阻抗量測基本原理介紹

品勛科技有限公司
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Agenda

» Introduction
» Impedance Basics & Measurement Method
» Fixturing and cabling
» Calibration and compensation
» Impedance product lines
  – Impedance analyzer / LCR meter

•延伸閱讀： RLC meter(電容電阻電感錶)
•延伸閱讀：查看如何使用網路分析儀量測阻抗
•延伸閱讀：LCR meter自動記錄軟體編程教學

Impedance Measurement Applications

- Material Measurements
- On-wafer C-V Measurements
- Diode Measurements
- MOS FET Measurements
- Inductor Measurements
- In-circuit Tests
- Capacitor Measurements
- Battery Measurements
- Cable Measurements
- Resonator Measurements
- Transformer Measurements
- Resistor Measurements

Auto-balancing Bridge

LCR Meters
Impedance Analyzers (ZA)
Wide Variety of Test Fixtures

RF I-V

http://www.pinsyun.com.tw/products-7.html

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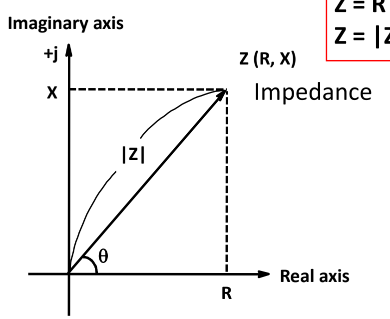
Z: Total opposition a device or circuit offers to the flow of AC

$Z = R + jX$ (rectangular-coord)

$Z = |Z| \angle \theta$ (polar form)



$R = |Z| \cos \theta$

$X = |Z| \sin \theta$

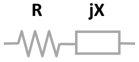
$|Z| = \sqrt{R^2 + X^2}$

$\theta = \tan^{-1}(X/R)$

Unit of impedance: ohm (Ω)

Series and Parallel Combinations

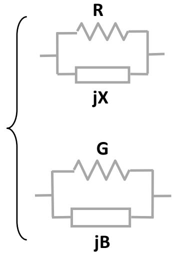
Real and imaginary components are connected in series



$Z = R + jX$

(Impedance is easier to express)

Real and imaginary components are connected in parallel



$$Z = \frac{jRX}{R + jX} = \frac{RX^2}{R^2 + X^2} + j\frac{R^2X}{R^2 + X^2}$$

(Impedance is too complex)

$Y = G + jB$

(Admittance is easier)

Unit of admittance: Siemens (S)

conductance, **G** and the **susceptance**, **B**

Inductive and Capacitive Reactance

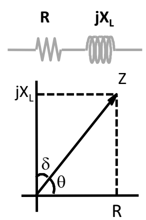
L (Inductance)

$X_L = 2\pi fL = \omega L$

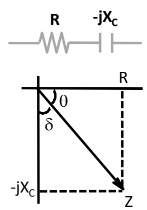
ω: Angular frequency (= 2πf)

C (Capacitance)

$X_C = \frac{1}{2\pi fC} = \frac{1}{\omega C}$



(a) Inductive vector on impedance plane



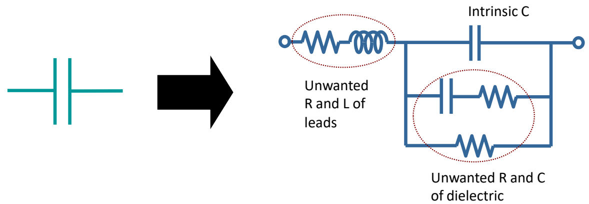
(b) Capacitive vector on impedance plane

Q = quality factor $= \frac{X_L}{R} = \frac{-X_C}{R}$ $= \tan\theta$

D = dissipation factor $= \frac{1}{Q}$ $= \tan\delta$

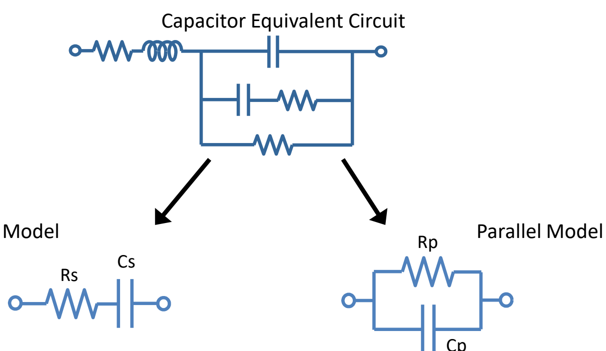
Parasitics

- **No real components are purely resistive or reactive**
  - Every component is a combination of R, C and L elements
  - The unwanted elements are called **parasitics**



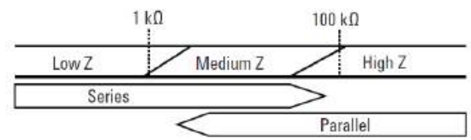
Capacitor Equivalent Circuit

Series and Parallel Models



Low-Impedance Device
(Large C, Small L; |Z| < 10 Ω)

High-Impedance Device
(Small C, Large L; |Z| > 10 kΩ)

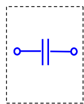


Relationship between Series and Parallel mode

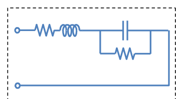
	Series	Parallel	Dissipation factor
			(Same value for series and parallel)
Capacitance	$Cs = Cp(1 + D^2)$	$Cp = Cs/(1 + D^2)$	$D = Rs/Xs = \omega CsRs$ $D = Gp/Bp = Gp/(\omega Cp) = 1/(\omega CpRp)$
Inductance	$Ls = Lp/(1 + D^2)$	$Lp = Ls(1 + D^2)$	$D = Rs/Xs = Rs/(\omega Ls)$ $D = Gp/Bp = \omega LpGp = \omega Lp/Rp$
Resistance	$Rs = RpD^2/(1 + D^2)$	$Rp = Rs(1 + 1/D^2)$	——

Ideal, Real, and Measured values

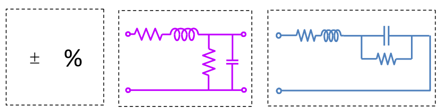
- **Ideal value**
  - Excludes effects of parasitics
  - Academic interest only



- **Real value**
  - Takes into consideration the parasitics
  - Frequency dependent



- **Measured value**
  - The value obtained with and displayed by the measuring instrument.



