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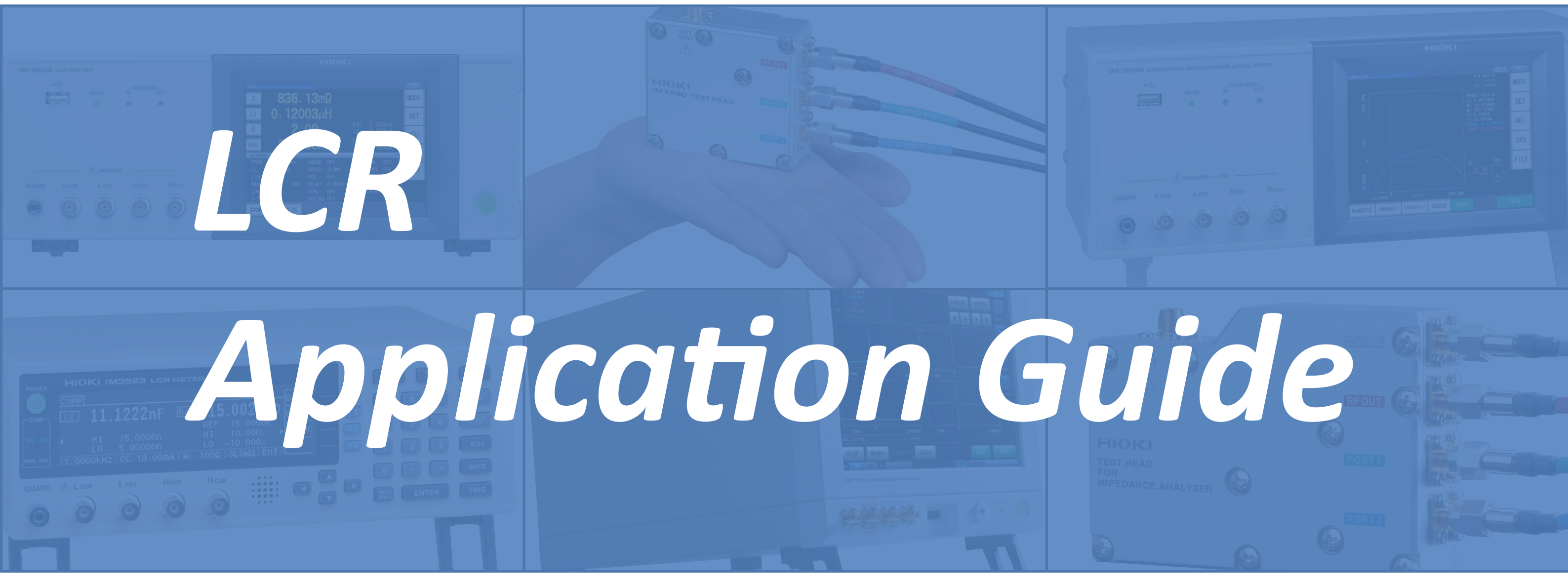


LCR Application Guide

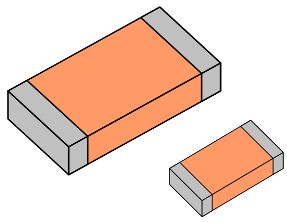
HIOKI

MLCC (Multi-Layer Ceramic Capacitors)

There are two types of MLCC: a high-dielectric-constant type whose capacitance varies with the measurement voltage and a temperature-compensated type whose capacitance does not vary. The measurement conditions used when defining capacitance are set forth by separate JIS standards for temperature-compensated and high-dielectric-constant MLCCs.

Setting example of measurement conditions

Parameters	Large capacitance:Cs-D, small capacitance:Cp-D
Frequency	See the table below
DC bias	OFF
Signal level	Rated voltage or less
Measurement range	AUTO
Speed	SLOW2
LowZ mode	OFF



*Otherwise, default settings are used.

*The above settings apply to an example measurement. Since optimal conditions vary with the measurement target, specific settings should be determined by the instrument operator.

IEC 60384-21 Fixed surface mount multilayer capacitors of ceramic dielectric(JIS C5101-21)

Class 1: Temperature compensating type (EIA type C0G, JIS type CH etc.)(IEC30384-21)

Parameters	Rated capacitance	Rated voltage	Measurement frequency	Voltage*1	DC bias *2
C,D（tanδ）	C≦1000pF	All	1MHz or 100kHz (Reference 1MHz)	5Vrms or less	–
	C＞1000pF		1kHz or 100kHz (Reference 1kHz)		

IEC 60384-22 Fixed surface mount multilayer capacitors of ceramic dielectric(JIS C5101-22)

Class 2: High dielectric constant type (EIA type X5R, X7R, JIS type B, F etc.)(IEC30384-22)

Parameters	Rated capacitance	Rated voltage	Measurement frequency	Voltage*1	DC bias *2
C,D（tanδ）	C≦100pF	All	1MHz	1.0±0.2Vrms	–
	100pF＜C ≦10μF	6.3V or more	1kHz	1.0±0.2Vrms	
		6.3V or less	1kHz	0.5±0.2Vrms	
	C＞10μF	All	100Hz or 120Hz	0.5±0.2Vrms	

*1 The measurement voltage (i.e., the voltage applied to the sample) is the voltage obtained by dividing the open-terminal voltage by the output resistance and the sample.

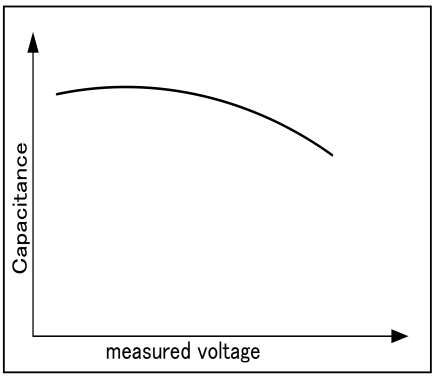
*1 The measurement voltage (i.e., the voltage applied to the sample) can be calculated based on the open-terminal voltage, the output resistance, and the sample's impedance.

*2 CV mode is convenient when measuring a sample whose impedance is unknown and when measuring multiple samples that exhibit a large degree of variability.

High-dielectric-constant capacitors

Capacitors bearing temperature characteristics such as B, X5R, and X7R use high-dielectric-constant materials.

While high-dielectric-constant capacitors can deliver high capacitance in a small package, their capacitance tends to vary greatly with the measurement voltage and temperature.



Products used

Mass Production Applications

Model	Measurement frequency	Features
3504-40	120Hz,1kHz	Ideal for large capacitance inspection High speed CV measurement
3504-50		
3504-60		
3506-10	1kHz,1MHz	Ideal for small capacitance inspection, high repeatability

Research and Development Applications

Model	Measurement frequency	Features
IM3570	DC,4Hz to 5MHz	Frequency sweep with analyzer mode

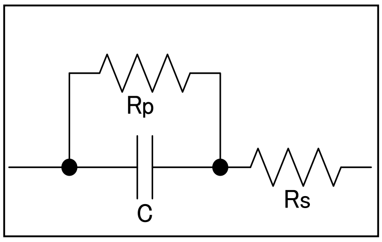
*For more information, plese see the product catalog.

Selecting Parameter, Cs or Cp

Impedance according to frequency (when D is sufficiently small)

	100Hz	120Hz	1kHz	100kHz	1MHz
1pF				1.6MegΩ	160kΩ
10pF				160kΩ	16kΩ
100pF				16kΩ	1.6kΩ
1nF			160kΩ	1.6kΩ	160Ω
10nF			16kΩ	160Ω	16Ω
100nF			1.6kΩ	16Ω	1.6Ω
1uF			160Ω	1.6Ω	160mΩ
10uF			16Ω	160mΩ	16mΩ
100uF	16Ω	13Ω	1.6Ω	16mΩ	1.6mΩ

Choose CP
Depends on the case
Choose Cs



Equivalent cuircuit of capacitors

Large capacitance capacitors: Rp can be ignored since impedance of C is low. Select series equivalent circuit modes.

Small capacitance capacitors: Rs can be ignored since impedance of C is high. Select series equivalent circuit modes.

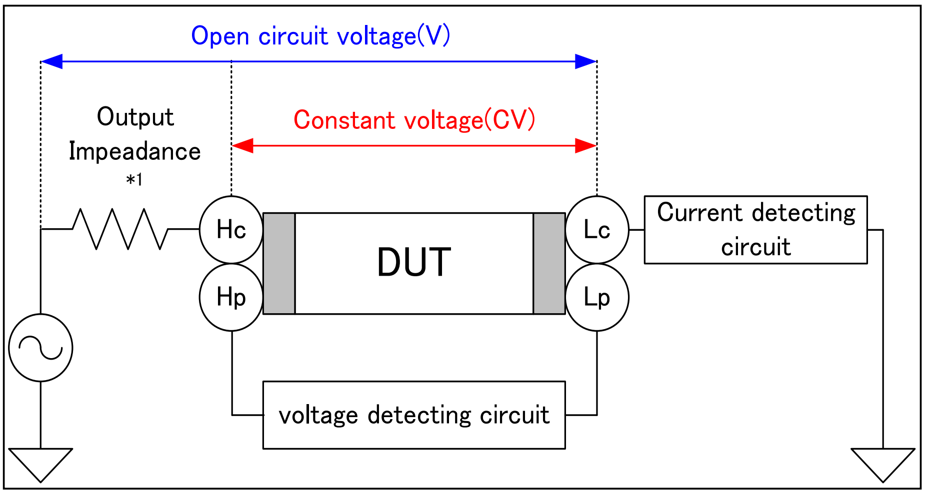
Generally speaking, series equivalent circuit mode is used when measuring low-impedance elements (approximately 100Ω or less) such as high-capacity capacitors, and parallel equivalent circuit mode is used when measuring high-impedance elements (approximately 10 kΩ or greater) such as low-capacity capacitors.

An actual capacitor will behave as though Rs and Rp have been connected in series and in parallel, respectively, with the ideal capacitor C, as in the figure. Rp is usually extremely large (megaohm-order or greater), and Rs is extremely small (several ohms or less). An ideal capacitor's reactance can be calculated using the following equation based on its capacitance and frequency: $Xc = 1/j\,2\pi f\,C[\Omega]$. When Xc is small, the impedance when Rp is placed in parallel can be considered to be approximately equal to Xc. On the other hand, because Rs cannot be ignored when Xc is small, the overall setup can be treated as a series equivalent circuit with Xc and Rs. By contrast, when Xc is large, Rp cannot be ignored but Rs can, so the setup can be treated as a parallel equivalent circuit.

