M^3 Digital LCR Meter

User's Manual

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A special thanks to the following individuals for their contributions in the development and realization of the M^3 Digital LCR Meter and documentation:

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GENERAL INFORMATION

The M^3 DIGITAL LCR Meter is a multi-frequency impedance measuring instrument capable of measuring resistance, capacitance, inductance or transformer parameters from 1 mÙ to 100 MÙ. The M^3 DIGITAL LCR meter has a basic accuracy of 0.2% and has 10 test frequencies.

The LCR meter is controlled by a high-speed microcontroller with embedded logic that controls the display and keypad, as well as setting measurement conditions and performing calculations.

SPECIFICATIONS:

Measurement Modes: Auto, L+Q, C+D, R+Q, |Z|+θ, R+X, G+B, N+θ, N^{-1}+θ ,Vs+Vp, M, L+AL, C+Vr (varactor option)

Equivalent Circuit: Series or parallel

Parameters Displayed: Value, Deviation, % Deviation

Measurement Display Range

L+Q:	L	0.01 µH – 99.99 H
	Q	0.001 – 100
C+D:	C	0.001 pF – 99999 µF
	D	0.001 – 10
R+Q:	R	1 mΩ – 99.9 MΩ
	Q	0.001 – 100
|Z|+θ:	|Z|	1 mΩ – 99.9 MΩ
	θ	-180.00° - +180.00°
R+X:	R	1 mΩ – 99.9 MΩ
	X	1 mΩ – 99.9 MΩ
G+B:	G	
	B	
N+θ:	N	1 – 9999
	θ	-180.00° - +180.00°
N^{-1}+θ	N^{-1}	0.0001 – 1
	θ	-180.00° - +180.00°
Vs+Vp	Vs	230V/N or 115V/N, 0.01V resolution
	Vp	115V or 230V
M	M	0.01 µH – 99.99 H
L+A_L	L	0.01 µH – 99.99 H
	A_L	L/N^2 (N set by user from 1 to 999)

With varactor option:

C+Vr	C	0.001 pF – 99999 µF
	Vr	0.00 - 5.0V or 0.0 – 30.0V

TEST CONDITIONS:

Test frequency: 100 Hz, 120 Hz, 250 Hz, 500 Hz, 1 kHz, 2.5 kHz, 5 kHz, 7.8125 kHz, 12.5 kHz, 15.625 kHz

Drive Voltage: 0.5 Vrms ±5%

Measurement Rate: 2 measurements per second

Ranging: Auto or Manual

ACCURACY:

Conditions	At least 15 minutes warm up, 23 °C ± 5 °C
Basic Accuracy	0.2 %
	See the accuracy section for detailed accuracy specifications

FEATURES:

Fixture	4-Wire Kelvin DIN socket
Protection	Protected up to 1 Joule of stored energy, 200 VDC max (for charged capacitors)
Zeroing	Open or Short Circuit compensation
Compensation Limits	Short: R < 20 Ω |Z| < 50 Ω
	Open: |Z| > 10 kΩ
Store and Recall	

GENERAL:

Operating Conditions	0 – 50 °C, < 80% relative humidity
Power	7.5 – 13V, 200 mA with backlight, 100 mA otherwise
Dimensions (W x H x L)	6.125 in X 1.5 in X 3.875 in

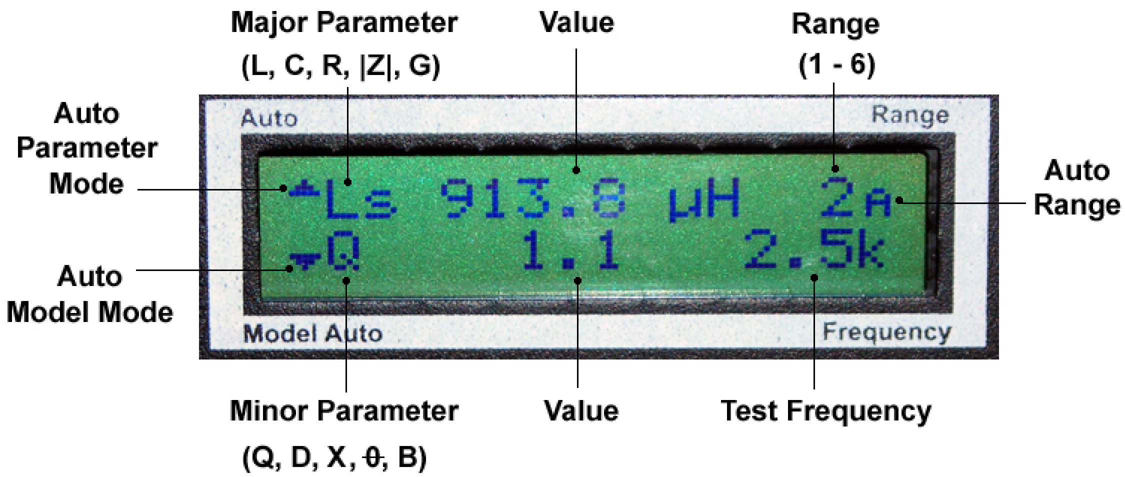
OPTIONS:

Varactor Test Fixture Kit

SYMBOLS and TERMS

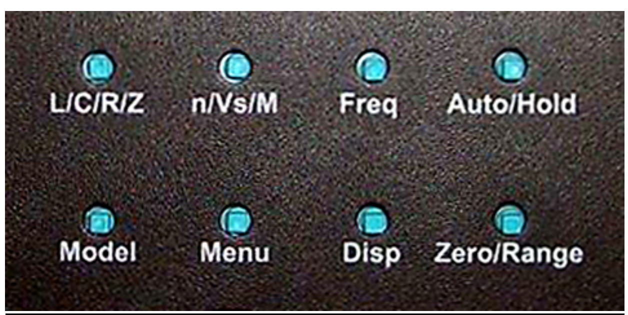
Parameter	**Measurement**	**Unit Symbol**
Z	Impedance	ohm, Ω
|Z|	Absolute Z	ohm, Ω
Rs or ESR	Resistance, Real part of Z	ohm, Ω
X	Reactance, Imaginary part of Z	ohm, Ω
G	Conductance, Real Part of Admittance (Y)	siemens, S
B	Susceptance, Imaginary part of Admittance	siemens, S
Cs	Series capacitance	Farad, F
Cp	Parallel capacitance	Farad, F
Ls	Series inductance	Henry, H
Lp	Parallel inductance	Henry, H
Rp	Parallel resistance	ohm, Ω
Q	Quality factor	none
D	Dissipation factor	none
θ	Phase angle of |Z|	Degree,
M	Mutual Inductance	Henry, H
N	Turns ratio	none
Vp	Transformer primary voltage	AC Volts, V
Vs	Transformer secondary voltage	AC Volts, V

DISPLAY AND CONTROLS



DISPLAY

The two lines of the LCD show measured values, selected parameters, instrument status and various messages. When making normal measurements, the major parameter (**L, C, R, |Z|, G**) is shown on the top line and the appropriate minor parameter (**Q, D, X, θ, B**), is shown on the bottom line. The number of displayed digits and the location of the decimal point are automatically adjusted according to the range and resolution. The Δ symbol in front of the major parameter indicates that the measurement is displayed as a relative or absolute deviation from a nominal value. A dark arrow present in the top left of the display indicates the unit is in the Auto Parameter mode. If a dark arrow is displayed in the bottom left of the LCD, the unit is in the Auto Model mode. The Range is indicated at the top right of the display. The 'A' character behind the Range number indicates that the instrument is in auto range mode. In Manual or Hold ranging mode, this letter becomes a blinking "H" character. The selected test frequency is displayed on the bottom right of the display.



KEYPAD

The keypad is used to select measurement conditions and to enter values. All keys have two functions, depending on whether the key is pressed momentarily or for two seconds or longer.

L/C/R/Z

This key selects the parameter being measured. Pressing the LCRZ key steps through the major parameters to manually select the desired function ([L+Q] or [L+A_L], [C+D], [R+Q], [|Z|+θ], [R+X], [G+B]). When this key is pressed for more than two seconds the instrument goes in Auto Parameter mode. In this mode, the instrument will select the most appropriate parameter pair and will display the dark arrow at the top left of the display.

[L+Q] – Inductance and Quality
[L+ A_L] - Inductance and A_L value for toroid core
[C+D] – Capacitance and Dissipation
[R+Q] – DC Resistance and Quality
[|Z|+θ] – Absolute impedance and phase angle
[R+X] – Resistance and Reactance
[G+B] – Conductance and Susceptance

n/Vs/M

This key selects the transformer measurement mode. Pressing this key steps through and permits the selection of the desired function ([N+θ], [1/N+θ], [Vs+Vp], [M+θ]).