Instrument Test fixture Real-world device

The goal of measurement: measured value very close to real value

Component Dependency Factors

- **Measurement conditions that determine the measured impedance value**
- **Effects depend on component materials and manufacturing processes**
- **Four major factors:**
  - **Test signal frequency**
  - **Test signal level**
  - **DC voltage and current bias**
  - **Environment**

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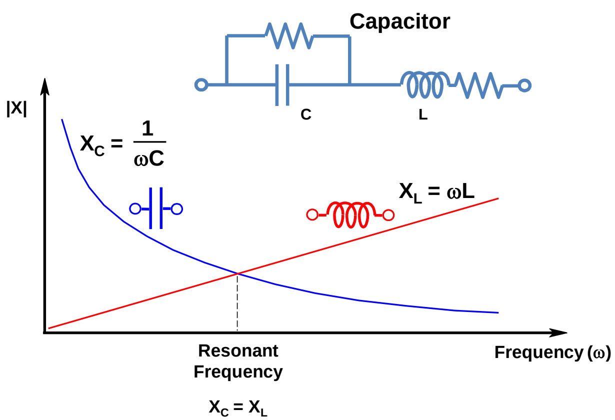
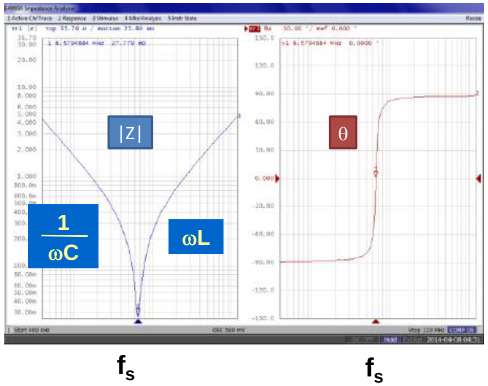
X versus Test Signal Frequency



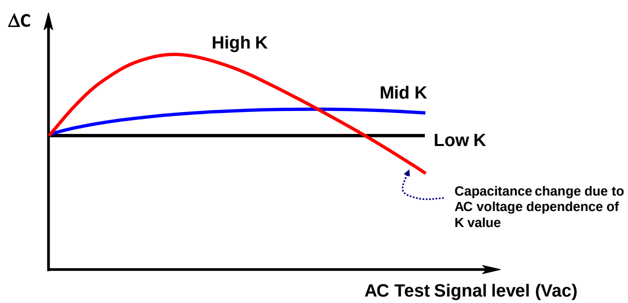
Example Capacitor Resonance

Impedance versus Frequency



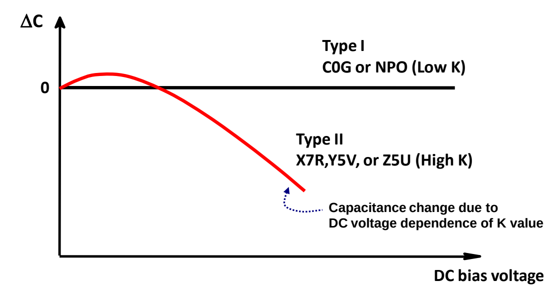
C versus Test Signal Level

AC voltage dependency of ceramic SMD capacitors for various values of dielectric constant (K)



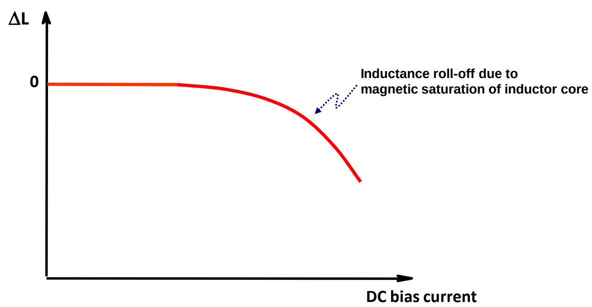
C versus DC Voltage Bias

DC bias voltage dependency of type I and II SMD capacitors



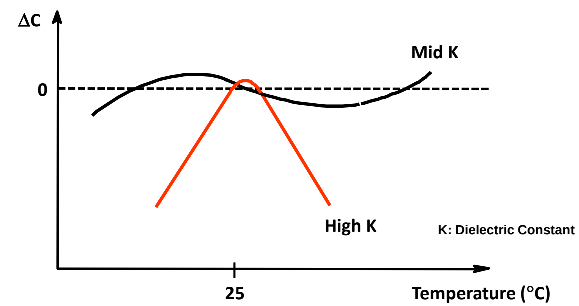
L versus DC Current Bias

DC bias current dependency of cored inductors



C versus Temperature

Temperature dependency of ceramic capacitors for different K values



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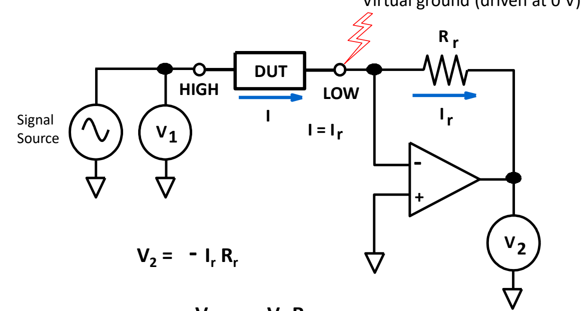
(1) Auto-Balancing Bridge method

Measurement Principle

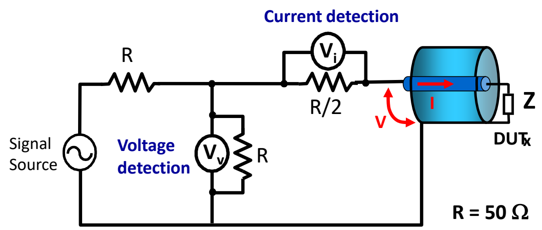


$$V_2 = -I_r R_r$$

$$Z = \frac{V_1}{I_r} = \frac{-V_1 R_r}{V_2}$$

(2) RF I-V method

Measurement Principle



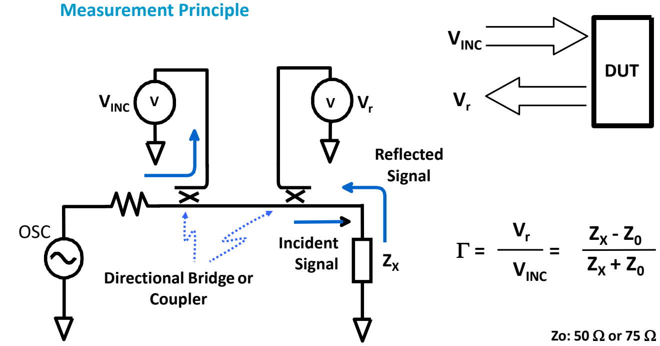
Test Head (High-Impedance type)

$$Z_x = \frac{V}{I} = \frac{R}{2}\left(\frac{V_v}{V_i} - 1\right)$$

As $V = V_v - V_i$ and $I = 2V_i/R$

(3) Network Analysis method

Measurement Principle



$$\Gamma = \frac{V_r}{V_{INC}} = \frac{Z_X - Z_0}{Z_X + Z_0}$$

Impedance Measurement Methods and Instrument selection

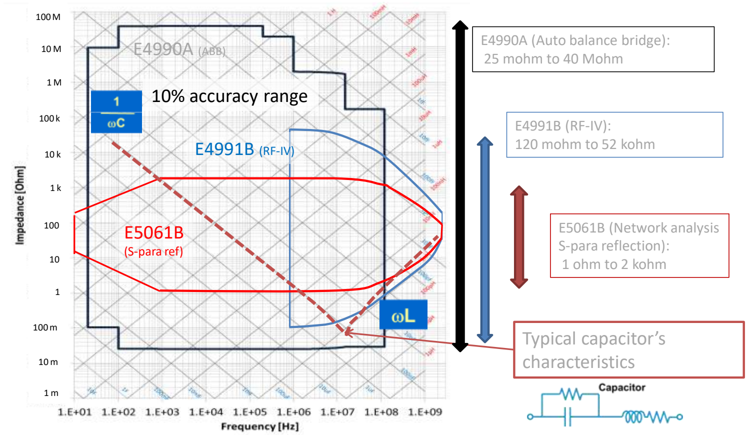
1) Frequency
2) DUT impedance
3) Required measurement accuracy