Open-Circuit Voltage Mode (V) and Constant Voltage Mode (CV)

The no-load voltage is the voltage at the Hc terminal when no sample is connected. The voltage applied to the sample is the result of dividing the no-load voltage by the output resistance and the sample.

In constant-voltage (CV) mode, the operator sets the voltage across the sample. The IM35xx reads the voltage monitor value and generates a CV by applying feedback in software. Since the 3504-xx generates a CV in hardware (using an analog circuit), that instrument is capable of constant-voltage measurement at high speeds. Although the 3506-10 offers only no-load voltage (V) mode, it has lower impedance than other models for samples for which the open-terminal voltage is approximately equal to the measurement voltage due to its low output resistance (1Ω for 2.2 mF and greater ranges at 1 kHz and 20Ω for other conditions).



Current flowing to DUT

*1 The output impedance varies depending on the model and on whether low-impedance high-precision mode has been enabled. Please refer to the product specifications in the instruction manual.

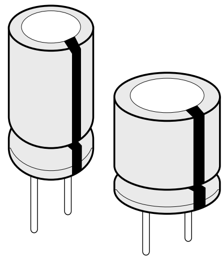
Electrolytic capacitors

The measurement conditions used to define an electrolytic capacitor's capacitance are set forth in IEC standards, and the nominal values cited by capacitor manufacturers are measured values obtained in accordance with those standards. However, because the capacitance values of electrolytic capacitors vary greatly with the measurement frequency, capacitance values should be checked at the frequency at which the circuit in question will actually be used.

Measure the equivalent series resistance (ESR), which includes factors such as the resistance of the electrolytic capacitor's internal electrodes and the electrolyte resistance, and the tangent D (tanδ) of the loss angle under the same conditions as the capacitance.

Setting example of measurement conditions

Parameters	Cs-D-Rs
Frequency	120Hz, frequency at which circuit will actually be used
DC bias	ON　1.0V
Signal level	0.5Vrms
Measurement range	AUTO
Speed	SLOW2
LowZ mode	ON



*Otherwise, default settings are used.

*The above settings apply to an example measurement. Since optimal conditions vary with the measurement target, specific settings should be determined by the instrument operator.

Fixed capacitors for use in electronic equipment Part 4: Sectional specification （IEC 60384-1）
Aluminium electrolytic capacitors with solid (MnO2) and non-solid electrolyte(JIS C5101-4)

Parameters	Rated capacitance	Rated voltage	Measurement frequency	Measurement voltage*1	DC bias *2
C,D （tanδ） Rs(ESR)	All	All	100Hz or 120Hz	0.5Vrms	0.7 to 1.0V

*1 The measurement voltage (i.e., the voltage applied to the sample) is the voltage obtained by dividing the open-terminal voltage by the output resistance and the sample.

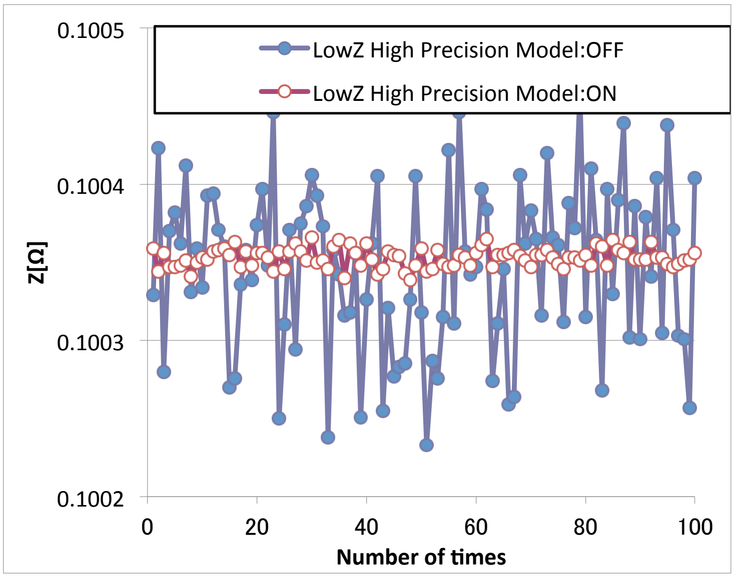
*1 The measurement voltage (i.e., the voltage applied to the sample) can be calculated based on the open-terminal voltage, the output resistance, and the sample's impedance.

*2 DC bias need not be applied.

Low impedance high accuracy mode

In low impedance high accuracy mode, the instrument's output resistance is reduced, and the measurement current is applied repeatedly for increased measurement precision. When measuring a capacitor with a high capacitance of greater than 100μF (and therefore low impedance), low-impedance high-precision mode yields more stable measurement. The graph below compares repeatability when using the IM3570 to make measurements with low-impedance high-precision mode enabled and disabled (100kHz, 1Ω range, 1V).

*The conditions under which low-impedance high-precision mode can be enabled vary with the instrument model. Please refer to the instruction manual of the instrument you are using.



Repeated measurement of a resistance of approximately 100 mΩ with the IM3570

Products used

Mass Production Applications

Model	Measurement frequency	Features
IM3523	DC, 40Hz to 200kHz	Measurement time: 2ms, high cost performance
IM3533	DC, 1mHz to 200kHz	Internal DC bias function, touch panel

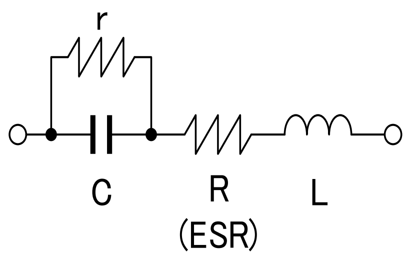
Research and Development Applications

Model	Measurement frequency	Features
IM3570 IM9000	DC, 4Hz to 5MHz	Frequency sweep with analyzer mode Optional equivalent cuircuit analysis firmware for the IM3570
IM3590	DC, 1mHz to 200kHz	Can measure ESR and ESL separately with its equivalent circuit analysis function.

*For more information, plese see the product catalog.

Equivalent series resistance (ESR) and loss coefficient D (tanδ)

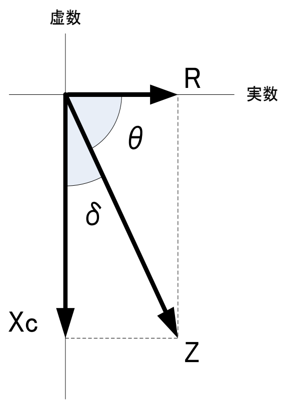
The figure below illustrates a standard equivalent circuit for an electrolytic capacitor.
At low frequencies (50 Hz to 1 kHz), the reactance (XL) resulting from the equivalent series inductance L is extremely small and can be considered to be zero. The resistance and reactance components of each element at this time are characterized by the vector relationship shown in the figure on a complex plane.
An ideal capacitor would have R = 0 and a loss coefficient D = 0, but since actual capacitors have various resistance components, including electrode foil resistance, electrolyte resistance, and contact resistance of leads and other parts, the equivalent series resistance ESR and loss coefficient D (tanδ) serve as useful indicators for use in evaluating electrolytic capacitor quality.
Since the IM3533 and IM3536 can simultaneously measure and display four parameters, they can be used to simultaneously check the reactance X, capacitance C, equivalent series resistance Rs, and loss coefficient D as indicators for use in evaluating electrolytic capacitors, as shown in the example screenshots below.



C: Capacitance
r: Equivalent series resistance of anodic oxidation coatings
R: Equivalent series resistance (ESR)
L: Equivalent series inductance

*General Description of Aluminum Electrolytic Capacitors (NICHICON CORPORATION)

Equivalent circuit of Electrolytic capacitors

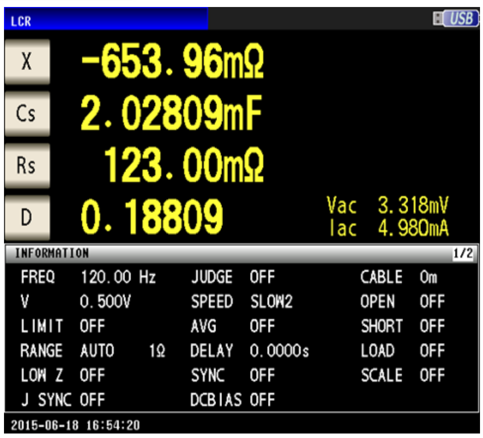


$$|Xc| = |Z|\sin\theta = \frac{1}{\omega C}$$

$$R = ESR = |Z|\cos\theta$$

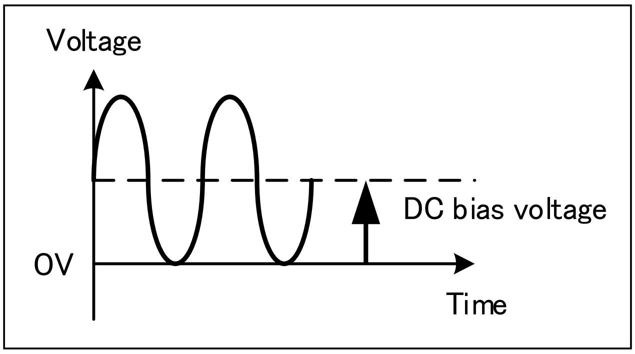
$$D = \tan\delta = \frac{\cos\theta}{|\sin\theta|} = \frac{R}{|Xc|} = \omega CR$$

Vector diagram



Display example of IM3536

DC bias measurement function



Electrolytic capacitors generally are available in polarized and bipolar variants. A DC bias voltage must be applied to polarized capacitors as necessary to prevent application of a reverse voltage.

Since the IM3533and IM3536 provide a built-in DC bias voltage function, they can apply a DC bias to capacitors, eliminating the need for an external DC power supply.