[N+θ] – Turns ratio and phase angle
[1/N+θ] – reciprocal turns ratio and phase angle
[Vs+Vp] – Secondary and Primary Voltage
[M+θ] – Mutual Inductance and phase angle

FREQ

The [Freq] key selects one of the following test frequencies: 100 Hz, 120 Hz, 250 Hz, 500 Hz, 1 kHz, 2.5 kHz, 5 kHz, 7.8125 kHz, 12.5 kHz and 15.625 kHz. The selected frequency is indicated just above this key. Pressing this key for longer than two seconds sets the LCR meter to use the default parameters. The default frequency is 1KHz.

AUTO/HOLD

The [Auto/Hold] key selects the impedance range of measurement appropriate for the device under test. Pressing this key holds the unit in its current measurement range. Repeated pressing of this key changes the measurement impedance range (1 – 6). Pressing this key for longer than two seconds returns the unit to auto-ranging or normal mode. The range is displayed in the top right corner of the display. The 'A' character behind the Range number indicates that the instrument is in Auto Range mode. In Manual or Hold ranging mode, this letter becomes a blinking "H" character. Pressing this key for two seconds or longer returns to the Auto mode.

Impedance Ranges:
Range 1: 0.001Ω to 15Ω
Range 2: 15Ω to 300Ω
Range 3: 300Ω to 3 kΩ
Range 4: 3 kΩ to 30 kΩ
Range 5: 30 kΩ to 600 kΩ
Range 6: 600 kΩ to 99.9 MΩ

MODEL

The [MODEL] key selects between a series or parallel equivalent circuit model for the device under test. Pressing this key for two seconds or longer places the Model selection in Auto mode.

MENU

The [MENU] key allows access to a series of special configurable parameters. Pressing this key displays the programmable options. The current state of each option is displayed on the first line of the LCD as that option is selected. To move through the Menu, press the key under the forward or back arrows displayed on the LCD.

- **Backlight** – default value is ON. The backlight can be set to ON or OFF. To turn the backlight off, press the key under OFF.
- **Sound** – default value is ON. This option turns the audible alert function ON or OFF.
- **Varactor** – default value is OFF. This option requires the Varactor Test Fixture available from M^3 Electronix. Turning the Varactor option to ON will place the LCR meter automatically in the Varactor measurement mode upon saving and exiting the Menu. To return to normal features, select the Menu key and turn the Varactor feature OFF.
- **Sorting** – default value is OFF. Use this feature to measure and sort like valued components.
    1. Turning the Sorting function ON will allow the user to set the Tolerance between the value of the benchmark component and like components to be measures. This Tolerance is selected by pressing the NEXT key.
    2. When the appropriate tolerance has been selected, pressing the key under the left arrow enables the value of the benchmark component to be entered by pressing the 'Edit' key. A cursor will appear under the first digit of the value. Pressing the NEXT key will move the cursor to the next digit. Pressing the 'Change' key will step the value of the selected digit. When the desired value has been entered, pressing the OK key will record this value.
    3. Pressing the key under the right arrow will allow the user to set the audible indication when a DUT meets the programmed parameters. Default value for the Pass Beep is SHORT. Pressing the NEXT key will change the value to LONG or NONE.
    4. Pressing the key under the right arrow will present the option of turning the backlight on or off when a valid component is measured. The default value is YES.

5. Pressing the Menu key now will allow you to save the selected configuration and place the LCR meter in the Relative measurement mode.
6. To turn the Sorting mode OFF, press the Menu key and step backward or forward using the appropriate arrow key until the Sorting option is displayed. Press the key under OFF. Press the Menu key and save this configuration.

- **Averaging** – default value is OFF. Set this feature to ON to compensate for random noise that is apparent when measuring some components. There are seven selectable step rates from 2 to 8. Each step adds approximately .25 seconds to the sampling refresh rate of the LCD display.

- **A_L measurement** – default value is OFF. Set this feature to ON to measure the A_L value of an unknown toroid core. Press the 'forward arrow' key to enter the number of turns on the inductor. To enter the number of turns, select EDIT. A cursor will be displayed under the last digit on the LCD. Pressing the Change key will step the value of the digit over the cursor. Pressing the NEXT key will move the cursor to the far left position. When the number of turns has been entered, press the OK key. For accuracy, a minimum of 10 evenly distributed turns on the core is recommended.

1. Pressing the Menu key and saving the current configuration will place the LCR meter in **L+ A_L** mode. The **A_L** value will be displayed on the second line of the display.
2. To return to normal measurements, press the Menu key and step backward or forward using the appropriate arrow key to the A_L display option. Select OFF and press the Menu key again. Save the current configuration.

DISP

The [Disp] key selects the manner that the value of a component will be displayed. If the Sorting mode is disabled, pressing [Disp] cycles through the following display types:

- The value being measured
- The deviation of the value from the current value – The Δ symbol next to the measured parameter indicates that this function is active.
- The percent of deviation from the current value - The Δ symbol next to the measured parameter indicates that this function is active.

In Sorting Mode pressing [Disp] cycles through the following display types:

- The value being measured
- The percent of deviation from a stored value - The Δ symbol next to the measured parameter indicates that this function is active. In this mode, a PASS/FAIL message is shown in the second line of the display according to the measured deviation and the selected tolerance.

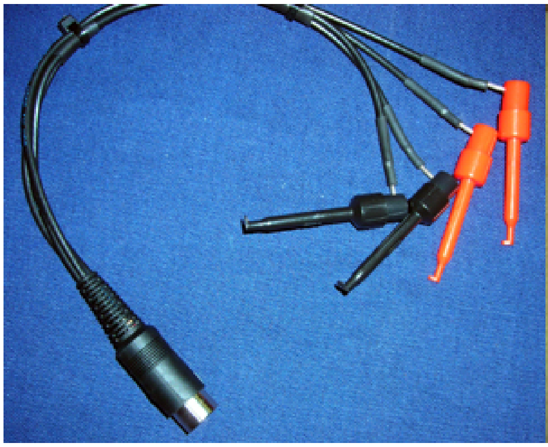
Zero/Range

The [Zero/Range] key allows access to open/short compensation. Pressing the [Zero/Range] key displays the zeroing options on the second line of the LCD – **Open Short Exit.** This option will zero the LCR meter for the currently selected test frequency. Pressing the [Zero/Range] for more than two seconds displays the zeroing options – **OPEN SHORT Exit** (note that the options are in all capital letters). This option performs an open/short calibration through the entire range of test frequencies.

Initial Calibration

Before the M^3 Digital LCR Meter can be used for the first time, it must be calibrated. This is a simple process and requires six precision resistors. The calibration resistors provided with the M^3 LCR Meter kit are 0.1% resistors with the following values: 10, 100, 1K, 10K, 100K, 1M ohms. If you have an *accurate* ohmmeter (0.01% accuracy or better), you can measure the value of the six calibration resistors and adjust the precise values within the calibration routine. Measure and note the value of each resistor. Remember, the accuracy of the measurements made by the LCR meter will be dependent on the accuracy of the initial calibration. If you are NOT sure of the accuracy of your ohmmeter, accept the default values. In this case add 0.1% to the basic accuracy value of the instrument.

Calibration also requires the 4-clip cable provided with the kit or a true Kelvin clip cable with HD/HS (High Drive/High Source) terminals connected to one clip, LD/LS (Low Drive/Low Source) terminals connected to the second clip, and the cable shields connected to ground at the plug end. The calibration sequence only needs to be performed once. The values derived during the calibration routine are stored in non-volatile memory and will remain stored in the instrument until the calibration routine is performed again.




left: 4-wire test cable **right: Kelvin Clip cable**

Turn on the M3 Digital LCR meter and allow it to warm up for at least 15 minutes to stabilize prior to calibration.

For a detailed explanation of the Calibration and Diagnostics options, see **DIAGNOSTICS AND CALIBRATION SCREENS** starting on page 19.

To begin calibration, connect the test cable to the DIN socket on the LCR meter. Short the HD and HS clips together using a short piece of wire. Short the LD and LS clips together using another short piece of wire. Turn the LCR meter off.

- Hold down the Model key and apply power to the LCR meter. Release the Model key when the DIAG/CAL screen appears.
- Press the key under CAL (n/Vs/M).
- Press the key under PARAM (L/C/R/Z)
- Press the key under NEXT (L/C/R/Z) until the display shows Mains Frq: 60 Hz on the first line and NEXT 50HZ 60Hz on the second line. Press the key under 60Hz (Freq).
- Press the key under NEXT. If you are NOT going to adjust the default values for the calibration resistors, proceed to the next step. If you want to change the default resistors values, first review the Calibration Mode (page 21), and continue as follows:

  Press the NEXT key. The display will show the calibration resistor value of RCAL1, which is 10.0000 ohms. Pressing the NEXT key will step through the value of all six resistors. To edit the value of any of the calibration resistor values more precisely, press the key under EDIT when the appropriate resistor is shown. A cursor will appear under the first digit. Pressing the key under CHANGE will increment this digit. When the correct number is displayed, pressing the key under NEXT will step to the next digit. Continue to adjust the numbers until the value of your calibration resistor is displayed.

