

Keiki Kanafuji

Keiki Kanafuji joined Yokogawa-Hewlett-Packard in 1972 shortly after obtaining a BSEE degree from the Tokyo Institute of Technology. Initially he worked on some investigative projects then contributed to the design of the Model 4272A Preset C Meter before undertaking the design of the analog circuitry in Model 4262A. Outside of working hours, Keiki relaxes by playing contract bridge and listening to music.

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