Determining Cs and Cp

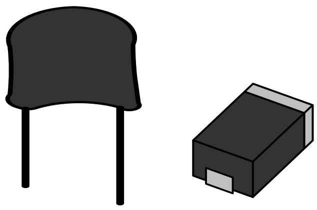
Generally speaking, series equivalent circuit mode is used when measuring low-impedance elements (approximately 100Ω or less) such as high-capacitance capacitors, and parallel equivalent circuit mode is used when measuring high-impedance elements (approximately 10 kΩ or greater) such as low-capacitance capacitors. When the appropriate equivalent circuit mode is unclear, for example when measuring a sample with an impedance from approximately 100Ω to 10 kΩ, check with the component's manufacturer.

Tantalum capacitors

Tantalum capacitors are a type of electrolytic capacitor that uses the metal tantalum for the anode. They provide higher capacitance in a smaller package than other types of capacitors, and they offer better voltage and temperature characteristics than high-capacitance ceramic capacitors.

Setting example of measurement conditions

Parameters	Cs-D (120Hz), Rs(100kHz)
Frequency	120Hz, 100kHz
DC bias	OFF
Signal level	0.5Vrms
Measurement range	AUTO
Speed	SLOW2
LowZ mode	ON



*Otherwise, default settings are used.

*The above settings apply to an example measurement. Since optimal conditions vary with the measurement target, specific settings should be determined by the instrument operator.

Surface mount fixed tantalum electrolytic capacitors with manganese dioxide solid electrolyte (IEC 60384-3) (JIS C5101-3)

Parameters	Rated capacitance	Rated voltage	Measurement frequency	Measurement voltage*1	DC bias *2
C,D(tanδ)	All	All	100Hz or 120Hz	0.5Vrms or less	0.7V to 1.0V
Rs(ESR), Z	All	All	100kHz	0.5Vrms or less	0.7V to 1.0V

Fixed tantalum capacitors with non-solid electrolyte and foil electrode(IEC 60384-15)(JIS C5101-15)

Parameters	Rated voltage Rated capacitance	Measurement frequency	Measurement voltage*1	DC bias *2
C,D(tanδ)	All	100Hz or 120Hz	0.1Vp to 1.0Vp	2.1V to 2.5V *3
Rs(ESR) Z	All	Choose the frequency that yields the lowest impedance value from the following: 100 Hz, 120 Hz, 1 kHz, 10 kHz, 100 kHz, 1 MHz.	0.1Vp to 1.0Vp	2.1V to 2.5V *4

Surface mount fixed tantalum electrolytic capacitors with conductive polymer solid electrolyte(IEC 60384-24) (JIS C5101-24)

Parameters	Rated capacitance	Rated voltage	Measurement frequency	Measurement voltage*1	DC bias *2
C,D(tanδ)	All	2.5V or less	100Hz or 120Hz	0.5Vrms or less	1.1V to 1.5V
		2.5V or greater			1.5V to 2.0V
Rs(ESR),Z	All	All	100kHz	0.5Vrms or less	OFF

*1 The measurement voltage (i.e., the voltage applied to the sample) is the voltage obtained by dividing the open-terminal voltage by the output resistance and the sample.

*1 The measurement voltage (i.e., the voltage applied to the sample) can be calculated based on the open-terminal voltage, the output resistance, and the sample’s impedance.

*2 DC bias need not be applied.

*3 DC bias need not be applied to bipolar capacitors.

*4 Apply only when using a measurement voltage of 0.5 Vp or greater.

Determining Cs and Cp

Generally speaking, series equivalent circuit mode is used when measuring low-impedance elements (approximately 100Ω or less) such as high-capacitance capacitors, and parallel equivalent circuit mode is used when measuring high-impedance elements (approximately 10 kΩ or greater) such as low-capacitance capacitors. When the appropriate equivalent circuit mode is unclear, for example when measuring a sample with an impedance from approximately 100Ω to 10 kΩ, check with the component’s manufacturer.

Products used

Mass Production Applications

Model	Measurement frequency	Features
IM3523	DC, 40Hz to 200kHz	Measurement time: 2ms, high cost performance
IM3533	DC, 1mHz to 200kHz	Internal DC bias function, touch panel

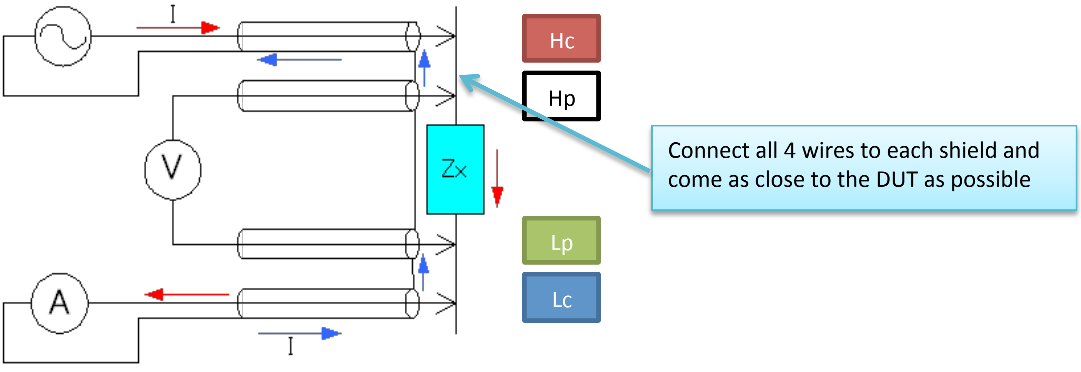
Research and Development Applications

Model	Measurement frequency	Features
IM3570 IM9000	DC, 4Hz to 5MHz	Frequency sweep with analyzer mode
		Optional equivalent cuircuit analysis firmware for the IM3570
IM3590	DC, 1mHz to 200kHz	Can measure ESR and ESL separately with its equivalent circuit analysis function.

*For more information, plese see the product catalog.

Four terminal method

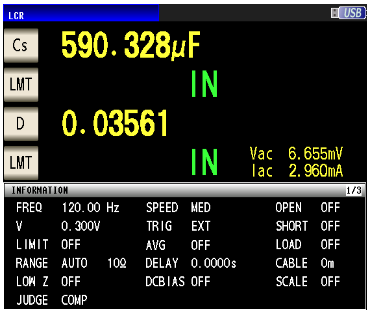
When shielding is connected close to the sample Zx, the measurement current I will return via the shielding. Because the magnetic flux generated by the current returning through the shielding negates the magnetic flux generated by the measurement current I, this technique is especially useful as a way to reduce measurement error during low-impedance measurement (IM35xx).

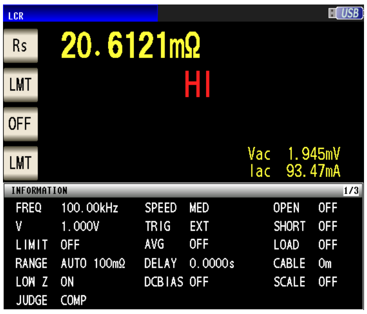


Four terminal method

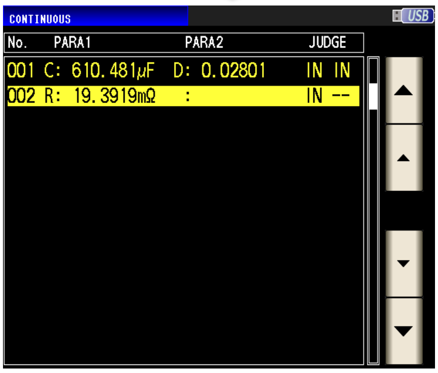
Continuous measurement mode

The IM35xx series' continuous measurement mode can be used to make continuous measurements while varying settings (frequency and level). In the following example, continuous Cs-D (120 Hz) and ESR (100 kHz) measurements are performed:





Save the 120 Hz and 100 kHz measurement condition panels.



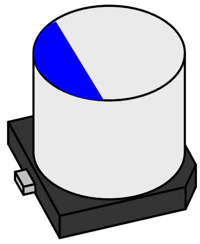
Make the measurements together in continuous measurement mode

Conductive polymer capacitors

Conductive polymer capacitors have lower ESR (see below) than aluminum electrolytic capacitors and are characterized by greater stability with regard to temperature variations. In addition, they offer excellent stability of capacitance relative to DC bias. Measurement conditions are defined by IEC standards 60384-25-1 and include measurements of equivalent series resistance (ESR) and the tangent D (tanδ) of the loss angle.

Setting example of measurement conditions

Parameters	Cs-D (120Hz), Rs (100kHz)
Frequency	120Hz, 100kHz
DC bias	ON 1.5V
Signal level	0.5Vrms
Measurement range	AUTO
Speed	SLOW2
LowZ mode	ON



*Otherwise, default settings are used.

*The above settings apply to an example measurement. Since optimal conditions vary with the measurement target, specific settings should be determined by the instrument operator.

IEC 60384-25-1 Surface mount fixed aluminium electrolytic capacitors with conductive polymer solid electrolyte

Parameters	Rated capacitance	Rated voltage	Measurement frequency	Measurement voltage*1	DC bias *2
C,D（tanδ）	All	2.5V or less	120Hz	0.5Vrms or less	1.1 to 1.5V
		2.5V or more			1.5 to 2.0V
Rs(ESR)	All	All	100kHz±10kHz	0.5Vrms or less	OFF

*1 The measurement voltage (i.e., the voltage applied to the sample) is the voltage obtained by dividing the open-terminal voltage by the output resistance and the sample.

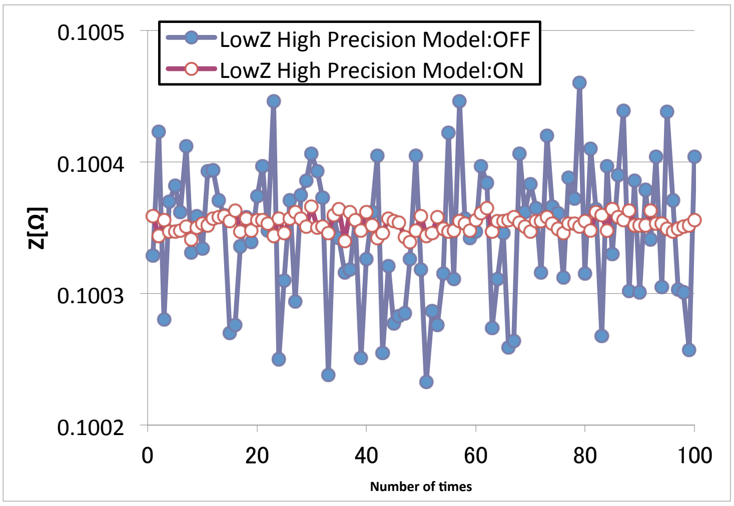
*1 The measurement voltage (i.e., the voltage applied to the sample) can be calculated based on the open-terminal voltage, the output resistance, and the sample's impedance.