As an example, assume that the 10 ohm calibration resistor measures 9.995 ohms using an ***ACCURATE*** ohmmeter. To enter this value, select EDIT for the 10.0000 ohms resistor. The cursor will appear below the first digit – under the number ‘1’. Press the key under change until this value goes to a blank position. Press the key under NEXT. The cursor will now be under the second digit – the number ‘0’. Press the CHANGE key until the number ‘9’ is in this position. Press the NEXT key and the cursor will move to the digit to the right of the decimal point. Press CHANGE until the ‘9’ appears in this position. Press the NEXT key and the cursor will move to the right under the next digit – the number ‘0’. Press the CHANGE key until the number ‘9’ is displayed. Repeat these steps until 9.995 ohms is displayed.

To save this value, press the key under OK. This value will be stored and the display will step to the next calibration resistor. When you have entered all of the values you want to change, press the NEXT key until SAVE PARAMETERS is displayed. Press the key under SAVE (n/Vs/M). Continue to the next step.

- Press the key under CAL (n/Vs/M). The instrument will display STP1: OPEN CAL on the first line with a left arrow arrow, right arrow, and OK displayed on the second line. Short the HD and HS clips together and short the LD and LS clips together. Position the two pair of clips the same distance apart as they will be when connected to the precision calibration resistors. It is recommended that the test cable not be moved during the entire calibration process. Do not allow the two sets of clips to short together. This step calibrates the LCR meter for an OPEN state. Press the key under OK (Freq). The calibration routine will calibrate the OPEN state for each of the 10 test frequencies. There will be a progress indicator bar displayed on the second line of the display. As each frequency is successfully calibrated, the instrument will step to the next frequency. If the calibration process fails at any frequency, the progress bar will stop and **!FAIL!** will be displayed on the second line. There will also be an audible alert – long tone. The calibration process will stop and the instrument will return to the starting screen for the failed step. Upon successful calibration of the OPEN state the instrument will proceed to step 2.
- The display will show STP2: SHORT CAL. Remove the short between the HD and HS clips. Remove the short between the LD and LS clips. Using a short piece of wire, short all 4 clips together with the separation between the HS and LS clips the same distance as they will be when connected across one of the precision calibration resistors. The HD and LD clips should be placed to the outside of the HS and LS clips. This step calibrates the instrument for a SHORTED state. Press the key under OK (Freq). The calibration process will again step through each of the 10 test frequencies. The process is identical to the OPEN calibration procedure above.
- Upon successful completion of the SHORT calibration, the instrument will continue to step 3.
- The instrument will display STP3: 100 ohm CAL. Pay particular attention to the value displayed here. This is 100 ohms. The 100 ohm level must be calibrated before the 10 ohm process. This is NOT an error. Remove the short from the 4 test clips. Connect the HS clip to one side of the 100 ohm resistor, close to the resistor body. Connect the LS clip to the other side, close to the resistor body. Connect the HD clip to the same lead as the HS clip and connect the LD clip to the opposite side with the LS clip. Press the key under OK to begin the calibration process. The calibration routine will calibrate the instrument at all ten test frequencies. The calibration process is the same as above. Successful completion of the 100 ohm calibration will move the routine to step 4.
- The instrument will display STP4: 10 ohm CAL. Connect the 10 ohm calibration resistor to the 4 test clips in the same manner as in the 100 ohm calibration step. Press the key under OK. The calibration routine will begin with the same process as in the previous steps.
- As each calibration step is completed, the routine will move to the next step. Step 5 requires the 1K calibration resistor, Step 6 requires the 10K calibration resistor, Step 7 requires the 100K resistor, and Step 8 requires the 1M resistor.
- Upon successful calibration of all 6 values, the instrument will then allow you to save the calibration values. The display will show STP8: SAVE. Press the key under OK. The instrument will display PASSED and change to the measurement mode.
- A failure to calibrate at any level, other than OPEN and SHORT, may require that the default resistor values be modified. The calibration routine compares the value entered against the measured value of the calibration resistor. If the measured value falls outside the program tolerance, the calibration will fail. In this case, adjust the value of the resistor that has failed in the PARAMETER setup as outlined above.
- Turn the LCR meter OFF and then ON. If the instrument failed any of the calibration steps above, the instrument will indicate this failure and the point of failure at power up. Successful calibration will place the instrument into measurement mode.

Accuracy:

- Basic accuracy is 0.2% for frequencies up to 1KHz with impedances between 15Ω to 600KΩ (range 2 to 5).

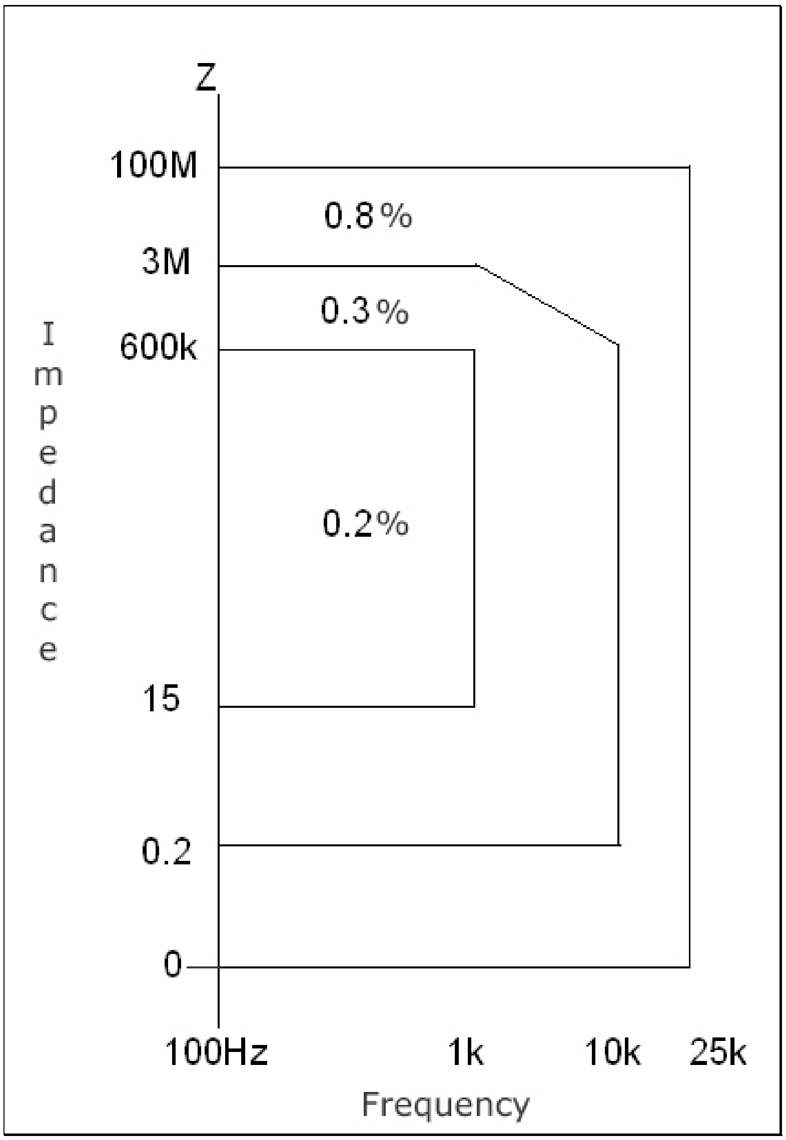
- Accuracy for frequencies between 1KHz and 10 KHz and a second area between 100Hz and 10 KHz and between 0.3Ω and 3 MΩ is 0.3%

- Accuracy for range 1 and 6 is lower because there are two resistors for the X10 amplifiers that introduce additional drift (0.1% additional).

- Accuracy is 0.8% for impedances between 0 and 0.3Ω, for frequencies above 10 KHz, and for impedances above 3 MΩ.

  Accuracy specifications are valid when the open/short calibration is performed and with appropriate Kelvin clips.

See chart below for graphical analysis of accuracy.

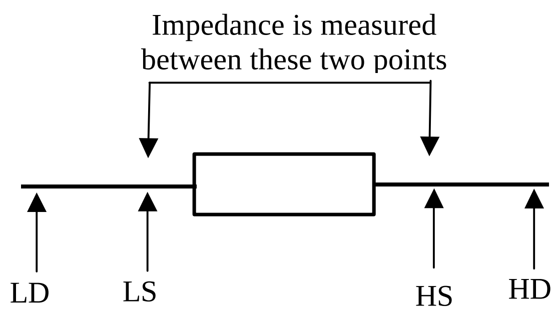


Operation

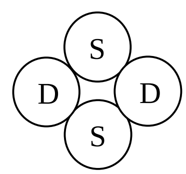
Connecting to the Device Under Test (DUT):

The M3 Digital LCR meter uses a 4-terminal configuration to connect to the DUT. This allows the LCR meter to apply current to the DUT with one pair of terminals (High Drive and Low Drive) and to measure the voltage across the DUT with the other pair (High Sense and Low Sense). This configuration increases accuracy for lower impedance measurements. For all measurements, except transformer measurements and special configurations, the two RED clips (HD/HS terminals) will be connected to one lead of the DUT and the two BLACK clips (LS/LD terminals) will connect to the other lead.