These determine the most suitable method

4) Electrical test conditions
5) Measurement parameters
6) Physical characteristics of DUT

These determine the proper instrument and test fixture

Impedance measurement range depends on the method



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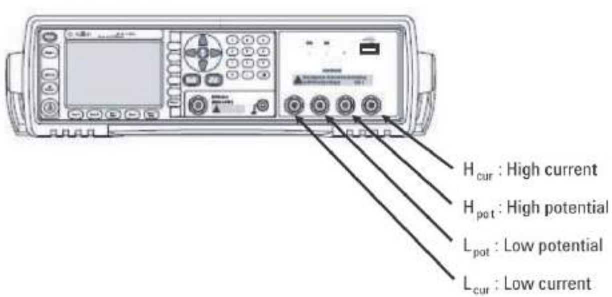
Fixturing and Cabling

LF impedance measurement
- 1-1 Terminal configuration
- 1-2 Guarding
- 1-3 Test Fixtures in the LF range

RF impedance measurement
- 2-1 Terminal configuration in the RF range
- 2-2 Test port extension in the RF range

1-1 Terminal Configuration

Precision LCR Meter



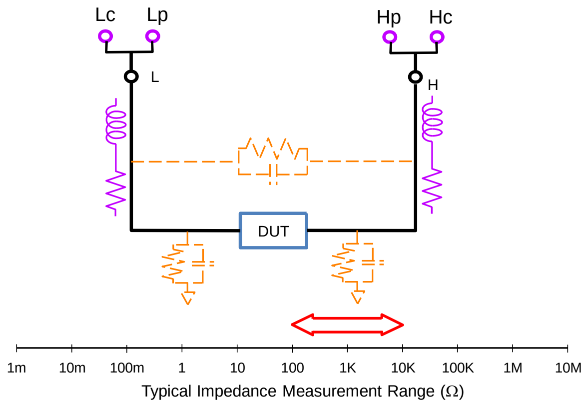
1-1 Terminal Configuration

» **Types of configuration**

- Two-terminal (2T) configuration
- Three-terminal (3T) configuration
- Four-terminal (4T) configuration
- Five-terminal (5T) configuration
- Four-terminal pair (4TP) configuration