*2 DC bias need not be applied.

Low impedance high accuracy mode

In low impedance high accuracy mode, the instrument's output resistance is reduced, and the measurement current is applied repeatedly for increased measurement precision. When measuring a capacitor with a high capacitance of greater than 100μF (and therefore low impedance), low-impedance high-precision mode yields more stable measurement. The graph below compares repeatability when using the IM3570 to make measurements with low-impedance high-precision mode enabled and disabled (100kHz, 1Ω range, 1V).

*The conditions under which low-impedance high-precision mode can be enabled vary with the instrument model. Please refer to the user's manual of the instrument you are using.



Repeated measurement of a resistance of approximately 100 mΩ with the IM3570

Products used

Mass Production Applications

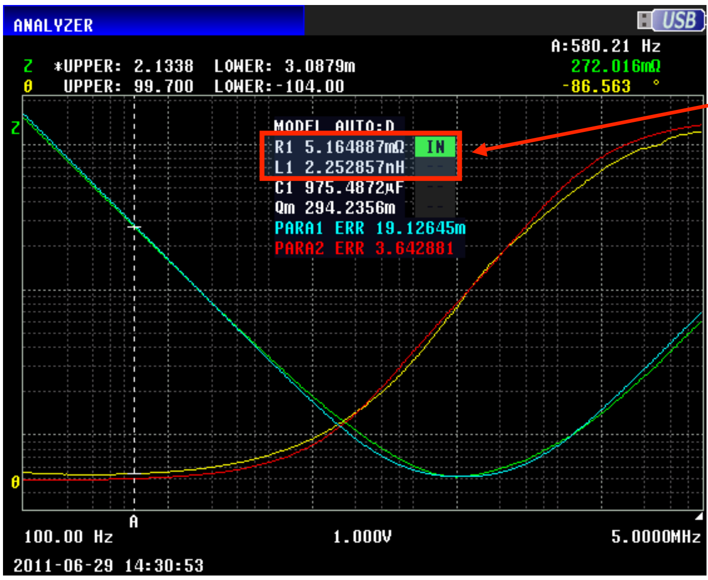
Model	Measurement frequency	Features
IM3523	DC, 40Hz to 200kHz	Measurement time: 2ms, high cost performance
IM3533	DC, 1mHz to 200kHz	Internal DC bias function, touch panel

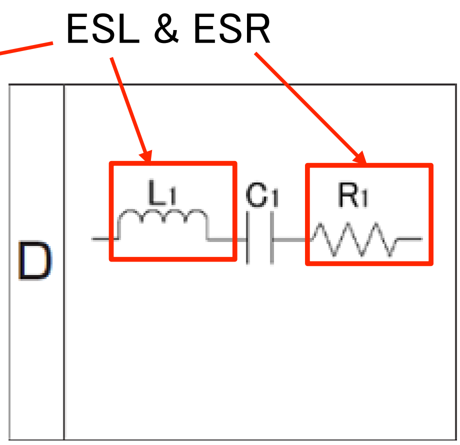
Research and Development Applications

Model	Measurement frequency	Features
IM3570 IM9000	DC, 4Hz to 5MHz	Frequency sweep with analyzer mode Optional equivalent cuircuit analysis firmware for the IM3570
IM3590	DC, 1mHz to 200kHz	Can measure ESR and ESL separately with its equivalent circuit analysis function.

Equivalent circuit analysis function

The instrument’s equivalent circuit analysis function can be used to analyze the L, C, and R elements that make up the component separately. In the following figure, a conductive polymer capacitor’s ESR and ESL are measured using the IM3570 and IM9000:

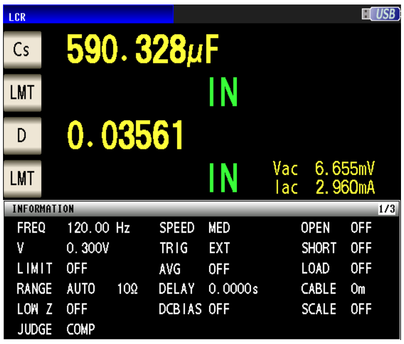


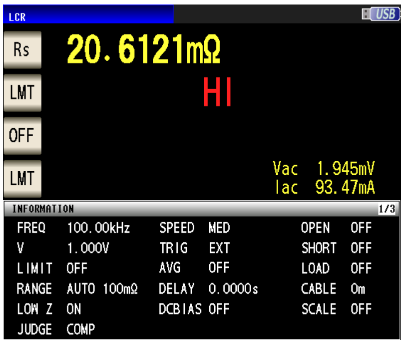


Equivalent circuit of conductive polymer capacitors

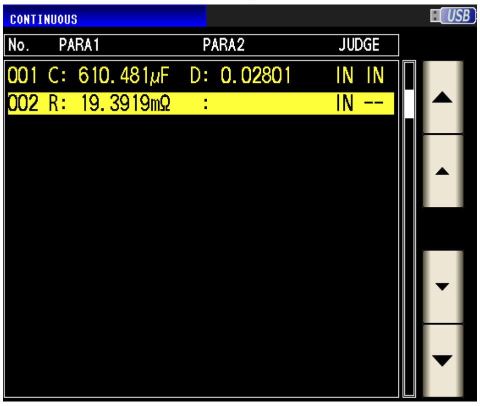
Continuous measurement mode

The IM35xx series' continuous measurement mode can be used to make continuous measurements while varying settings (frequency and level). In the following example, continuous Cs-D (120 Hz) and ESR (100 kHz) measurements are performed:





Save the 120 Hz and 100 kHz measurement condition panels.



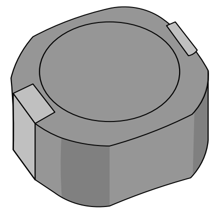
Make the measurements together in continuous measurement mode.

Inductors (Coils)

Coils may be coreless (having an air core or a core made of a non-magnetic metal), or they may have a core made of a magnetic metal (i.e., a metal with high magnetic permeability) such as ferrite. Inductors with cores exhibit current dependence.

Setting example of measurement conditions

Parameters	Ls,Q,Rdc
Frequency	Self-resonant frequency or less
DC bias	OFF (cannot measure when setting ON)
Signal level	CC (constant current) mode, rated current or less
Measurement range	AUTO
Speed	SLOW2
LowZ mode	OFF



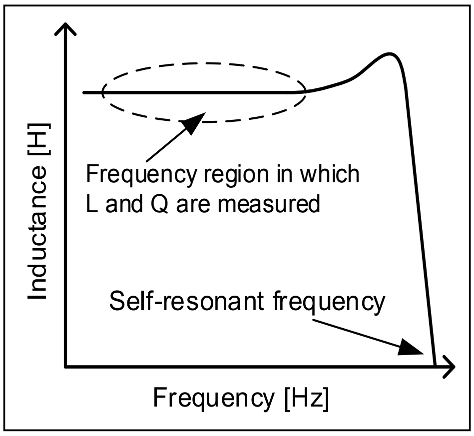
*Otherwise, default settings are used.

*The above settings apply to an example measurement. Since optimal conditions vary with the measurement target, specific settings should be determined by the instrument operator.

Setting the measurement frequency

The phenomenon of LC resonance with the coil's (inductor's) inductance and parasitic capacitance is known as self-resonance. The frequency at which self-resonance occurs is known as the self-resonant frequency. When evaluating coils, be sure to measure L and Q at a frequency that is sufficiently lower than the self-resonant frequency.

A coil's inductance, which increases with frequency, can be calculated using the following equation: $Z=j2\pi fL$. To measure inductance efficiently while varying the frequency, set the measurement range to AUTO. To measure with a higher degree of precision, set the frequency to produce an impedance that can be measured with a high-accuracy range.



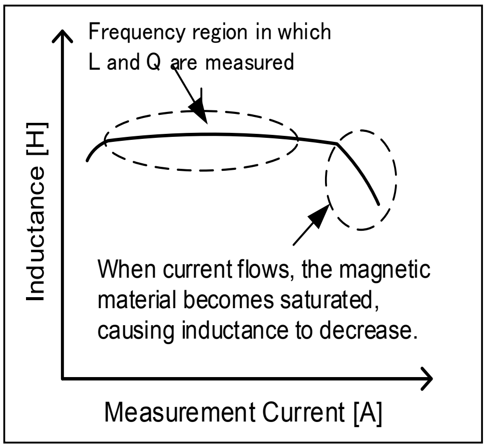
Frequency characteristics of the inductance

Setting the measurement signal level

The measurement current can be calculated from the open-terminal voltage, the instrument's output impedance, and the measurement target's impedance. Set the measurement voltage so that the rated current is not exceeded.

When measuring a coil that exhibits current dependence (i.e., a coil with a magnetic core), set the instrument to a signal level such that the magnetic core is not saturated. When measuring a coil that does not exhibit current dependence, it is recommended to set the instrument to the signal level with the best accuracy. With the IM35xx series, the best accuracy is achieved with the V mode's 1 V setting. With the IM758x series, the measurement signal level is defined for the power when using the DUT port's 50 Ω termination, and the setting with the best accuracy is +1 dBm.

When measuring a coil with a core or a coil with a low rated current, the IM35xx series' CC (constant current) mode is convenient. The measurement current is controlled in software so that it remains constant.



Current dependence of the inductance

Products used

Mass Production Applications

Model	Measurement frequency	Features
IM3533	DC,40Hz to 200kHz	Temperature correction function of Rdc
IM3536	DC,4Hz to 8MHz	Standard model,high-speed,highly stable, cost-effective analyzer
IM7581	100kHz to 300MHz	High-speed measurement of coils for high frequency

Research and Development Applications

Model	Measurement frequency	Features
IM3570	DC,4Hz to 5MHz	Frequency sweep with analyzer mode

*For more information, plese see the product catalog.