NOTE: For low impedance measurement, a cable with four independant leads may be used. If possible, twist the two current leads (HD/LD) and the two voltage leads (HS/LS) separately. The sense signals determine the points where the impedance is measured.

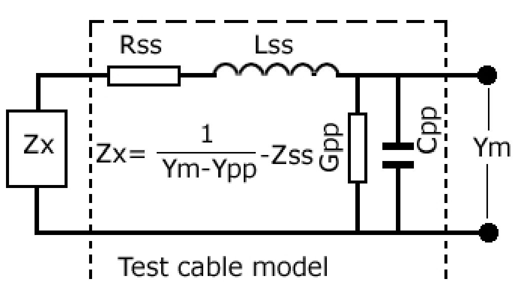


When measuring high impedances (i.e. low capacitance), use cables that are shielded all the way to the test clips. This will minimize stray capacitance between the high and low test leads. Using the provided 4-terminal test leads (shielded coax) is recommended. If a different test cable is used, it should be constructed from coaxial cables. Twist the coax cables and make sure the cables are arranged as shown in the cross-sectional view to the right. This will minimize errors when performing high impedance measurement. The shorter the cables, the less the error.



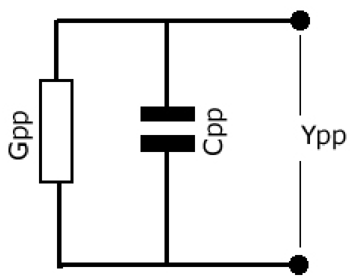
Open/Short Compensation:

Before making any measurements the LCR meter must be zeroed each time it is turned on. Zeroing must also be performed each time the test fixture is changed. This open/short compensation, when properly performed, is important in subtracting out effects of residual impedance and stray admittance caused by test cables. Open/Short compensation is one of the most important steps to insure accuracy in measurement. Through this process each residual parameter value can be measured and the value of a component under test automatically corrected. The model of the measurement circuit is given in the figures below.

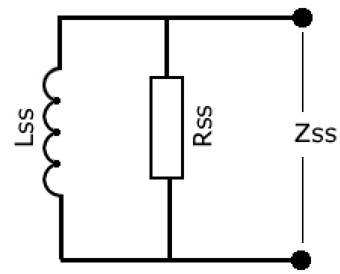


NORMAL MEASUREMENT MODE

- Ym = Virtual admittance
- Zx = Measured impedance
- Zss = Residual impedance
- Rss = Residual resistance
- Lss = Residual inductance
- Ypp = Stray admittance
- Gpp = Stray conductance
- Cpp = Stray capacitance



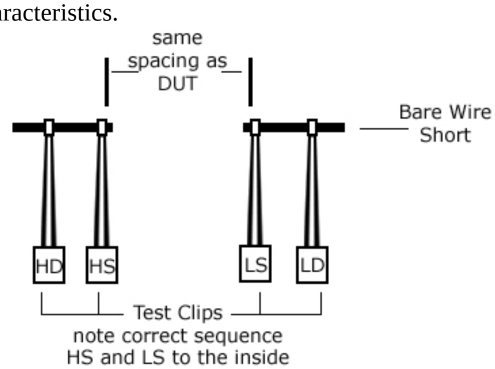
OPEN zero mode



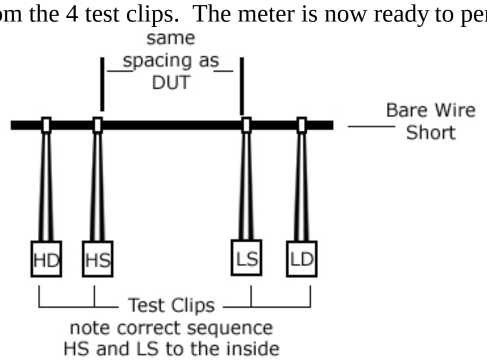
SHORT zero model

One of the most important things to remember is to make a concerted effort to achieve consistency in measurement techniques and fixturing. Of equal importance, when performing open/short compensation, is the test clips must be positioned exactly as the device under test expects to see them. In other words, position the clips the same distance apart as they will be when connected to the DUT.

There are two methods of zeroing the meter. The first method is to zero at the selected test frequency. To perform this function, the HD and HS clips must be shorted together and the LD and LS clips must be shorted together. Position the two sets of clips as shown below. Press the Zero/Range key. The second line of the LCD will show 'Open Short Exit'. Press the key under 'Open' (LCRZ). The instrument will measure stray admittance (parallel resistance and capacitance) and use these values to zero the meter at the selected frequency. The correctable range is 10 k minimum for the absolute impedance. An error message will be displayed if the impedance doesn't fit these characteristics.



Short all 4 test clips together, spacing the HS and LS clips the same distance apart as the leads on the DUT. The HD and LD clips should be placed to the outside of the HS and LS clips. Press the Zero/Range key and the LCD will again display 'Open Short Exit' on the second line. Press the key under 'Short' and the instrument will measure the residual impedance and zero the meter for 0 ohms resistance at the selected frequency. The correctable range is 50 Ω maximum for the absolute impedance and 20 Ω for the resistance. An error message will be displayed if the impedance doesn't fit into these characteristics. One possible cause for an error is poor contact between the test clips and the DUT. Try to clean the clips and the leads and perform another zero correction. Remove the short from the 4 test clips. The meter is now ready to perform measurements.



The second method will zero the meter at all ten test frequencies at one time. Use this option when measuring several different type components at different frequencies. To perform this function, connect the clips leads as above for performing an OPEN zeroing. Press and hold the Zero/Range key for two seconds or longer. The LCD will display 'OPEN SHORT Exit'. Notice that the Open and Short options are capitalized. Press the key under 'OPEN' and the instrument will zero the meter at each of the 10 frequencies. Connect the clips as above for a SHORT. Press and hold the Zero/Range key for two or more seconds. The LCD will again display 'OPEN SHORT Exit' with the functions in capital letters. Press the key under 'SHORT' and the instrument will zero at each of the 10 test frequencies.

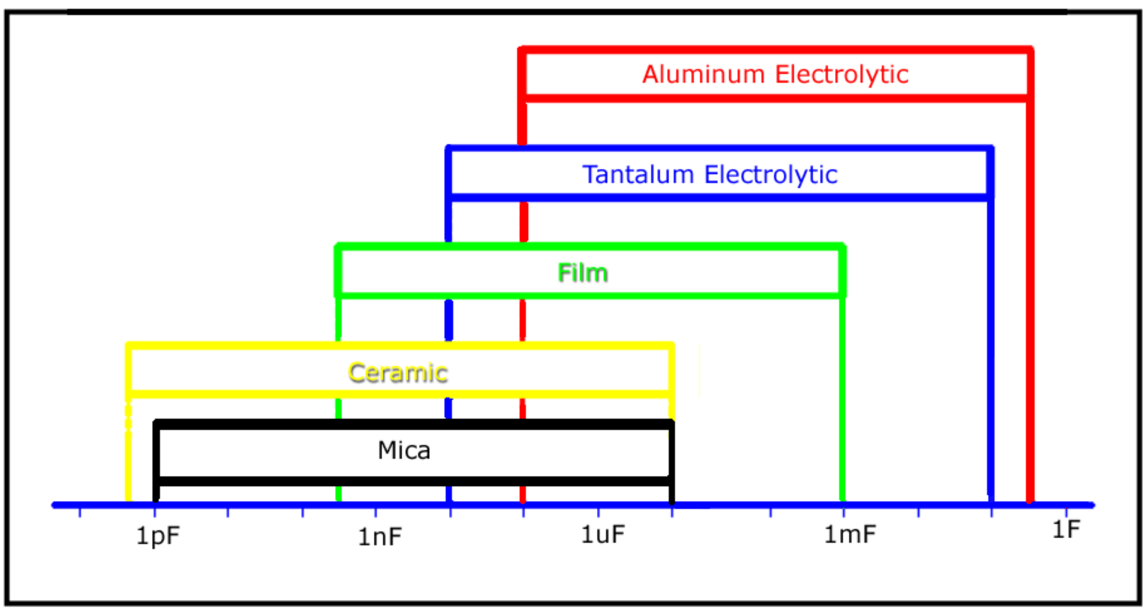
Measurement :

The M^3 Digital LCR meter defaults to Auto-detect, Auto-model operation at power up with a test frequency of 1kHz. When a capacitor, inductor, or resistor is properly connected to the test clips, the device will be recognized automatically, within limitations as defined below. To measure a device, connect the HD and HS clips to one lead of the DUT and connect the LD and LS clips to the other device lead. **Do not hold the clip leads while the DUT is being measured**. The LCR meter will automatically select the correct Range for the detected device as well as the most appropriate Model (series or parallel). Pressing the L/C/R/Z key will manually step through the measured major and minor parameters for the DUT. Pressing the Model key will manually switch between Series and Parallel equivalent circuits. To return to the Auto detection mode, press the L/C/R/Z key for two seconds or more. To return to the Auto-Model mode, press and hold the Model key for two seconds or longer.