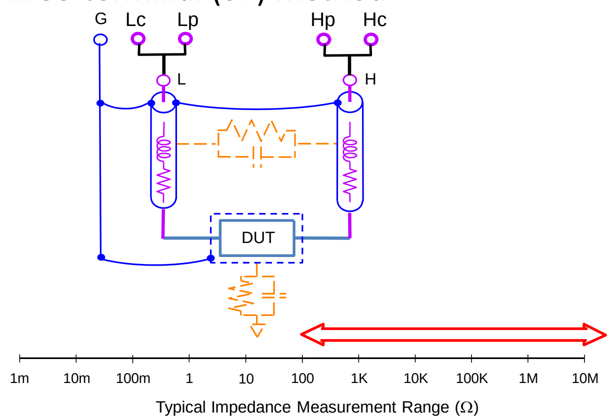
1-1 Terminal Configuration

» Two-terminal (2T) method



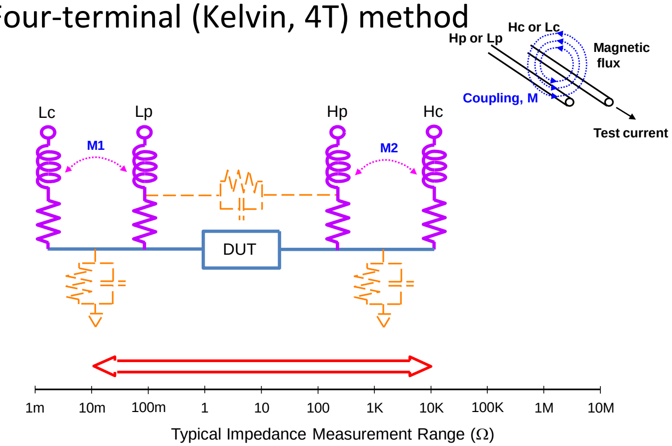
1-1 Terminal Configuration

» Three-terminal (3T) method



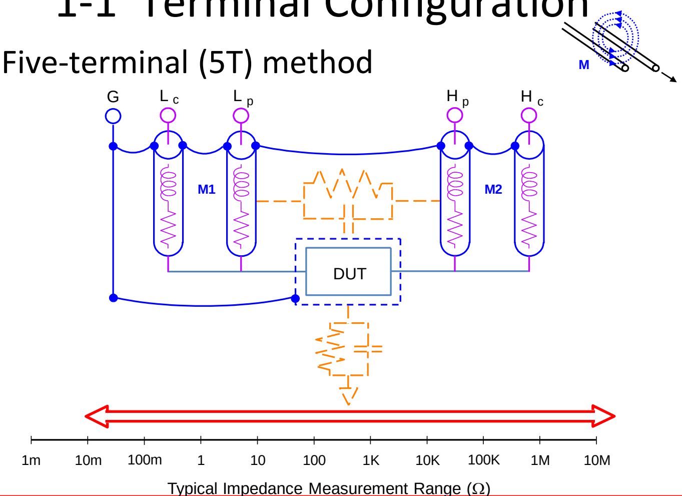
1-1 Terminal Configuration

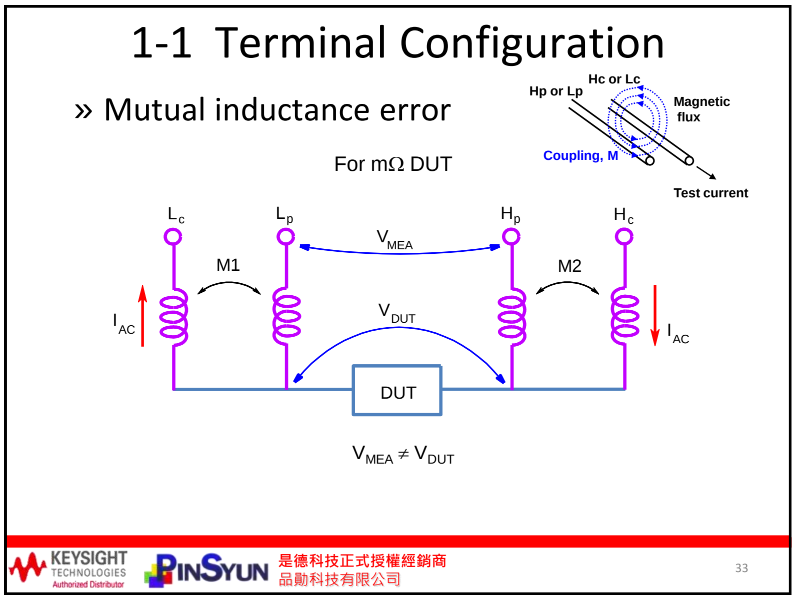
» Four-terminal (Kelvin, 4T) method



1-1 Terminal Configuration

» Five-terminal (5T) method




1-1 Terminal Configuration
» Mutual inductance error
For mΩ DUT
Hp or Lp
Hc or Lc
Magnetic flux
Coupling, M
Test current
Lc
Lp
Hp
Hc
VMEA
M1
M2
IAC
VDUT
DUT
VMEA ≠ VDUT
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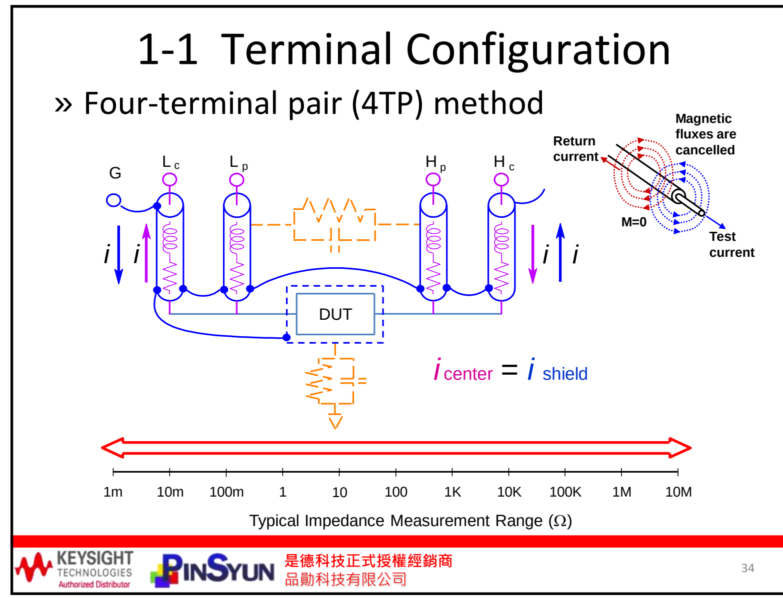
1-1 Terminal Configuration
» Four-terminal pair (4TP) method
Magnetic fluxes are cancelled
Return current
M=0
Test current
G
L c
L p
H p
H c
i
DUT
i center = i shield
1m
10m
100m
1
10
100
1K
10K
100K
1M
10M
Typical Impedance Measurement Range (Ω)
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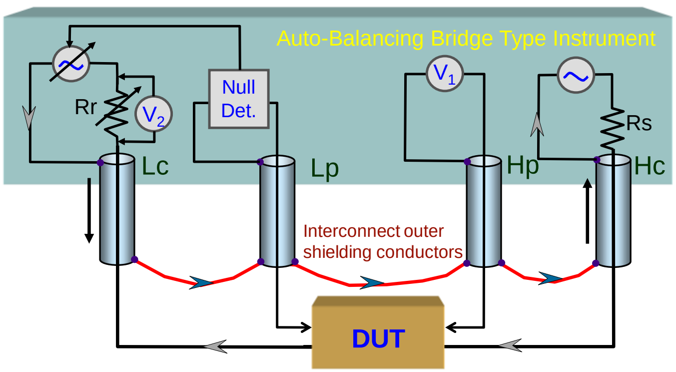
1-1 Terminal Configuration

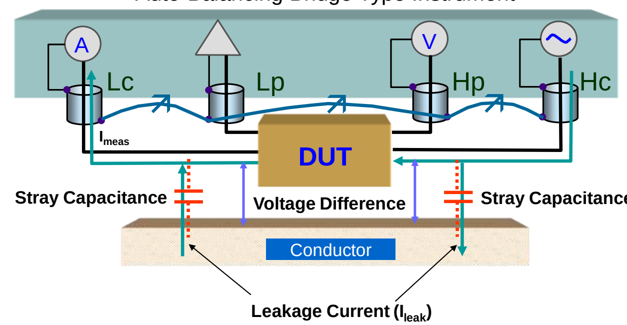
» Four-terminal pair (4TP) simplified schematic



1-2 Guarding (1 of 3)

Stray capacitance and leakage current

Auto-Balancing Bridge Type Instrument

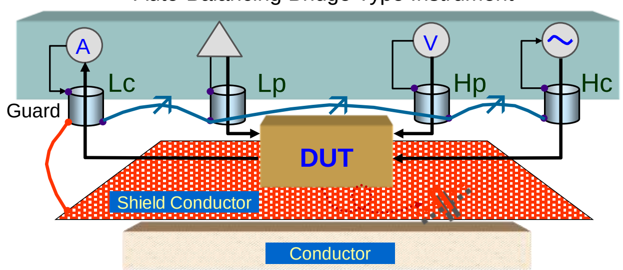


$I_{meas} = I_{dut} + I_{leak}$

1-2 Guarding (2 of 3)

Guard Mechanism and Solution

Auto-Balancing Bridge Type Instrument



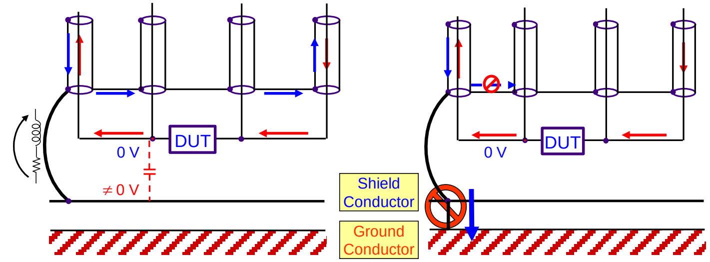
Potential difference → 0 V
Stray C effect → Nothing

1-2 Guarding (3 of 3)

Key Points to Consider

(a) Minimize impedance of guard line.

(b) Do NOT connect the guard terminal directly to the ground conductor.