Selecting Parameter, Ls or Lp

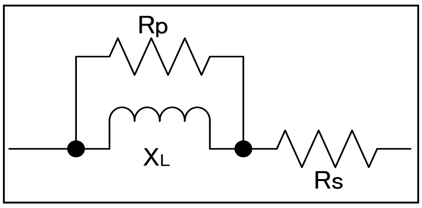
Impedance according to frequency (when D is sufficiently small)

	10Hz	1kHz	100kHz	5MHz	300MHz
100mH	6.3Ω	630Ω	63kΩ	3.1MΩ	
10mH	630mΩ	63Ω	6.3kΩ	310kΩ	
1mH	63mΩ	6.3Ω	630Ω	31kΩ	
100uH	6.3mΩ	630mΩ	63Ω	3.1kΩ	
10uH		63mΩ	6.3Ω	310Ω	
1uH		6.3mΩ	630mΩ	31Ω	1.9kΩ
100nH			63mΩ	3.1Ω	190Ω
10nH			6.3mΩ	310mΩ	19Ω
1nH					1.9Ω

Choose Lp

Depends on the case

Choose Ls



Equivalent cuircuit of inductors

*Low-inductance coils

Rp can be ignored since impedance is low. Select series equivalent circuit modes.

*High-inductance coils

Rs can be ignored since impedance is high.Select series equivalent circuit modes.

Generally speaking, series equivalent circuit mode is used when measuring low-impedance elements (approximately 100Ω or less), and parallel equivalent circuit mode is used when measuring high-impedance elements (approximately 10 kΩ or greater). When the appropriate equivalent circuit mode is unclear, for example when measuring a sample with an impedance from approximately 100Ω to 10 kΩ, check with the component's manufacturer.
An inductor will behave as though the winding's copper loss Rs and the core loss Rp have been connected to an ideal inductor L. An ideal coil's inductance can be calculated as follows: XL = j2πfL. Although no general formulation is possible since it varies with the magnitude of Rs and Rp, low-inductance coils are characterized by a small XL, allowing the impedance when Rp and L are placed in parallel to be treated as roughly equivalent to XL. Rs can be ignored since Ls is small, so the series equivalent circuit is used. By contrast, when the impedance is high, Rp cannot be ignored but Rs can, so the setup can be treated as a parallel equivalent circuit.

The Current flowing to the coil

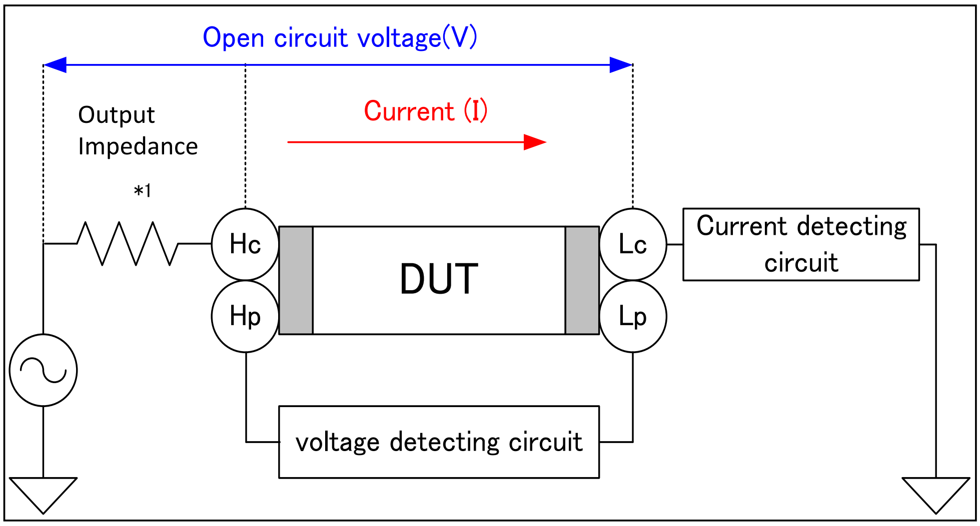
The current flowing to the coil can be calculated based on the open-terminal voltage, the instrument's output impedance, and the measurement target's impedance.

$|Z|=\sqrt{(R_{out}+R_{coil})^2+(2\pi fL)^2}$

R_out:Output resistance of coil

$|I|=|V|/|Z|$

L:Inductance of coil



Current flowing to DUT

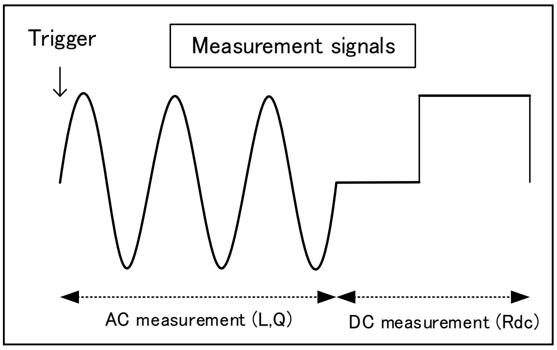
*1 The output impedance varies depending on the model and on whether low-impedance high-precision mode has been enabled. Please refer to the product specifications in the instruction manual.

Measuring Rdc

In coil evaluation, L, Q, and Rdc are measured. Instruments such as the IM3533 and IM3536 can measure L, Q, and Rdc without the need to use any other devices. After measuring L and Q with an AC signal, measure Rdc with a DC signal.

*Rs and Rp are not equal to Rdc. Rs and Rp are resistance values that are measured with an AC signal. They include components such as coil loss and winding resistance, which increases due to conductor skin effects and proximity effects.

When the winding material has a large temperature coefficient, Rdc will vary with temperature. The IM3533 has temperature correction functionality for Rdc.

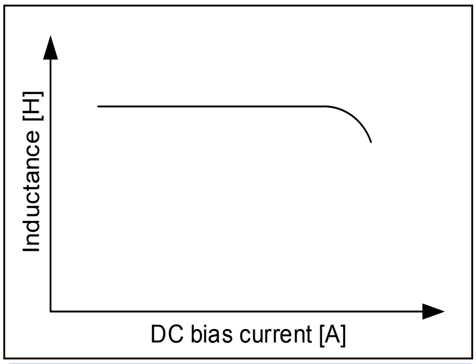


Measurement signals

DC superposition characteristics

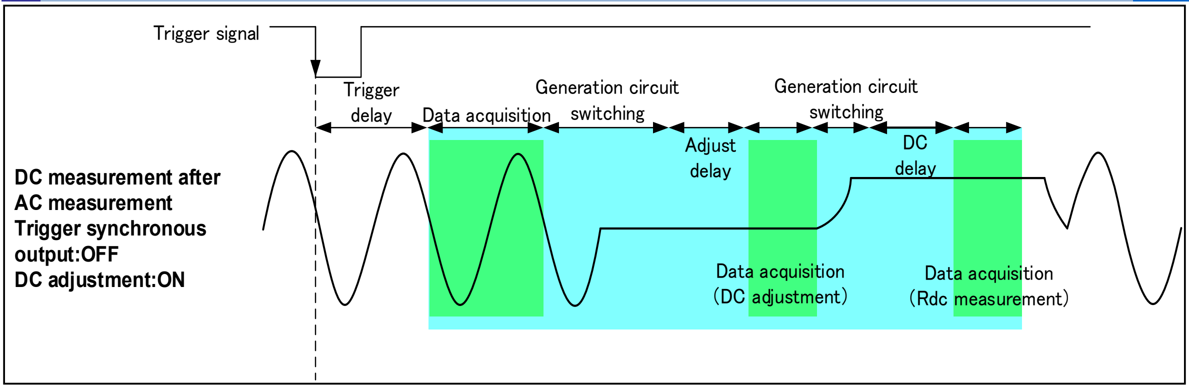
Coil characteristics include DC superposition characteristics, which indicate the extent to which inductance decreases relative to DC current, an important evaluation item for coils that will be used in circuits such as power supply circuits that handle large currents.

The DC bias voltage application function built into Hioki LCR meters is designed for use in measuring capacitors, and it cannot be used to apply a DC current. To superpose a DC signal, either use the DC Bias Current Unit 9269 (or 9269-10) and an external power supply, or create your own circuit for the purpose.



DC superposition characteristics of L

Setting the delay time

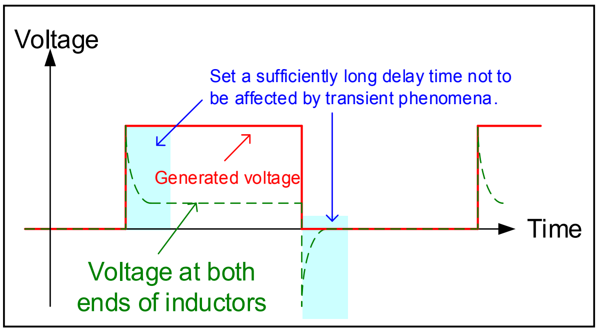


Example of measurement timing (IM3536)

To reduce measurement error during Rdc measurement, Hioki LCR meters cycle the generated voltage on and off to cancel the internal offset (DC adjustment function).

When the voltage being applied to the inductor changes, the output resistance and inductor's equivalent series resistance and inductance cause transient phenomena. Set a sufficiently long delay time during Rdc measurement to ensure that the measurement results are not affected by these phenomena. The name given to the delay time setting varies by model, as does measurement timing. For more information, please see the instruction manual for the model you intend to use.

If you are unsure of the appropriate delay time, first set as long a delay time as possible. Then gradually shorten the delay time while verifying that measured values do not exhibit any variability.

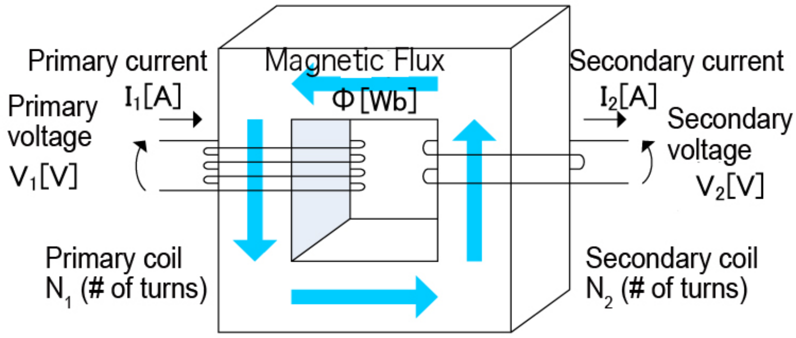


Transient phenomena of inductors

Electric Transformers

AC voltages can be stepped up or down using a transformer. In terms of their basic structure, transformers consist of primary and secondary windings around an iron core.