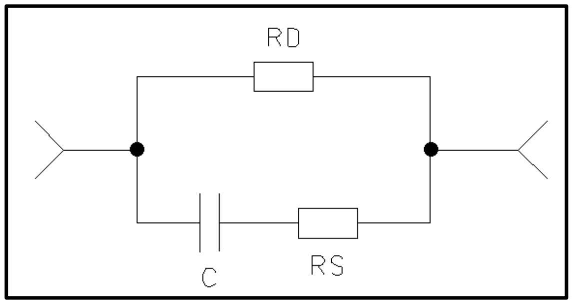
Temperature can have a large impact on the DUT impedance. Usually, capacitors have large temperature coefficients except for ceramic COG capacitors, which can exhibit only a 0.003%/°C variation. Inductors, especially those with non-air cores, may vary largely with temperature. Ambient and DUT temperature drifts may introduce error into the measurement. Control ambient temperature changes to reduce errors.

Capacitors :

Capacitors are measured in Farads. The basic construction of a capacitor is a dielectric material between two electrodes. The many different types of capacitors available are classed according to their dielectric types. The figure below shows the range of generic capacitance values for standard types.



A capacitor can be modeled as a pure capacitor C with some parasitic elements, see the figure below.
RS is the actual series resistance, comprised of the lead resistance and the foil resistance. RS is generally very low (a few mΩ). RD symbolizes the dielectric loss. Its value changes with frequency.



Capacitance C, dissipation factor D, and equivalent series resistance ESR (Rs under the major parameters) are the parameters usually measured. Capacitance is the measure of the quantity of electrical charge that can be held (stored) between the two electrodes. Dissipation factor, also known as loss tangent, indicates capacitor quality. Like most everything else about capacitors, it changes with time, frequency, and temperature. ESR is a single resistive value of a capacitor representing all real losses. It includes effects of the capacitor's dielectric loss. ESR is related to D (dissipation) by the formula ESR =D/ωC where ω =2πF.

- Model

Measuring a capacitor in series or parallel mode can provide different results. The difference can depend on the quality of the device, but primarily the capacitor's measured value most closely represents its effective value when the more suitable equivalent circuit, series or parallel, is used. To determine which model is best, consider the impedance magnitudes of the capacitive reactance and Rs and Rp. Remember that reactance is inversely proportional to C, so a small capacitor yields a large reactance. This implies that the effect of parallel resistance (Rp) has a more significant effect than that of Rs. Since Rs has little significance in this case, the parallel circuit model should be used to more closely represent the effective value. The opposite is true when C has a large value. In this case the Series Resistance (Rs) is more significant than Rp, thus the series circuit model becomes appropriate. Mid range values of C require a more precise reactance-to-resistance comparison but the logic remains the same. The rule of thumb for selecting the most appropriate model should be based on the impedance (|Z|) of the capacitor:
Above approximately 10 KΩ - use parallel model
Below approximately 10Ω - use series model
Between these values - follow the manufacturers’ recommendation

- **Frequency**:

Generally high value capacitors should be measured at lower test frequencies because the impedance of the component will be very low. Low value capacitors should be measured at higher frequencies.

Electrolytic Capacitors:

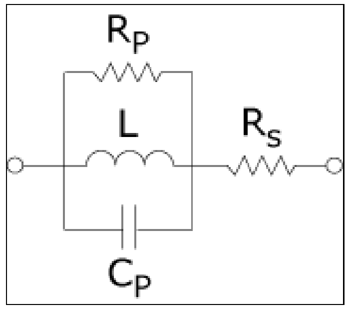
The accurate measurement of electrolytic capacitors, particularly large value caps, can present unique requirements. The M^3 LCR meter applies an AC signal to the DUT. To test some polarized components, such as electrolytic and tantalum capacitors, it may be preferable to use only positive voltages. During normal operation, the AC current source swings negative 50% of the time, which results in an inverse polarization of the capacitor under test. To prevent this inverse polarization, a DC bias can be applied to prevent the voltage across the part from becoming negative. The schematic for a simple test fixture to apply DC bias is provided at Appendix 1.

Inductors :

Inductors are measured in Henries. An inductor is a device for storing energy in a magnetic field (which is the opposite of a capacitor that is a device for storing energy in an electric field). An inductor consists of wire wound around a core material. Air is the simplest core material for inductors because it is constant, but for physical efficiency, magnetic materials such as iron and ferrites are commonly used. The core material of the inductor, its length, and number of turns directly affect the inductor’s value.

- Model and frequency

An inductor can be graphically represented as in the figure below:



The series resistance, Rs, represents the resistive losses in the windings. The parallel capacitance, Cp, is the equivalent capacitive effect between the turns of the coil, and the parallel resistance, Rp, is the sum of all losses in the core. Open flux inductors are more sensitive to metallic materials that are in close proximity, because such materials modify the magnetic field. Toroidal inductors keep the flux inside the core and are less sensitive to external conductors in close proximity.

Inductor measurements can be made in either the series or parallel model. Where the inductance is large, the reactance at a given frequency is relatively large so the parallel resistance becomes more significant than any series resistance, therefore the parallel model should be used. For very large inductance values a lower measurement frequency will yield better accuracy.

For low value inductors, the reactance becomes relatively low, so the series resistance is more significant and the series model is the appropriate choice. For very small inductance values a higher measurement frequency will yield better accuracy.

All inductors have a maximum allowable current. Above this value the core saturates, the magnetic field remains constant, and the inductance decreases to near zero. The maximum current is dependent on the core material. A core material with high permeability gives a higher inductance for the same number of turns as a core of low permeability. The drawback is that the core saturates at a much lower current.

Note: Inductors with a Q less than 1 will not be automatically detected. The LCR meter will default to the Rs mode. Increasing the test frequency to where the inductor Q is greater than 1 will then switch the major parameter to L. If, at the highest test frequency, the Q does not raise above 1, manually selecting the L mode will give the value of the inductor.

Resistors:

The unit of measurement for resistance is the Ohm. Of the three basic circuit components, resistors cause the fewest measurement problems. This is true because it is practical to measure resistors by applying a dc signal or relatively low ac frequencies. Resistors are usually measured at dc or low frequency ac where Ohm's Law gives the true value under the assumption that loss factors are accounted for.

- Model

For low values of resistors (below 1kΩ) the choice usually becomes a low frequency measurement in a series equivalent mode. Series because the reactive component most likely to be present in a low value resistor is series inductance, which has no effect on the measurement of series R. For high values of resistors (greater than several MΩ) the choice usually becomes a low frequency measurement in a parallel equivalent mode. Parallel because the reactive component most likely to be present in a high value resistor is shunt capacitance, which has no effect on the measurement of parallel R.

Dissipation Factor (D) or Quality Factor (Q):

D and Q are useful as measures of the "purity" of a component, that is, how close it is to being ideal or containing only resistance or reactance. D, the dissipation factor, is the ratio of the real part of impedance, or resistance , to the imaginary part (reactance). D is commonly used when describing capacitors of all types. A low D indicates a nearly pure capacitor. Q, the quality factor, is the reciprocal of this ratio. For inductors, a high Q indicates a more reactively pure component. The importance of D or Q is the fact that they represent the ratio of resistance to reactance or vice versa. In order to achieve reliable measurement results a short zeroing must be performed before any ESR or D measurement.

Range Auto/Hold:

In order to measure both low and high impedance values, several measurement ranges are provided in the M^3 LCR meter. Ranging is usually done automatically and selected depending on the impedance of the DUT. **Note that these ranges are impedance ranges, not inductance or capacitance ranges. Range depends of the component value and the test frequency.** Allowing the LCR meter to automatically select the correct range helps maintain the maximum signal level and highest signal-to-noise ratio for best measurement accuracy. The process keeps the measured impedance close to full scale for any given range, again, for best accuracy. Range holding, rather than auto-ranging, is a feature most applicable for repetitive testing of similar value components. Range holding can reduce test time. Another use of Range Hold would be when measuring components whose value falls within the overlap area of two adjacent ranges.

Impedance Ranges:
Range 1: 0.001Ω to 15Ω (*)
Range 2: 15Ω to 300Ω
Range 3: 300Ω to 3 kΩ
Range 4: 3 kΩ to 30 kΩ
Range 5: 30 kΩ to 600 kΩ
Range 6: 600 kΩ to 99.9 MΩ (*)

(*) ***ranges 1 and 6 are extended ranges respectively, using the reference resistor of range 2 and 6. Extended ranges use voltage amplification (range 1) or current amplification (range 6).***

Transformer Measurements:

The M^3 LCR meter has a special function to determine the turns ratio between the primary and secondary windings of a transformer, calculate the secondary voltage for a power transformer, and measure the mutual inductance between the primary and secondary winding.