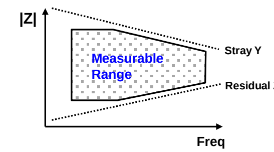


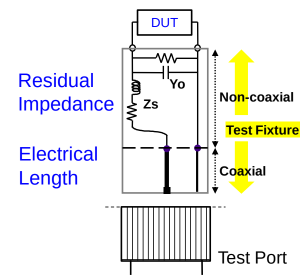
1-3 Test Fixtures and test leads in the LF range

Fixture and cable type	DUT connection configuration	Fixture model number	Applicable DUT type
Direct attachment type fixture	5-terminal	16047A 16044A	Lead type SMD type
	3-terminal	16047E 16034G/H	Lead type SMD type
Fixture with test leads	4-terminal	16089A/B/C/D	Lead type
	3-terminal	16334A 16065A	SMD type Lead type
Test leads	4-terminal pair	16048A/D/E/G/H	---

2-1 Terminal Configuration of RF Test Fixtures

Coaxial One Port Measurement



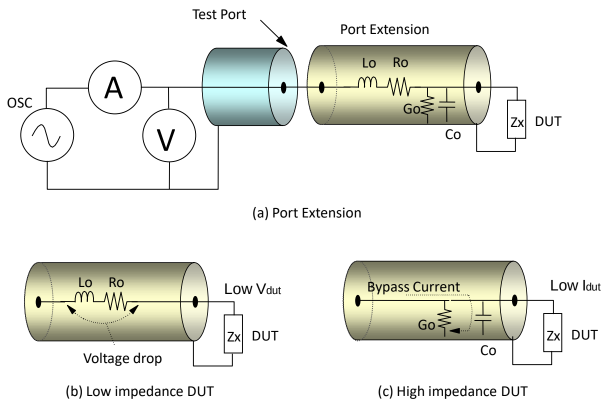


The measured value is also affected by a number of conditions surrounding the DUT:

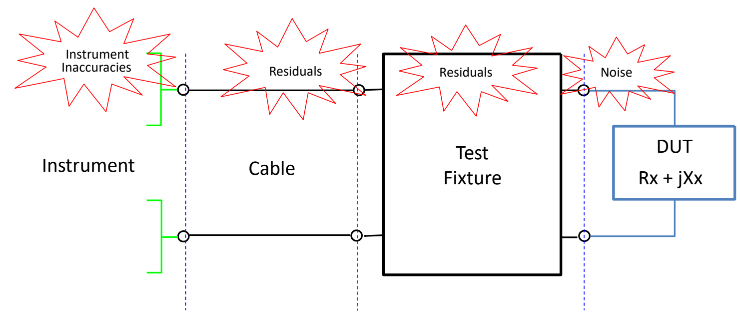
- Ground plate
- Terminal layout
- Dielectric constant of the insulator
- Other conditions

2-2 Test Port Extension in RF Range

» Calibration plane extension



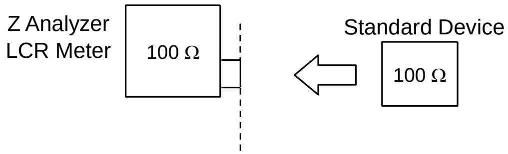
Measurement Error



Calibration and Compensation

Compensation ≠ Calibration

Defining the "Calibration Plane" at which measurement accuracy is to be specified.

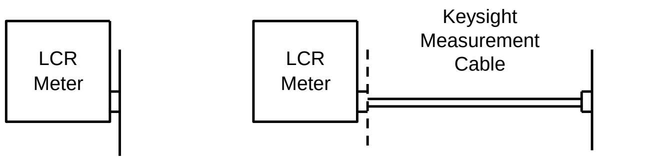


Calibration Plane
(Measurement accuracy is specified.)

Calibration and Compensation

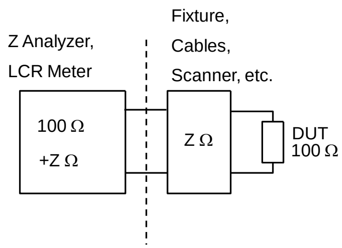
» Cable Correction

Extending the Calibration Plane using specified Keysight cables.
(Keysight 16048A/B/D/E)



Calibration and Compensation

Reducing the effects of error sources existing between the DUT and the instrument's "Calibration Plane".



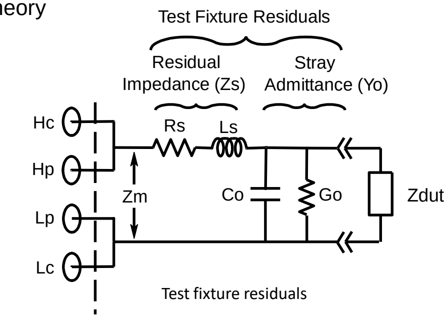
Calibration Plane

- 2 types of compensation:
  - OPEN/SHORT compensation
  - OPEN/SHORT/LOAD compensation