When current flows, a magnetic field is generated inside the windings, creating a voltage. The size of this voltage is proportional to the number of turns. For example, a primary winding (on the input side of the transformer) with 100 turns and a secondary winding (on the output side of the transformer) with 200 turns would step up an input voltage of 100 V to an output voltage of 200 V since the number of output turns is twice the number of input turns. Note that there is no change in power between the primary and secondary sides of the transformer.



$V_2/V_1 = I_1/I_2 = N_2/N_1$

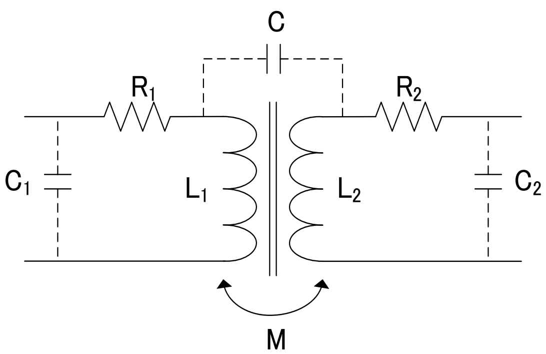
Setting example of measurement conditions

Parameters	Ls,Q,Rdc
Frequency	Self-resonant frequency or less *1
DC bias	OFF(ON is NOT applicable)
Signal level	Rated current or less *1
Measurement range	AUTO
Speed	SLOW2
LowZ mode	OFF

※1 Cf. Inductors Application note

*Otherwise, default settings are used.

*The above settings apply to an example measurement. Since optimal conditions vary with the measurement target, specific settings should be determined by the instrument operator.



R_1: Primary winding resistance
R_2: Secondary winding resistance
C_1: Primary winding floating capacity
C_2: Secondary winding floating capacity

The Parameter for each electric transformer

The transformer is an application of an inductor, and measurement methods are the same as for other inductors. Transformer measurement includes the following principal evaluation parameters:

- Primary inductance (L1) and secondary inductance (L2)
- Leakage inductance
- Capacitance between windings ©
- Mutual inductance (M)
- Turn ratio

Products used

Mass Production Applications

Model	Frequency	Features
IM3533	DC,40Hz to 200kHz	Temperature correction function of Rdc,transformertesting mode
IM3533-01	DC,40Hz to 200kHz	IM3533+ Frequency sweep
IM3536	DC,4Hz to 8MHz	Standard model, high-speed, highly stable, cost-effective analyzer

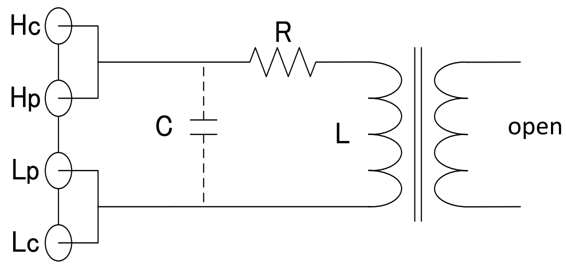
Research and Development Applications

Model	Frequency	Features
IM3570	DC,4Hz to 5MHz	Frequency sweep with analyzer mode

*For more information, plese see the product catalog.

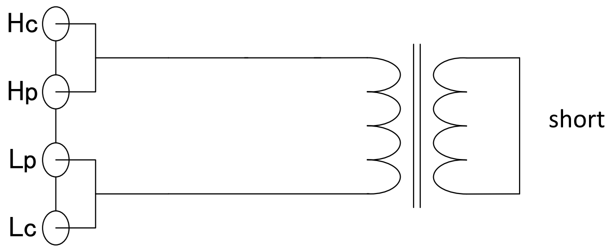
Primary inductance (L1) and secondary inductance (L2)

As shown in the figure to the right, a measuring instrument can be connected directly to the primary or secondary side of the transformer to measure the primary or secondary inductor. However, all other windings must be left in the open state. Exercise care as inductance measurement results include the effects of the winding's distributed capacitance.

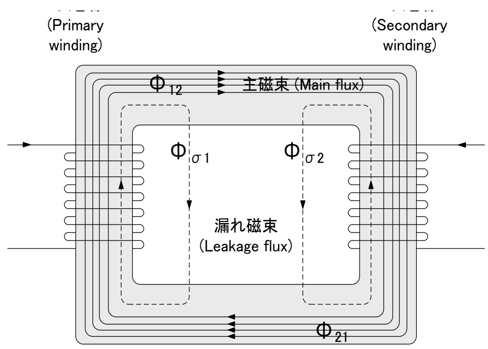


Measuring circuit for primary and secondary inductance

Leakage inductance



Measuring circuit for leakage inductance



Leakage flux

In an ideal transformer, shorting output causes input to be shorted as well. However, in an actual transformer, leakage inductance remains even when output is shorted. As shown in the above figure, the leakage inductance can be determined by shorting the secondary side of the transformer and measuring the primary side's inductance.

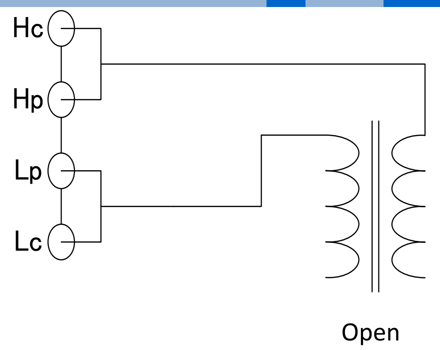
What is leakage inductance?

The magnetic flux that links the transformer's primary and secondary windings is known as the main magnetic flux (φ12 or φ21). Apart from the main magnetic flux, the transformer's magnetic flux also includes primary leakage flux (φs1) , which links the primary winding but not the secondary winding, and secondary leakage flux (φs2), which links the secondary winding but not the primary winding.

Although only the main magnetic flux exists in an ideal transformer, actual transformers always have magnetic leakage, and therefore leakage flux. Since this leakage flux does not link only the primary and secondary windings, it does not contribute to the transformer's voltage-modifying operation. At the same time, the fact that the leakage flux does not link only the primary and secondary windings also means that it contributes as each winding's inductance. In this way, the primary leakage flux acts as the primary leakage inductance, and the secondary leakage flux acts as the secondary leakage inductance.

Capacitance between windings

As shown in the figure to the right, the winding capacitance between the primary and secondary sides of the transformer can be measured by connecting each winding to the measuring instrument.

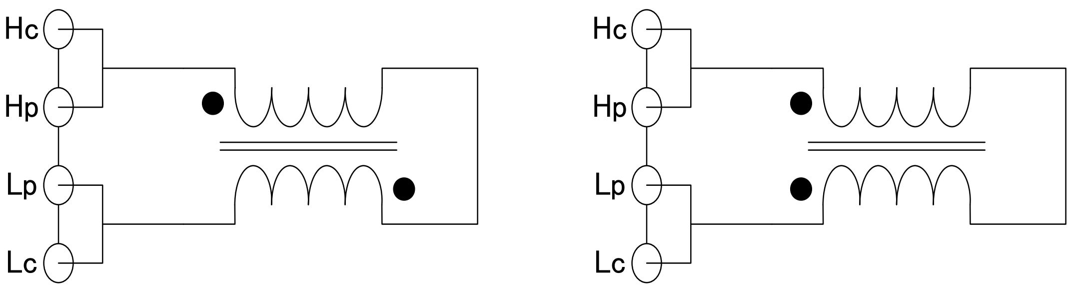


Measuring circuit for capacitance between windings

Mutual inductance

The mutual inductance can be calculated by measuring the inductance in parallel while in phase and then in series out of phase and then using the equation shown below.

M=(La−Lo)/4



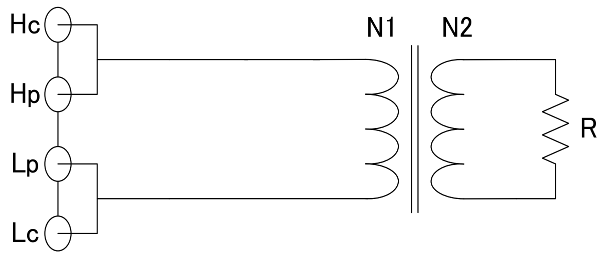
L measurement

Measuring circuit for mutual inductance between coils

Lo measurement

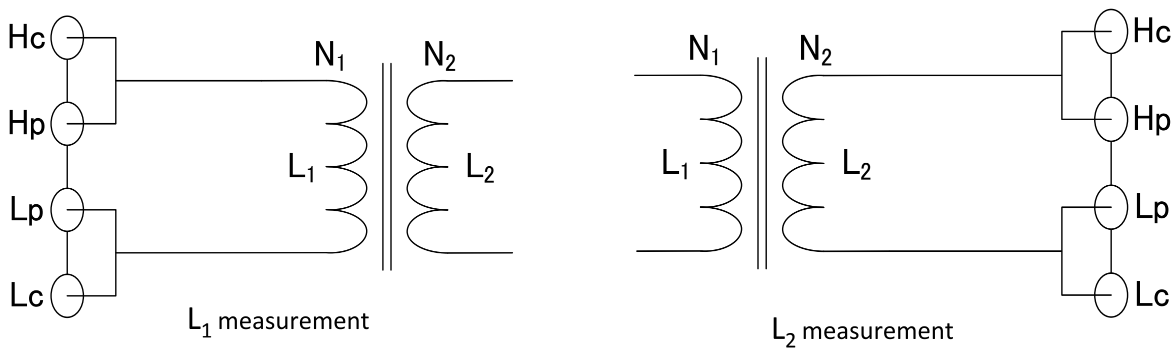
Turn ratio

As shown in the figure to the right, the turn ratio can be approximated by measuring the impedance value Z on the primary side of the transformer after connecting the resistance R to the secondary side.



Measuring circuit for turn ratio of windings

In addition, the turn ratio can be calculated by measuring the primary inductance L1 and the secondary inductance L2. However, the value will only be an approximation due to the effects of factors such as magnetic leakage.