The use of this option requires the 4-wire cable provided with the LCR meter. To enter this mode, press the n/Vs/M key. Connect the HD and LD clips to the winding having the greater number of turns and the HS and LS clips to the smaller winding. For a low voltage transformer (i.e., 115VAC primary and 24VAC secondary), the primary will be the larger winding and for a high voltage transformer (i.e., 115VAC primary and 800VAC secondary), the secondary winding will be the larger. See figure 1-3, page 20 for typical connection.

Incorrectly connecting the test clips to the transformer will result in an **OVERFLOW** condition being displayed on the LCD.

```
N      5.85      1H
θ     -0.23    1.0k
```

The first option (n) will provide the turns ratio between the two windings for a low voltage transformer on the first line of the display. The range will default to 1. The phase angle and test frequency will be displayed on the second line.

```
N-1    0.71      1H
θ     -0.23    1.0k
```

Pressing the n/Vs/M key a second time will select the inverse function $\mathbf{N^{-1}}$. Use this function to properly display the turns ratio for a high voltage transformer.

There are two ranges available for measurement. The default setting is Range1. If the turns ratio is very high, the display may not be stable at Range 1. Press the Auto/Hold key to step the meter to Range 2. Stepping to Range 2 may cause the meter to go in to an **OVERFLOW** condition. In this case, pressing the Auto/Hold key will return the meter to Range 1.

The second special transformer measurement function is the ability to calculate the secondary winding voltage of a power transformer. With either a low voltage or high voltage transformer correctly connected as above, press the n/Vs/M key until the Vs and Vp parameters are displayed.

```
Vs   39.33 V    1H
Vp   230 V     1.0k
```

The default primary voltage is 230V. To change the primary voltage to 115V, press the Menu key.

```
Vs   39.33 V    1H
115   [230]   EXIT
```

The bottom line of the display will present the primary voltage options. Press the key under **115** to select this as the primary voltage. The brackets will move to **[115]**. Press the key under **EXIT** to display the correct secondary voltage.

```
Vs   19.67 V    1H
Vp   115 V     1.0k
```

The display now reflects the calculated secondary voltage based on the turns ratio with the designated primary voltage.
The third transformer measurement option is the calculation of the Mutual Inductance between the primary and secondary windings. With the transformer connected as above, press the n/Vs/M key until the Mutual Inductance value is displayed on the display.

```
M      720.9 mH    2H
                  1.0k
```

To calculate the Mutual Inductance the meter measures the primary winding inductance as normal inductance, but the voltage measured is the secondary winding voltage. This automatic measurement can introduce some errors due to parasitic capacitance between the windings. You can compare the result given in this mode to the result given by the method of measuring the opposing and aiding inductance and calculating for M. $M = (L_{aiding} - L_{opposing})/4$

Sorting:

The M^3 Digital LCR meter offers the option of measuring like-valued components compared against a fixed value. The meter will display the difference of each measured component, from the fixed value, as a percentage. The fixed value and tolerance value are user programmable.

To access the Sorting function, press the Menu key. For other Menu functions, refer to the MENU KEY description on page 6.

```
Backlight      ON
  <-    ->     [OFF]
```

Press the key under the right arrow **(n/Vs/M)** until the Sorting Option is displayed.

```
Sorting   OFF
  <-     ->    [ON]
```

Press the key under **[ON]**. Sorting will be activated. Press the key under the right arrow.

```
Tolerance:    1%
  <-     ->    Next
```

To set the percent of tolerance**,** press the key under **Next** until the desired tolerance is displayed**.** The selectable tolerances are 1%, 2%, 5%, 10%, and 20%. Press the key under the right arrow.

```
Value 1.000000 k
  <-     ->    Edit
```

Enter the base value of the component to be compared against. To do this, press the key under **Edit**.

```
1.000000 k
NEXT   CHANGE   OK
```

A cursor will be displayed under the digit to be changed. To change the value of this number, press the key under **CHANGE**. The number will increment one number each time the **CHANGE** key is pressed. To select the next digit, press the key under **NEXT**. The cursor will move under the active digit. Continue to edit the values until the desired base value is entered. The 'multiplier' at the end of the value can also be edited. The options are p (pico), n (nano), µ (micro), m (milli), blank (as displayed), K (kilo), and M (Mega). When the correct value has been entered, press the key under **OK**.

```
Value   120.0000   p
  <-     ->    Edit
```

The entered value will now appear on the top line of the display. Press the key under the right arrow.

```
Pass  Beep:   SHORT
  <-     ->    Next
```

Set the alert notification when a measured component is within the selected tolerance. Default is a SHORT beep. To change this, press the key under **Next.** The options are **SHORT,** **LONG** or **NONE**. Press the key under the right arrow.

```
Backlight:   YES
<-     ->    [NO]
```

This backlight option is for a visual indication when a component is within the specified tolerance. Do not confuse this with the Backlight option under the General Settings in the normal Menu. The default value is **YES**, which means that the LCD backlight will only light when a measured component is within the tolerances entered. To disable this function, press the key under [**NO**].

Press the Menu key.

```
Save  config?
  YES      NO
```

To save the current configuration, press the key under YES. This will save the settings that were entered and place the LCR meter in Sorting Mode. The first time that the Sorting Mode is configured and this configuration is saved, it will be necessary to turn the power to the LCR meter off and then back on. After this initial entry into memory, the Sorting mode can be activated or deactivated through the Menu options and it will not be necessary to remove power to the LCR meter.

To exit the Sorting Mode and return to normal functions, press the Menu key. Press the key under the right arrow until the Sorting Mode is selected. Press the key under [**OFF**]. Press the Menu key and select **YES** to save this configuration.

A_L Value:

The M^3 Digital LCR meter has the capability of calculating the A_L value for unknown toroid cores. A_L is defined as the inductance index of a core. To calculate the number of turns required for a given inductance the A_L value of the toroid core must be known. The formula for calculating the number of turns is $N= \sqrt{(L/A_L)}$ where N is the number of turns, L is the desired inductance (in Henries), and A_L is the A_L value as determined by the M^3 LCR meter (in Henries).

To determine the A_L value of an unknown toroid, press the Menu key and then press the key under the right arrow. Step through the menu options with the right arrow to the A_L display option.

```
AL display:   OFF
  <-     ->    [On]
```

Press the key under the [**ON**] option. The AL measurement option is now active. Press the key under the right arrow

```
Turns number:   10
  <-     ->    Edit
```

Edit the number of turns on the core by pressing the key under '**Edit**'.

```
Turns:      10
NEXT   CHANGE    OK
```

The default value of 10 will be shown the first time this option is accessed. Notice the cursor underline under the second digit. This indicates the digit to be changed. To change this value, press the key under **CHANGE** until the correct value is displayed. To change to the next digit, press the key under **NEXT**. The underline cursor will move to the next digit. Edit this number by pressing the key under **CHANGE** until the correct value is displayed. For greater accuracy, a minimum of 10 turns is recommended. When the correct number of turns has been entered, press the key under **OK**. Press the Menu key and select YES to save this configuration.

```
Ls   56.1  µH      1A
AL   561  nH     1.0k
```

Connect the toroid inductor to the LCR meter and the A_L value will be displayed on the second line of the LCD where, by the example used here, A_L = 561nH. Assume that an inductance of 100µH is needed. To determine the number of turns required (N), using the formula presented above, L=100µH or .0001H; A_L=561nH or .000000561H. N=√(.0001H/.000000561H) =√(178) =13, so 13 turns would be required on this core for an inductance of 100 µH.

To return the LCR meter to normal operation, press the Menu key, step to the AL display screen, select **[OFF]**, press the Menu key and select **YES** to save the current configuration.

THEORY OF OPERATION

The M3 DIGITAL LCR meter uses an auto-balancing bridge technique to measure unknown impedance by measuring the voltage across the device under test (DUT) and the current through it. Figure 1-1 is the basic block diagram of the M3 DIGITAL LCR meter and shows how the instrument measures unknown impedances. The output of a signal source is applied through a source resistor R_S, which varies according to the measurement range, to the unknown device *ZX* and range resistor R_R. The effect of amplifier *A1* is to cause the same current *Ir* that flows through the unknown device to flow through R_R, and, as a result, to drive the junction of the unknown device and R_R to zero volt (virtual ground). Across R_R there is a voltage $V2 = Ir \times R_R$. Voltages V1 and V2 across the unknown device and across R_R , respectively, are connected to selector switch *S*. The output of the switch is connected to a differential amplifier *A2*. Using the same differential amplifier for both the voltage and the voltage measurements ensures that the scaling factor and the offset errors cancel each other during final calculations. The real and imaginary components of the voltage and current signals are obtained by multiplying these voltages with a square wave that is coherent with the stimulus (Phase Detector). An output proportional to the in-phase, or quadrature component, of the voltage is obtained. Measurements are performed using a dual-slope A/D converter that is read by the controller. The complex ratio of voltage to current is equal to the complex impedance. The measured complex impedance is corrected by calibration factors, for both absolute value and phase. The other parameters, such as L, C, R, Q, D, are derived mathematically from the corrected impedance value, with the model and the test frequency chosen by the user.