Calibration and Compensation

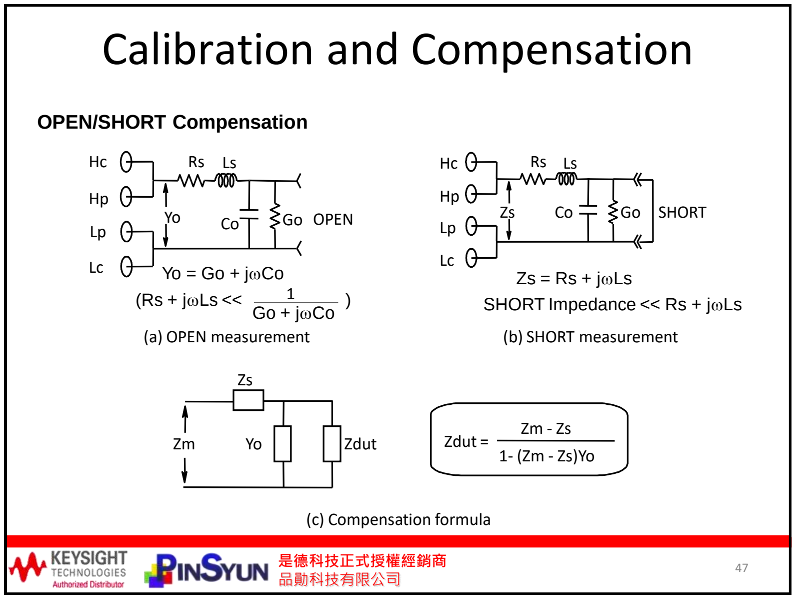
OPEN/SHORT Compensation

Basic Theory



Test fixture residuals

$$Zdut = \frac{Zm - Zs}{1 - (Zm - Zs)Yo}$$


Calibration and Compensation
OPEN/SHORT Compensation
Hc
Hp
Lp
Lc
Rs
Ls
Yo
Co
Go
OPEN
Yo = Go + jωCo
(Rs + jωLs << 1 / (Go + jωCo))
(a) OPEN measurement
Hc
Hp
Lp
Lc
Rs
Ls
Zs
Co
Go
SHORT
Zs = Rs + jωLs
SHORT Impedance << Rs + jωLs
(b) SHORT measurement
Zs
Zm
Yo
Zdut
Zdut = (Zm - Zs) / (1- (Zm - Zs)Yo)
(c) Compensation formula
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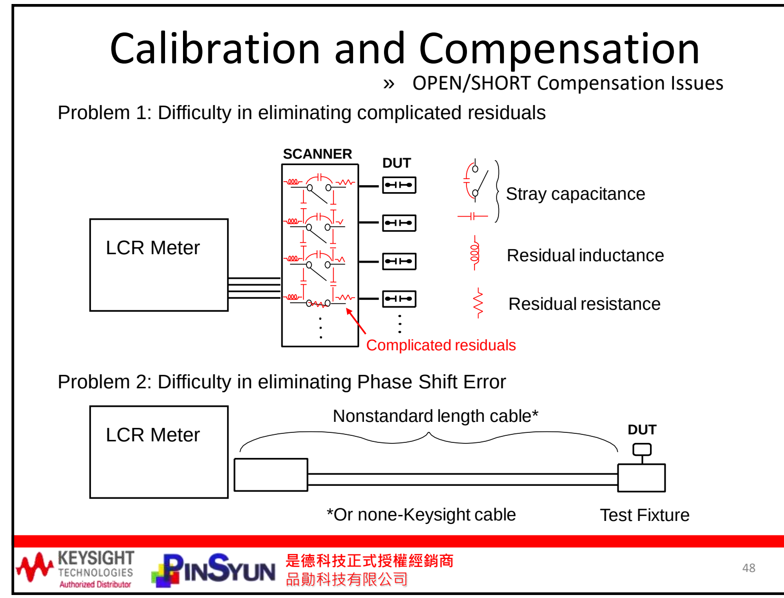
Calibration and Compensation
» OPEN/SHORT Compensation Issues
Problem 1: Difficulty in eliminating complicated residuals
LCR Meter
SCANNER
DUT
Stray capacitance
Residual inductance
Residual resistance
Complicated residuals
Problem 2: Difficulty in eliminating Phase Shift Error
LCR Meter
Nonstandard length cable*
DUT
*Or none-Keysight cable
Test Fixture
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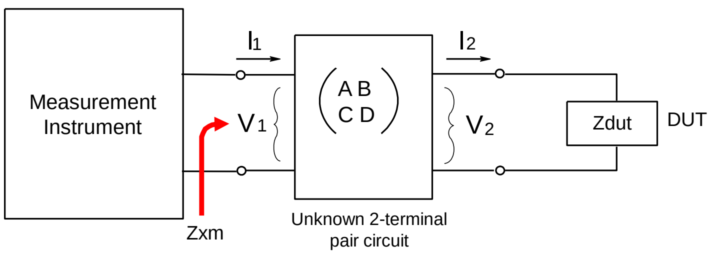
Calibration and Compensation

» OPEN/SHORT/LOAD Compensation

Basic Theory



$$Zdut = (A \times V_2 + B \times I_2) / (C \times V_2 + D \times I_2) = (A \times Zxm + B) / (C \times Zxm + D)$$

where $Zdut = V_1/I_1$ and $Zxm = V_2/I_2$

Calibration and Compensation

OPEN/SHORT/LOAD Compensation

Basic Theory

$$Zdut = \frac{Zstd\ (Zo - Zsm)\ (Zxm - Zs)^{*}}{(Zxm - Zs)\ (Zo - Zxm)}$$

Zo : OPEN measurement value

Zs : SHORT measurement value

Zsm : Measurement value of the LOAD device

Zstd : True value of the LOAD device

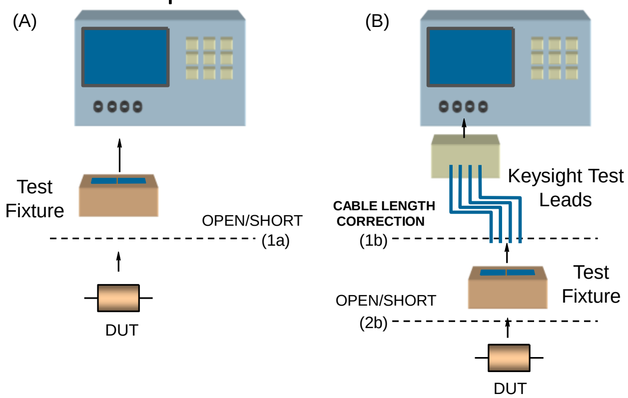
Zxm : DUT Measurement value

Zdut : DUT Corrected value

*These are complex vectors. Conversions to real and imaginary components are necessary

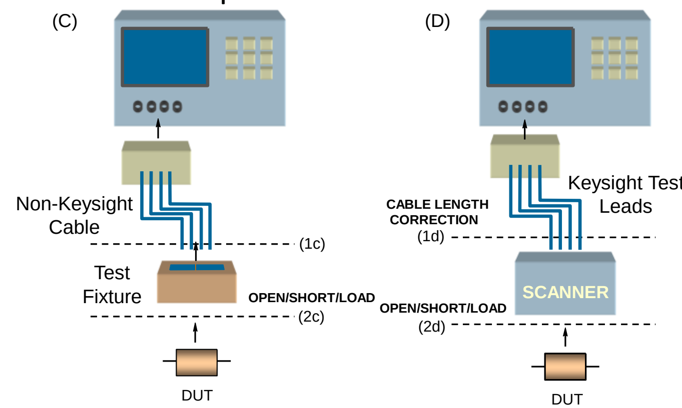
Practical compensation examples

» Practical Examples



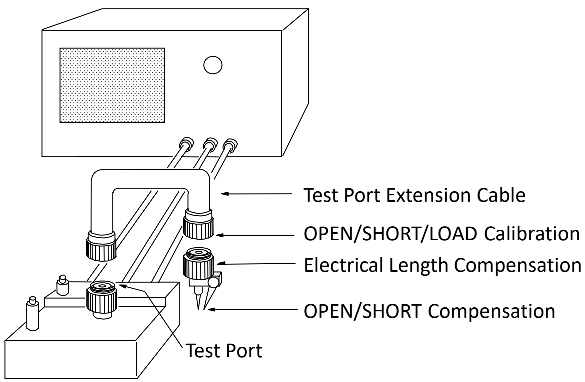
Practical compensation examples

» Practical Examples



Practical calibration and compensation in RF range

Port Extension



Agenda

- » Introduction
- » Impedance Basics & Measurement Method
- » Fixturing and cabling
- » Calibration and compensation
- » Impedance product lines
  - – LCR meter / Impedance analyzer

•延伸閱讀： RLC meter(電容電阻電感錶)
•延伸閱讀：查看如何使用網路分析儀量測阻抗
•延伸閱讀：LCR meter自動記錄軟體編程教學

Product Overview

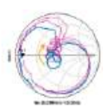
LCR Meters & Impedance Analyzers & Network Analyzers

LCR Meters & Impedance Analyzers

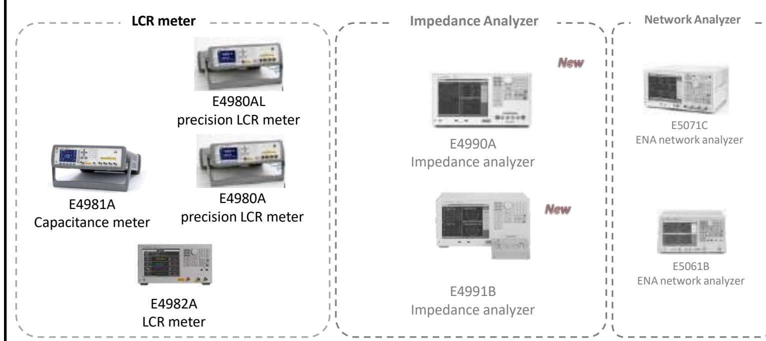
- ✓ Specialized to measure LCR & impedance
- ✓ High impedance accuracy
- ✓ Wide impedance measurement range
- ✓ Main target application:
  - Capacitors, inductors, resonators
  - Materials
  - Semiconductor
  - In-circuit (E4990A w/42941A)

Network Analyzers

- ✓ Measure S-parameter, also can be used for impedance measurement
- ✓ Higher Frequency range
- ✓ Main target application:
  - Filters, Antennas
  - DC-DC converters
  - Amplifiers, Mixers



LCR Meters



LCR Meters

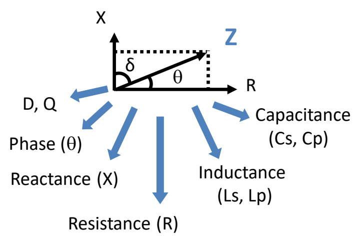
What Is LCR & Impedance Measurement?