Measuring circuit for turn ratio of windings

The LCR Meter IM3533/IM3533-01's transformer measurement functionality can be used to calculate the mutual inductance, turn ratio, and inductance difference.

Turn ratio measurement with the IM3533/IM3533-01 involves measuring the primary and secondary inductance values and then calculating the turn ratio.

RFID (Contactless IC cards, Contactless IC tags)

The operating frequencies of RFIDs, which are also known as IC tags or contactless IC cards, are defined by standards. When performing L measurement of a board used by a contactless IC card, the measurement must be made near the operating frequency of 13.56 MHz.

Setting example of measurement conditions

Measurement mode	ANALYZER
Parameters	Z-θ frequency characteristics analysis（L-Q、R evaluation available）
Sweep parameter	FREQ
Sweep frequency	Sweep measurement close to the operating frequency (See the table below)
Signal level	V mode 1V (350x, IM35xx series) or 1dBm (IM758x series)

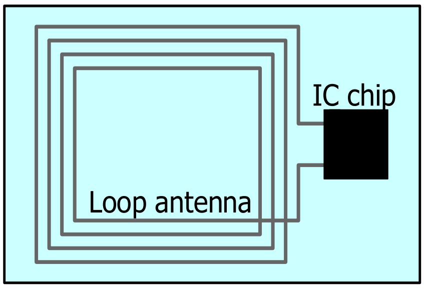
*The above settings apply to an example measurement. Since optimal conditions vary with the measurement target, specific settings should be determined by the instrument operator.

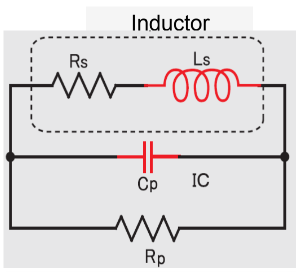
RFID standards

Category	Frequency	Effective distance	Standard
ID cards	13.56MHz	Up to 10cm (Proximity applications)	ISO14443
Automatic recognition	125kHz	Up to 70cm (Vicinity applications)	ISO14443
	13.56MHz		ISO15693

Structure of RFID tag

RFIDs generally consist of an antenna and IC. Signal transmission is accomplished by a resonant circuit formed by the antenna inductor (Ls) and the IC chip's built-in input capacitance (Cp).

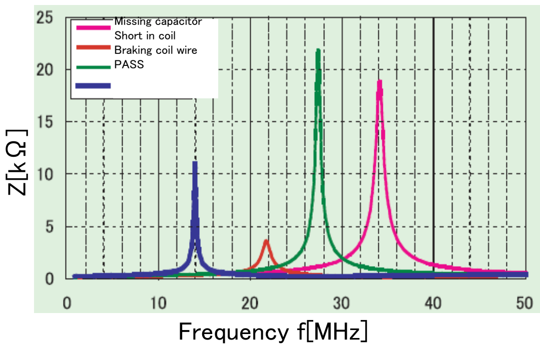




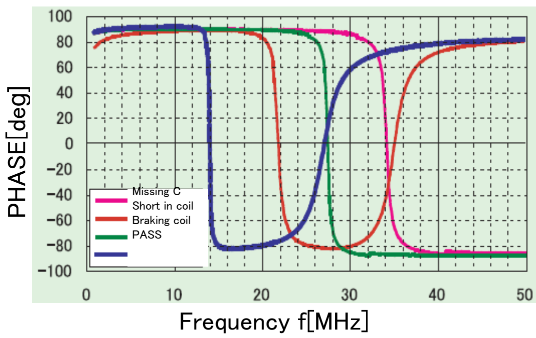
Circuit model

Frequency characteristics of defective and non-defective components

As shown in the following figures, the Z-θ frequency characteristics of defective and non-defective components differ. The non-defective component exhibits a resonance point near the operating frequency.



Frequency characteristics of impedance



Frequency characteristics of phase

Products used

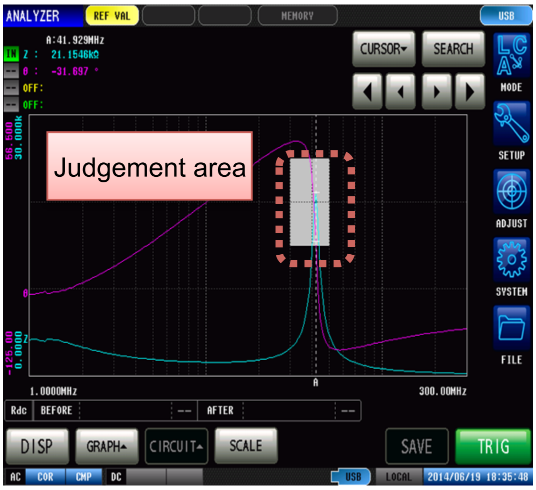
Production line and R&D applications

Model	Measurement frequency	RFID
IM758x series	100k to 1.3GHz *	Mainly for high-frequency RFID
IM3570	4Hz to 5MHz	Mainly for low-frequwncy to midium frequency RFID

*For more information, plese see the product catalog.

Pass/fail judgments using analyzer mode

Either of two methods can be used to generate pass/fail judgments when using analyzer mode: peak judgment and area judgment.

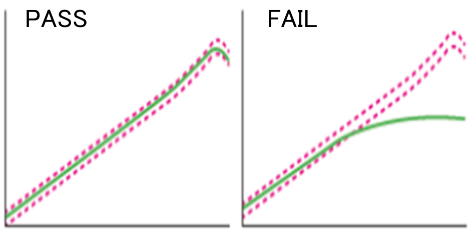


Judgement method: Whether the resonance points fall inside a judgement area.

Peak judgement

Judgement method: Whether all measured values fall inside a judgement area.

Area judgement



Judgement areas can be set as follows.

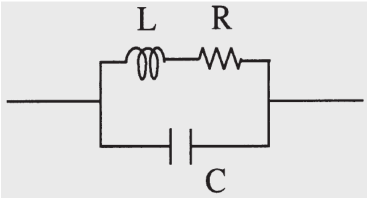
• A known-good element's measured value can be used as the reference (±10% of the reference element's measured value, etc.).

• A user-specified value can be entered (1 k±10%, etc.).

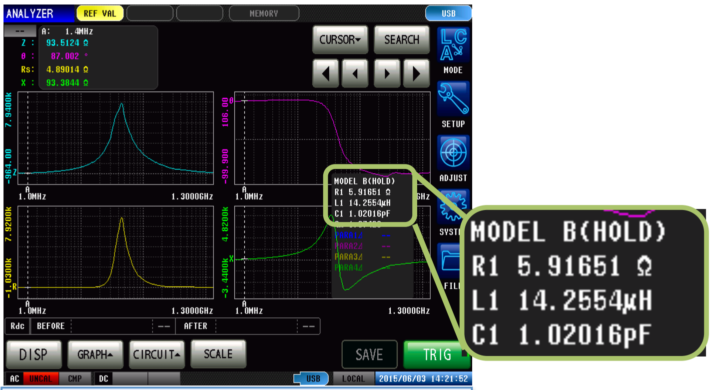
Ascertaining electrical constants by means of equivalent circuit analysis

The instrument's equivalent circuit analysis function can be used to calculate the constants in a three-terminal circuit model such as an RFID antenna.

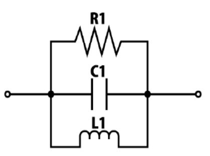
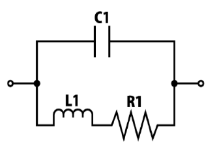
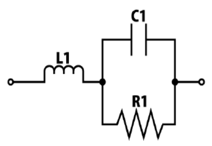
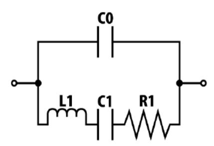
*Model A should be used for coils with a large core loss (R) in order to facilitate more accurate analysis.



Equivalent circuit of an antenna



Equivalent circuit analysis result

Equivalent circuit models				
A	B	C	D	E
				

Piezoelectric elements

Piezoelectric elements are used in a wide range of applications, including buzzers, sensors, and filters. Since resonant and antiresonant frequencies characterize their impedance/frequency characteristics, an impedance analyzer is the ideal instrument for use in analyzing their characteristics.

Setting example of measurement conditions

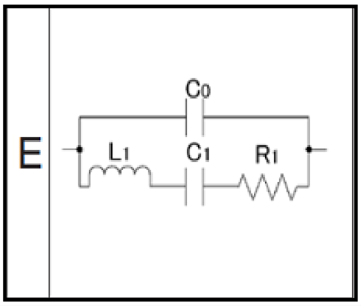
Measurement modes	ANALYZER
Parameters	Z-θ
Sweep parameter	FREQ
Sweep frequency	Set to a range within which the resonant, antiresonant frequency can be checked.
Signal level	Depends on the measurement items
Equivalent cuicuit model	E

*The above settings apply to an example measurement. Since optimal conditions vary with the measurement target, specific settings should be determined by the instrument operator.

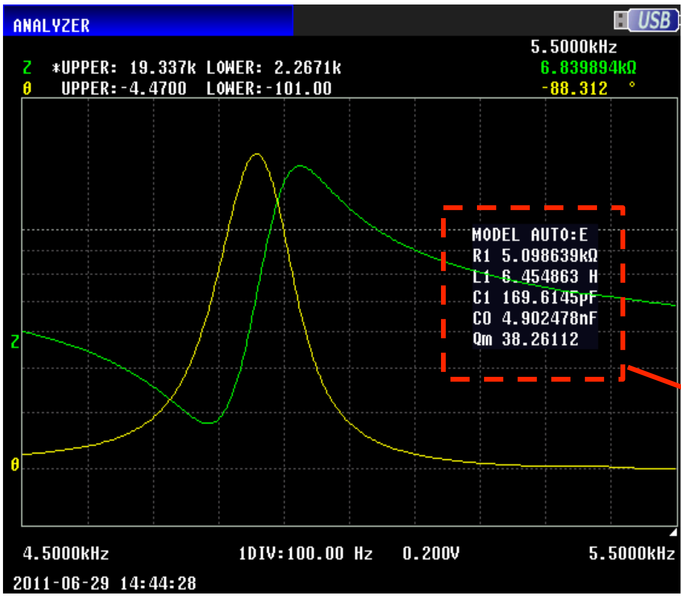
Equivalent circuit of piezoelectric elements

Close to its resonant frequency, a piezoelectric element can be depicted as an electrical equivalent circuit. Specifically, such an element can be depicted as a parallel capacitance CO that is connected in parallel to a series circuit consisting of the series inductance L1, the series capacitance C1, and the series resistance R1.