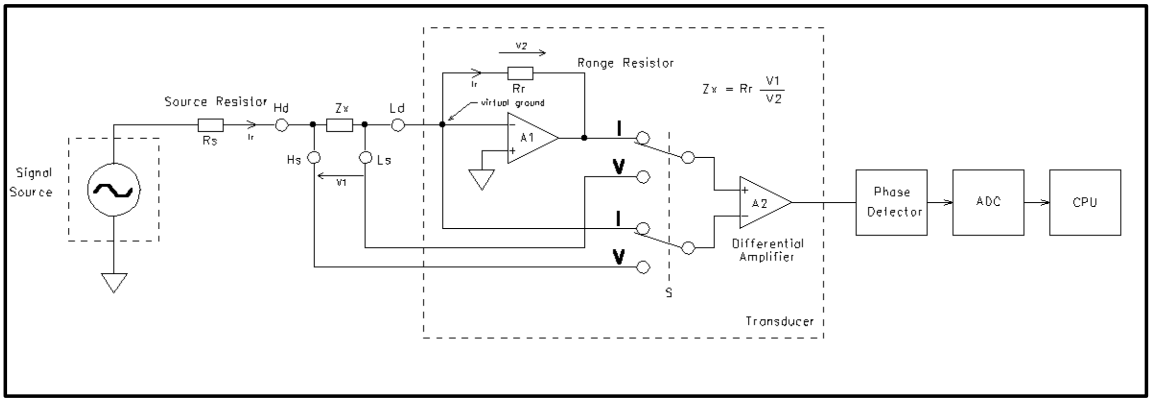


Figure 1-1. Overall Block Diagram

SIGNAL SOURCE

The signal source section generates a low distortion sine signal. The frequency can be selected from among ten choices, 100, 120, 250, 500, 1 k, 2.5 k, 5 k, 7.8 k, 12.5 k and 15.6 kHz. The signal level is 0.5V rms.
The sine signal is generated using a square wave filtered by a 5^{th} order switched capacitor elliptic filter (*LPF1*). The cut-off frequency is determined by the frequency of the filter clock signal and is set to 1.28 times the test signal frequency. The output of the filter is a (×100) over-sampled signal and a first order low-pass filter (*LPF2*) removes most unwanted harmonics. Total harmonic distortion is approximately 0.05%. The LPF2 filter is followed by a buffer and a source resistor selector.

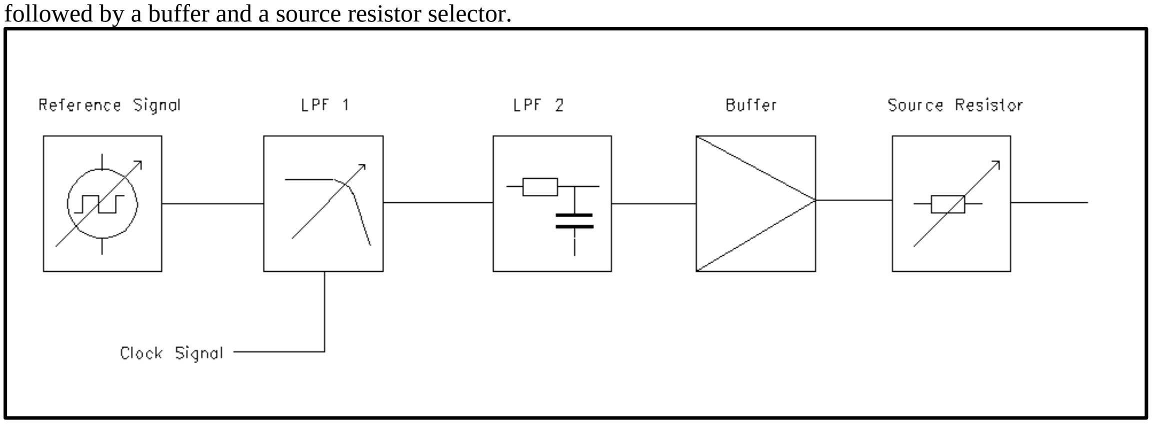


Figure 1-2. Signal Source Section Block Diagram

PHASE DETECTOR AND A/D CONVERTER

Phase and absolute value of the unknown impedance is obtained by multiplying the unknown AC voltage with a square wave that is coherent with the stimulus. The mean value of the multiplier output is proportional to the in-phase or quadrature component of the unknown voltage. A total of four such measurements, in which the phase of the square wave is advanced by 90°, resolves the unknown voltage into orthogonal components. This process is applied for both the voltage and the current. Therefore, eight measurements are needed for the final calculation. Anti-phase components are substrated (0° with 180° and 90° with 270°), consequently eliminating all common offsets and reducing noise. Each of these voltages measurements is meaningless by itself, because the reference square waves signals have no particular phase relationship to the measured analog signals, and because the current through *Zx* is not controlled.

The AC signal voltage from the phase-sensitive detector is integrated, during an integer test signal period that is near 20ms (50Hz operation) or 16.67ms (60Hz operation), together with a DC offset. This ensures that the final result is always the same sign. The value of the voltage is obtained by timing the discharge of the capacitor with a 17-bit counter inside the controller.

TRANSFORMER PARAMETER MEASUREMENT

This function measures transformer parameters through an IC switch, permitting the measurement of the High Sense voltage for the secondary side or High Drive for the primary side of the transformer. The Low Drive and Low Source terminals are connected to ground through a virtual ground. In Mutual Inductance measurement mode, the instrument measures the primary current and the secondary voltage to compute the mutual inductance.

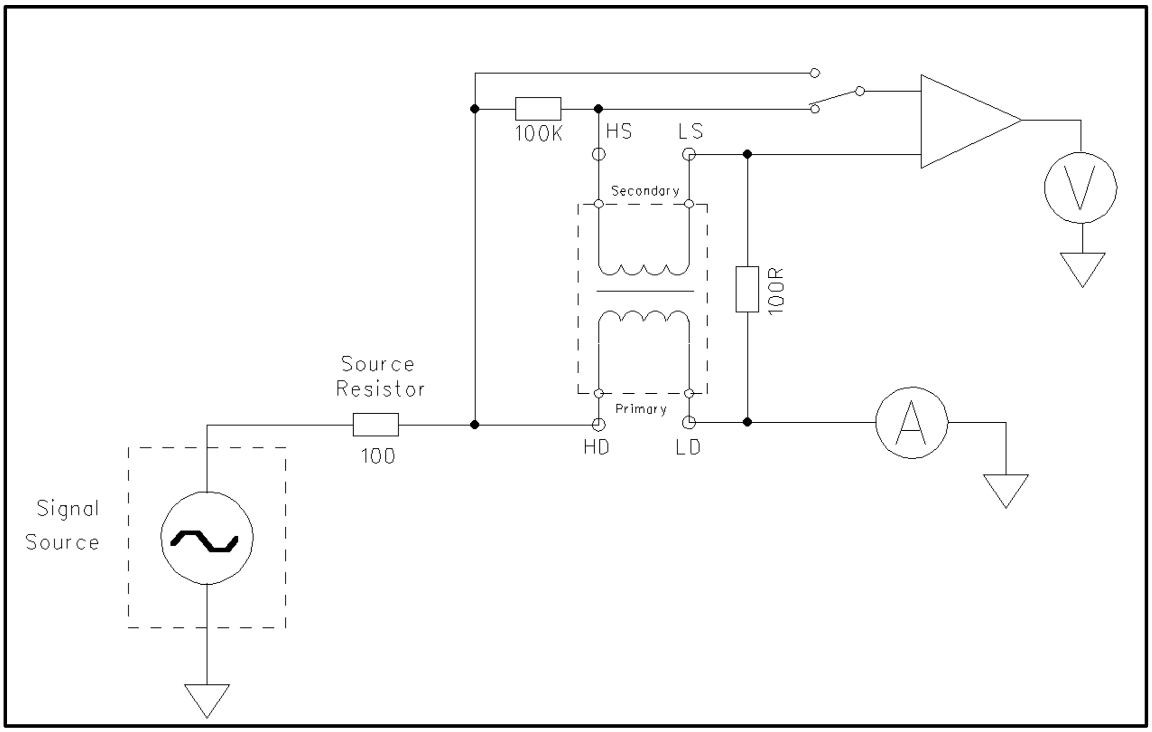


Figure 1-3. Basic Transformer Measurement Setup

DIAGNOSTICS AND CALIBRATION SCREENS

DIAGNOSTIC MODE

Pressing and holding the MODEL key during power-up permits access to one of two modes: Diagnostic mode and Calibration mode. The instrument displays the following screen:

```
DIAG   CAL   EXIT
```

Select diagnostic mode by pressing L/C/R/Z key. You can now select one of the four diagnostic modes by selecting NEXT.

```
Keyboard
NEXT   OK    EXIT
```

Press **OK** to access the keypad diagnostic mode. Press **EXIT** to return to the main menu. Press **NEXT** to access next diagnostic function.

```
Sound
NEXT   OK    EXIT
```

Press **OK** to access the buzzer test. Press **EXIT** to return to the main menu. Press **NEXT** to access next diagnostic function.

```
Complex i/v
NEXT   OK    EXIT
```

Press **OK** to access complex voltage / current measurement. Press **EXIT** to return to the main menu. Press **NEXT** to access next diagnostic function.

```
A/D results
NEXT   OK    EXIT
```

Press **OK** to access analog-digital converter results. Press **EXIT** to return to the main menu. Press **NEXT** to return to the keypad diagnostic function.