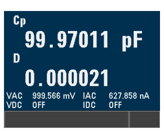
Measure Z, then calculate LCR value...

Measurement parameters

- Cp-D, Cp-Q, Cp-G, Cp-Rp
- Cs-D, Cs-Q, Cs-Rs
- Lp-D, Lp-Q, Lp-G, Lp-Rp, Lp-Rdc[1]
- Ls-D, Ls-Q, Ls-Rs, Ls-Rdc[1]
- R-X
- Z-θd, Z-θr
- G-B
- Y-θd, Y-θr
- Vdc-Idc[1]

1. Option E4980A-001 is required.



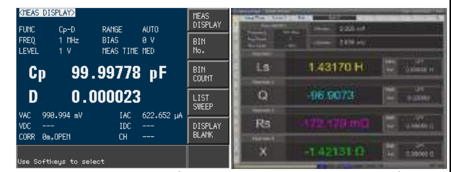


E4980A
(Cp-D measurement)

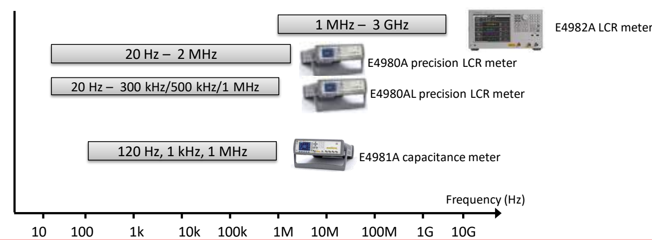
LCR Meters

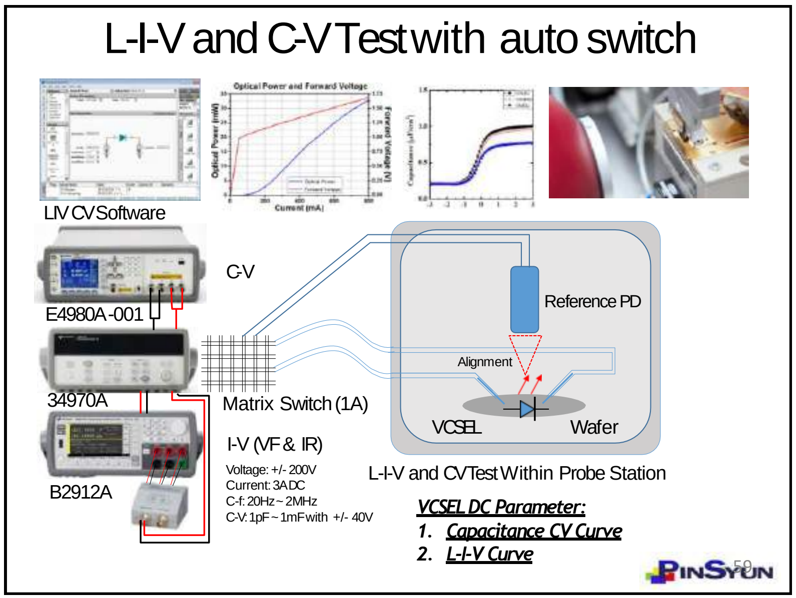
Overview

- Spot frequency measurement
- Numeric only display
- Lower price than analyzer
- High speed
- Application specific



E4980A Measurement Display E4982A Measurement Display




L-I-V and C-V Test with auto switch
LIV CV Software
E4980A-001
C-V
34970A
Matrix Switch (1A)
B2912A
I-V (VF & IR)
Voltage: +/- 200V
Current: 3A DC
C-f: 20Hz ~ 2MHz
C-V: 1pF ~ 1mF with +/- 40V
Reference PD
Alignment
VCSEL
Wafer
L-I-V and CV Test Within Probe Station
VCSEL DC Parameter:
1. Capacitance CV Curve
2. L-I-V Curve
PINSYUN
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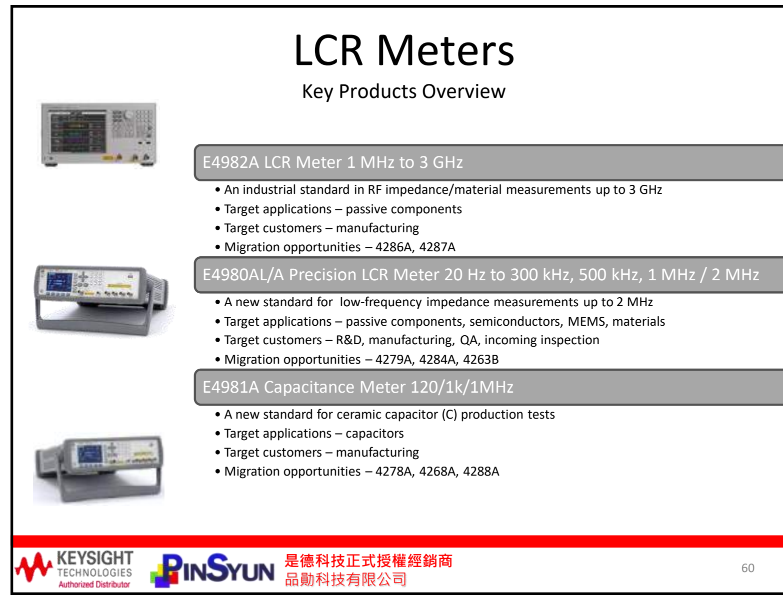
LCR Meters
Key Products Overview
E4982A LCR Meter 1 MHz to 3 GHz
• An industrial standard in RF impedance/material measurements up to 3 GHz
• Target applications – passive components
• Target customers – manufacturing
• Migration opportunities – 4286A, 4287A
E4980AL/A Precision LCR Meter 20 Hz to 300 kHz, 500 kHz, 1 MHz / 2 MHz
• A new standard for low-frequency impedance measurements up to 2 MHz
• Target applications – passive components, semiconductors, MEMS, materials
• Target customers – R&D, manufacturing, QA, incoming inspection
• Migration opportunities – 4279A, 4284A, 4263B
E4981A Capacitance Meter 120/1k/1MHz
• A new standard for ceramic capacitor (C) production tests
• Target applications – capacitors
• Target customers – manufacturing
• Migration opportunities – 4278A, 4268A, 4288A
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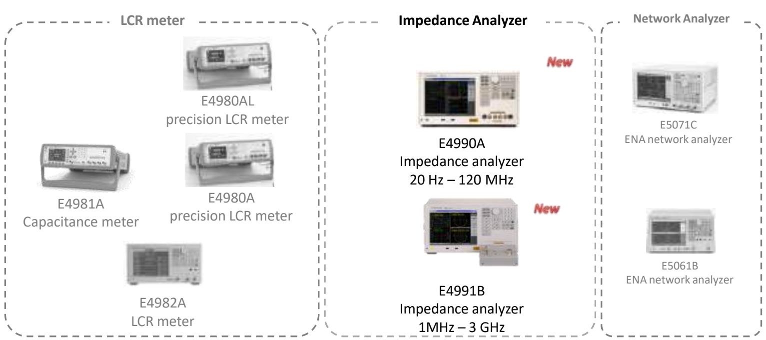
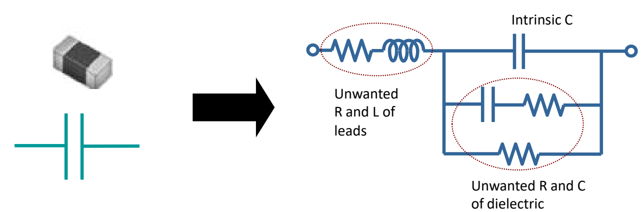
Impedance Analyzers