The following describes actual measurement and analysis with an IM3570 and IM9000 (optional equivalent circuit analysis software).



Equivalent cuicuit model of piezoelectric elements



Equivalent circuit analysis results

Frequency sweep results

Products used

Model	Frequency	Features
IM3590	DC,1mHz to 200kHz	Analyzer mode (low frequency), equivalent cuircuit analysis
IM3570	DC,4Hz to 5MHz	Frequency sweep with analyzer mode
IM9000		Optional equivalent cuircuit analysis firmware for the IM3570
IM7581	100kHz to 300MHz	Analyzer mode (high frequency), equivalent cuircuit analysis

*For more information, plese see the product catalog.

Measuring resonant frequency and antiresonant frequency

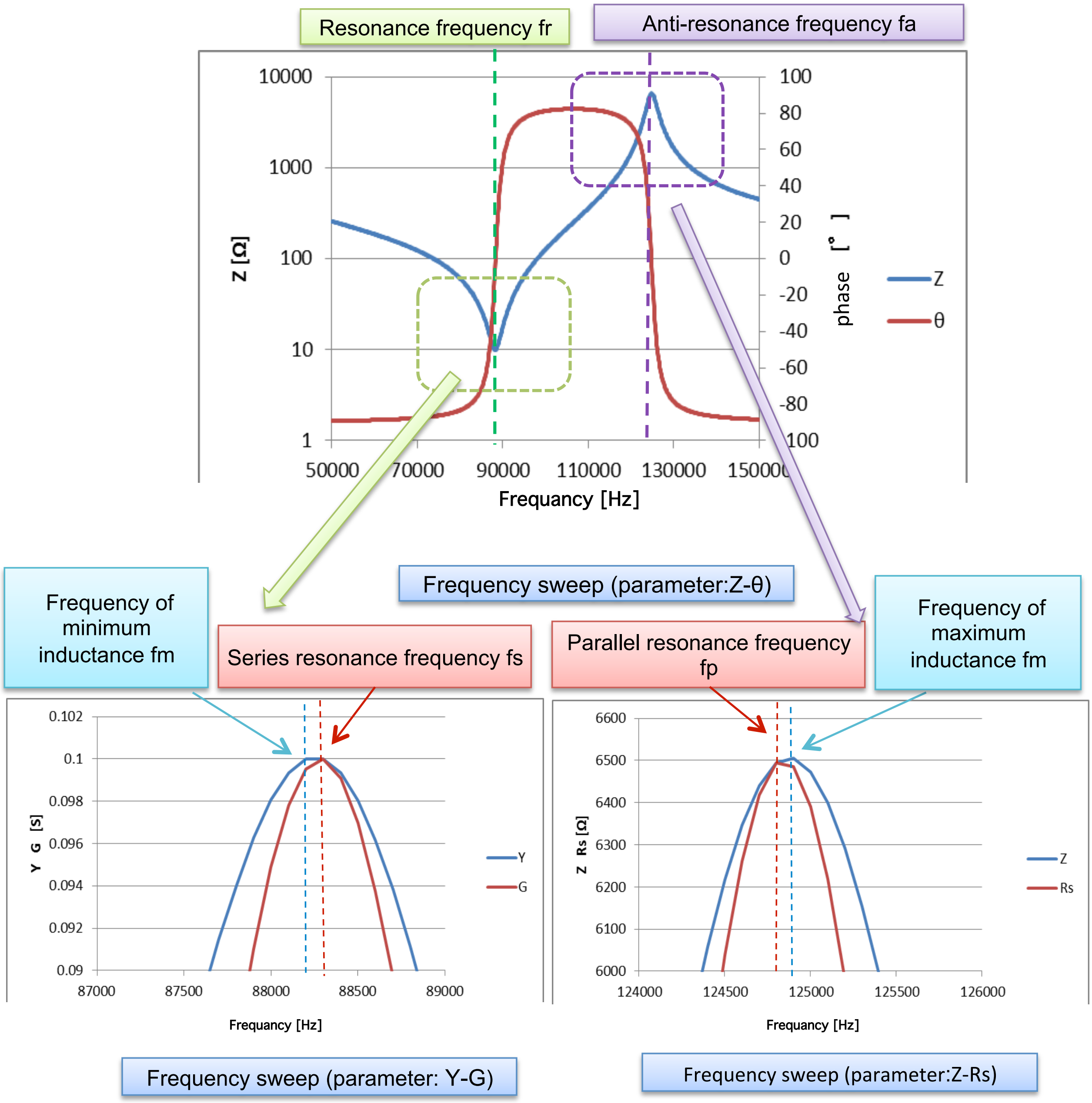
The frequency *fm* characterized by minimum inductance and the frequency fn characterized by maximum inductance can be calculated from the element's impedance/frequency characteristics using the instrument's peak search function. In addition, it is possible to calculate the resonant frequency *fr*, which is characterized by a phase of *0*, and the antiresonant frequency *fa.*

The series resonant frequency *fs* and the parallel resonant frequency *fp* can be expressed as follows:

$$fs = 1/2\pi\sqrt{L1C1}$$

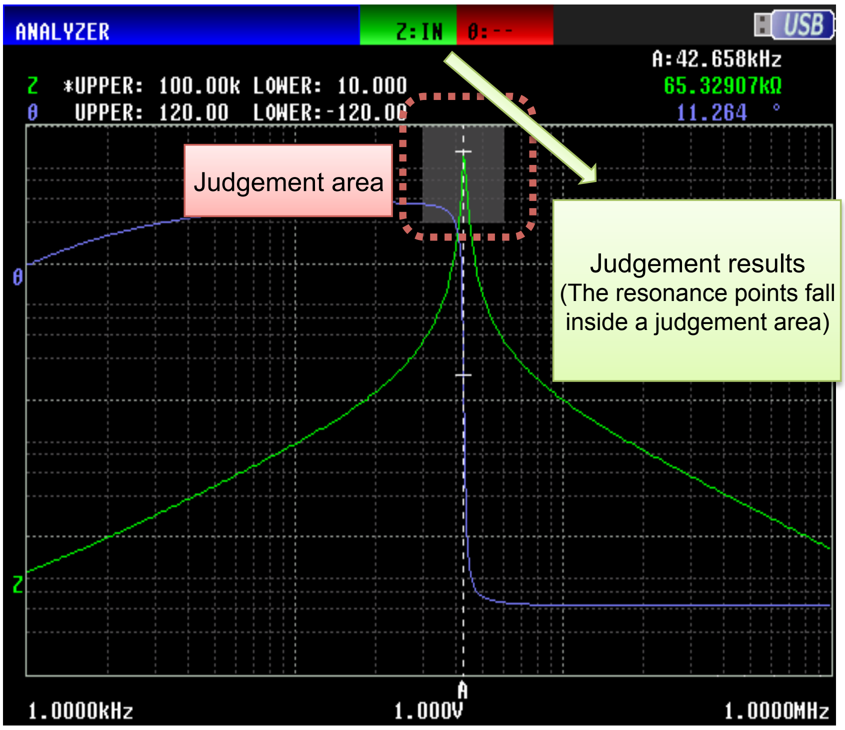
$$fp = 1/2\pi\sqrt{L1 \cdot C0C1/(C0+C1)}$$

fs is the frequency when the conductance G reaches its maximum, and fp is the frequency when the actual resistance Rs reaches is maximum. These can be calculated from C0, L1 and C1 obtained via equivalent circuit analysis.

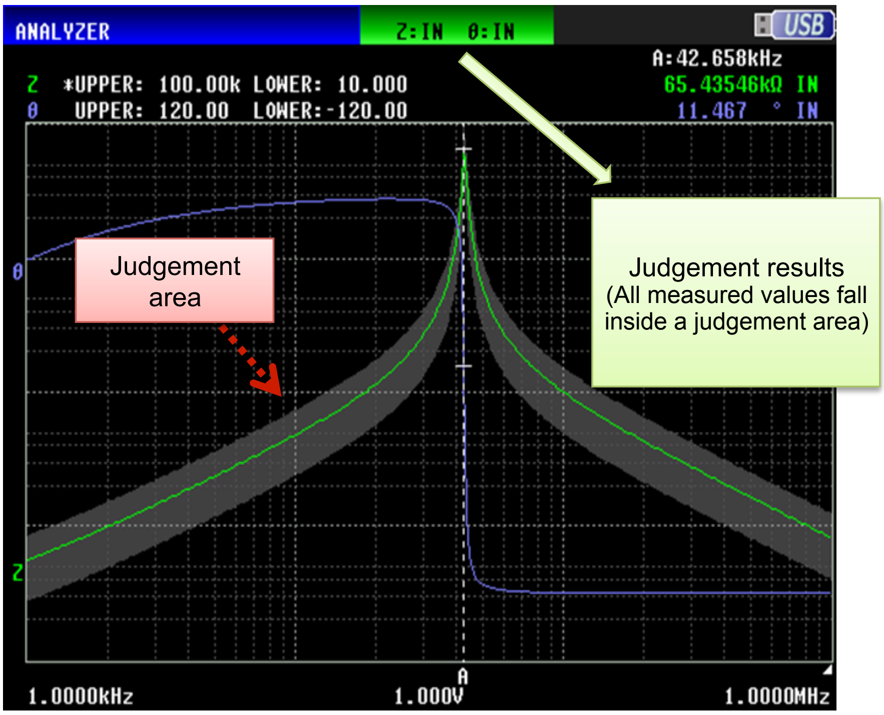


Pass/fail judgments using analyzer mode

Either of two methods can be used to generate pass/fail judgments when using analyzer mode: peak judgment and area judgment.



Peak judgement



Judgement areas can be set as follows.

• A known-good element's measured value can be used as the reference (±10% of the reference element's measured value, etc.).

• A user-specified value can be entered (1 k±10%, etc.).

Area judgement

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