Keypad test

This test is useful to test the operations of keypad circuits. The keypad delivers a voltage that is read by the micro-controller. The result of the conversion is displayed in the top right of the screen. An 'X' is also displayed according to key pressed. The 'X' remains in the display after the key is released. You can exit this mode **only** when all 8 keys have been pressed.

```
                0
      Press a key
```

This is the first screen when entering the keypad diagnostic mode.

```
X            1023
      Press a key
```

This screen is displayed when the L/C/R/Z key is pressed.

```
XX            825
      Press a key
```

This screen is displayed when the n/Vs/M key is pressed.

Compare the results with the table below. Alternatively, measure the voltage across R70 resistor on the keypad assembly. Actual values can differ by a small percent due to resistors tolerances.

KEY	Voltage (R70) (V)	Displayed value
LCRZ	3.30	1023
N/Vs/M	2.65	823
FREQ	2.15	667
AUTO/HOLD	1.73	538
ZERO/RANGE	1.37	426
DISP.	1.23	323
MENU	0.717	220
MODEL	0.379	117

Buzzer test

This test is used to test the operation of the audible alert feature.

```
Buzzer test
 ON    OFF   EXIT
```

Press **ON** to activate the buzzer test. Press **OFF** to terminate the buzzer test. Press **EXIT** to return to the main menu.

Complex i/v

This diagnostic mode gives access to the in-phase and quadrature measurements that are used to compute the final value. The instrument determines two complex vectors, one for the current and one for the voltage. Each vector has an in-phase (real) component and a quadrature (imaginary) component. The coordinates of these vectors are relative to the reference range resistors. These values must be multiplied by the current range resistor value to get the actual vectors.

In this mode the range and the frequency can be changed. The LCRZ key permits toggling between the Voltage coordinates and the Current coordinates. The screens below show the results when a 1µF capacitor is connected to the instrument at 1kHz frequency. The theoretical absolute value of the capacitor impedance is 159Ω at 1kHz. We will select the range 2 to get optimum signal/noise ratio.

```
Vi  0.557780    2
Vq -0.34690  1.0k
```

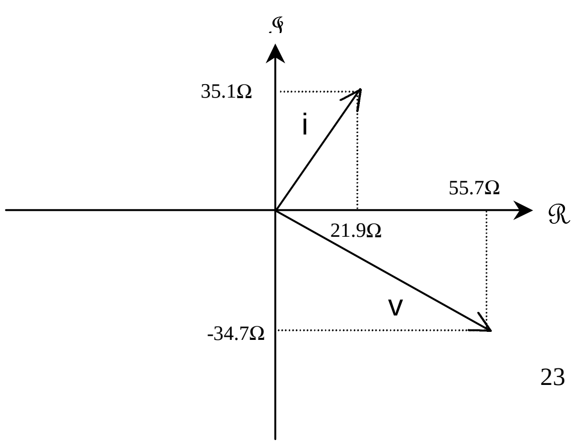
Range resistor is 100Ω typical for range 2. The coordinates of the Voltage vector are 55.7Ω for the real part and -34.7Ω for the imaginary part.

Press L/C/RZ key to get the Current vector coordinates

```
Ii  0.218630    2
Iq  0.350920 1.0k
```

The coordinates of the Current vector are 21.9Ω for the real part and 35.1Ω for the imaginary part.

We can now draw a complex graphic to show the final result.



It is possible to calculate the absolute impedance of the capacitor:
$|Z| = 100 \times |v| / |i| = 100 \times 65.62/41.36 = 158.6\Omega$.
Note that this value is close to the theoretical value (159Ω).

A/D results

This diagnostic mode gives access to the primary measurements that are used to compute the in-phase and quadrature values. The values displayed correspond to the *phase detector output signal mean value* measured by the A/D converter. The phase detector is a +/- multiplier. The input of the multiplier is either the Voltage or the Current signal. One can switch between these two signals using the L/C/R/Z key. The +/-1 gain is driven by a square wave signal that has the same frequency as the test signal. The phase of this signal can be shifted from 0° to 270° with 90° step with the n/Vs/M key.

```
V    0.69090      2
Ph         0   1.0k
```

Press LCRZ key to select Voltage measurement, then n/Vs/M key to select 0° phase angle. Press Auto/Hold and set the Range to 2. The display shows the result of the A/D conversion.

```
V    0.79745      2
Ph        90   1.0k
```

Pressing the N/VS/M key permits the measurement of this voltage with 90°, 180° and 270° phase angle.

```
V    0.34400      2
Ph       180   1.0k
```

Subtracting anti-phase values gives the quadrature voltage value, here Vq = 0.344 – 0.6909 = -0.34690

```
V    0.23967      2
Ph       270   1.0k
```

Subtracting anti-phase values gives the in-phase voltage value, here Vi = 0.79745 – 0.23967 = 0.55778

Perform the same tests with the current measurement, by pressing the LCRZ key.

Calibration Mode:
Pressing and holding the MODEL key during power-up permits access to one of two modes: Diagnostic mode and Calibration mode. The instrument displays the following screen:

```
DIAG   CAL    EXIT
```

Select calibration mode by pressing the n/Vs/M key. The instrument now displays two setup modes – Parameters or Calibration.

```
 PARAM   CAL  EXIT
```

The **PARAM** mode allows selection of 50Hz or 60Hz operation and adjustment to set the precise values of the calibration resistors.
The **CAL** mode provides the calibration routine the LCR meter.

Select the Parameter mode by pressing the LCRZ key. The instrument now displays the following screen:

```
RCAL1  :10.0000 Ω
NEXT      EDIT EXIT
```

Calibration resistor values are 10, 100, 1K, 10K, 100K, 1M ohms. Pressing the n/Vs/M key will allow editing the precise values of the currently displayed resistor. Pressing the LCRZ key will step to the next resistor.

Stepping past the 6 calibration resistors values, the instrument will display the Mains Frequency option. **<u>This option must be set prior to adjusting any resistor values</u>**.

```
Mains Frq :60 Hz
NEXT  50Hz
```

Select the appropriate frequency for the region where the LCR meter will be used. In the United States select 60 Hz by pressing the Freq key. Select the **NEXT** option by pressing the LCRZ key.

```
Save Parameters
NEXT  SAVE  EXIT
```

This will bring up the option to **SAVE** the edited parameters by pressing the n/Vs/M key. Selecting **NEXT**, by pressing the LCRZ key, will return the display to the RCAL1 screen, and pressing the Freq key will **EXIT** the Parameters setup without saving any entered values.

Selecting **SAVE** will force the entered parameters to be stored in memory, overwriting the default parameters. Successful completion of storing the saved parameters will be verified with **PASSED** displayed on the LCD. The instrument will then display the opening Calibration screen as in the first screen of this section.

Select the Calibration Routine by pressing the n/Vs/M key. The following screen will be displayed:

```
STP1 :  OPEN CAL
  <-     ->   OK
```

Step 1 of the calibration routine calibrates the **OPEN** mode of the instrument. To start this routine, press the Freq key.

```
Opening   100Hz
```

The display will begin the calibration routine stepping through all ten test frequencies. A progress bar will be displayed on the second line of the display. Successful completion at each frequency will cause the instrument to proceed to the next frequency. Failure to calibrate at a given frequency will be indicated by **!FAIL!** being displayed on the LCD and the instrument will return to this step in the menu.

Successful completion of the OPEN calibration routine will result in the instrument stepping to Step 2: SHORT Calibration. Following successful calibration of the **SHORT** routine, the calibration will step through the six resistor values required to calibrate the LCR meter – Steps 3 through 8. When the entire calibration routine has been completed, the instrument will display the following:

```
STP8 :  SAVE
  <-     ->   OK
```

Save the calibration values into non-volatile memory by pressing the Freq key. The instrument will acknowledge the completion of this step and the instrument will be placed in to measurement mode.

Appendix 1

TEST FIXTURE FOR EXTERNAL DC BIAS
Or Battery Internal Resistance Measurement