Impedance Analyzers

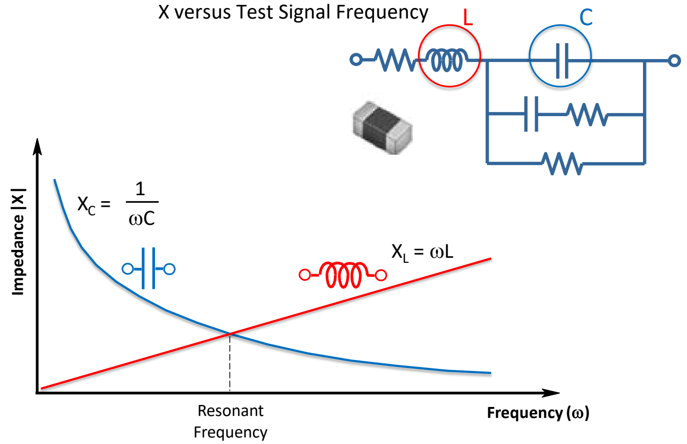
- **No real components are purely resistive or reactive**
  - Every component is a combination of R, C and L elements
  - The unwanted elements are called **parasitics**



Capacitor Equivalent Circuit

Impedance Analyzers

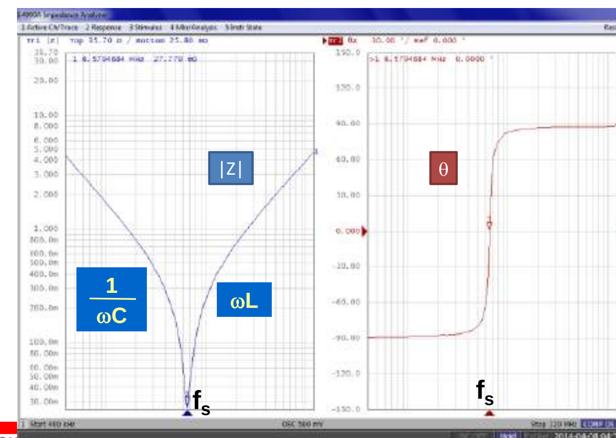
X versus Test Signal Frequency



Impedance Analyzers

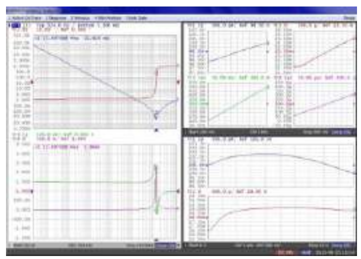
Example Capacitor Resonance

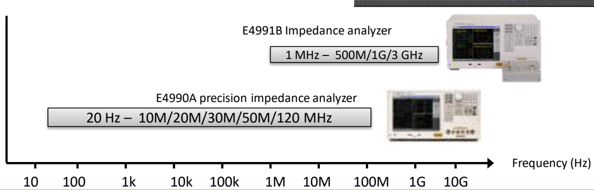
Impedance versus Frequency



Impedance Analyzers

- Sweeps parameter, displays graphics
  - Frequency
  - DC Bias
  - AC level
- Use model
  - Frequency characteristics analysis
  - Resonant analysis
  - Circuit modeling





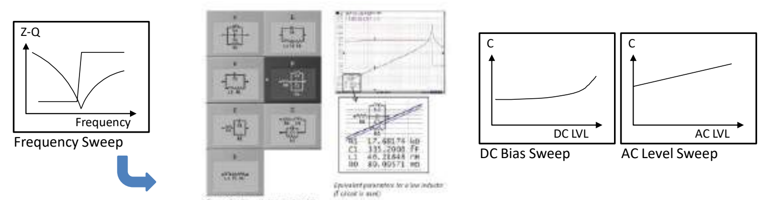
Impedance Analyzers

E4990A Impedance Analyzer

Key numbers…

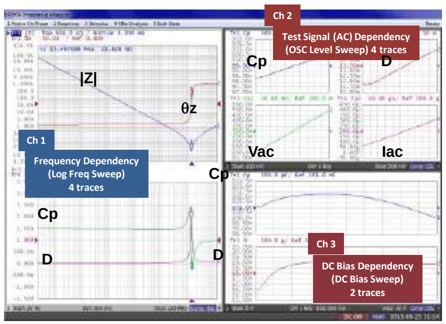
- Frequency range: 20 Hz ～ 10M/20M/30M/50M/120 MHz
- Basic measurement accuracy: 0.08% (0.045 % typical)

Versatile Analysis Functions



Equivalent Circuit Calculation

Quick and comprehensive analysis by Multi-channel and Multi-trace



Example
- Check wide frequency performance of Z, theta, Cp and D in Channel 1
- Check AC level dependency at 1kHz in Channel 2
- Check DC Bias level dependency in Channel 3

Impedance Analyzers

Key Products Overview

E4991B Impedance/Material Analyzer 1 MHz to 500 MHz/1 GHz/3 GHz
- An industrial standard in RF impedance/material measurements
- Target applications – passive components, semiconductors, materials
- For – R&D, QA, incoming inspection
- Replaces 4291A, E4991A
- 0.65% basic accuracy

E4990A Impedance Analyzer 20 Hz to 10M/20M/30M/50M/120MHz
- An industrial standard in mid-freq. impedance measurements
- Target applications – passive components, semiconductors, materials, in-circuit
- For– R&D, QA, incoming inspection
- Replaces – 4192A, 4194A, 4294A
- 0.045% (typ.) basic accuracy

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