Retos y Soluciones en Medidas de Impedancia

Adolfo Del Solar

Application Engineer
adolfo_del-solar@agilent.com

Agenda

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

- Introduction
- Impedance fundamentals
- Measurement methods
- Fixturing and cabling
- Calibration and compensation
- Solution selection process

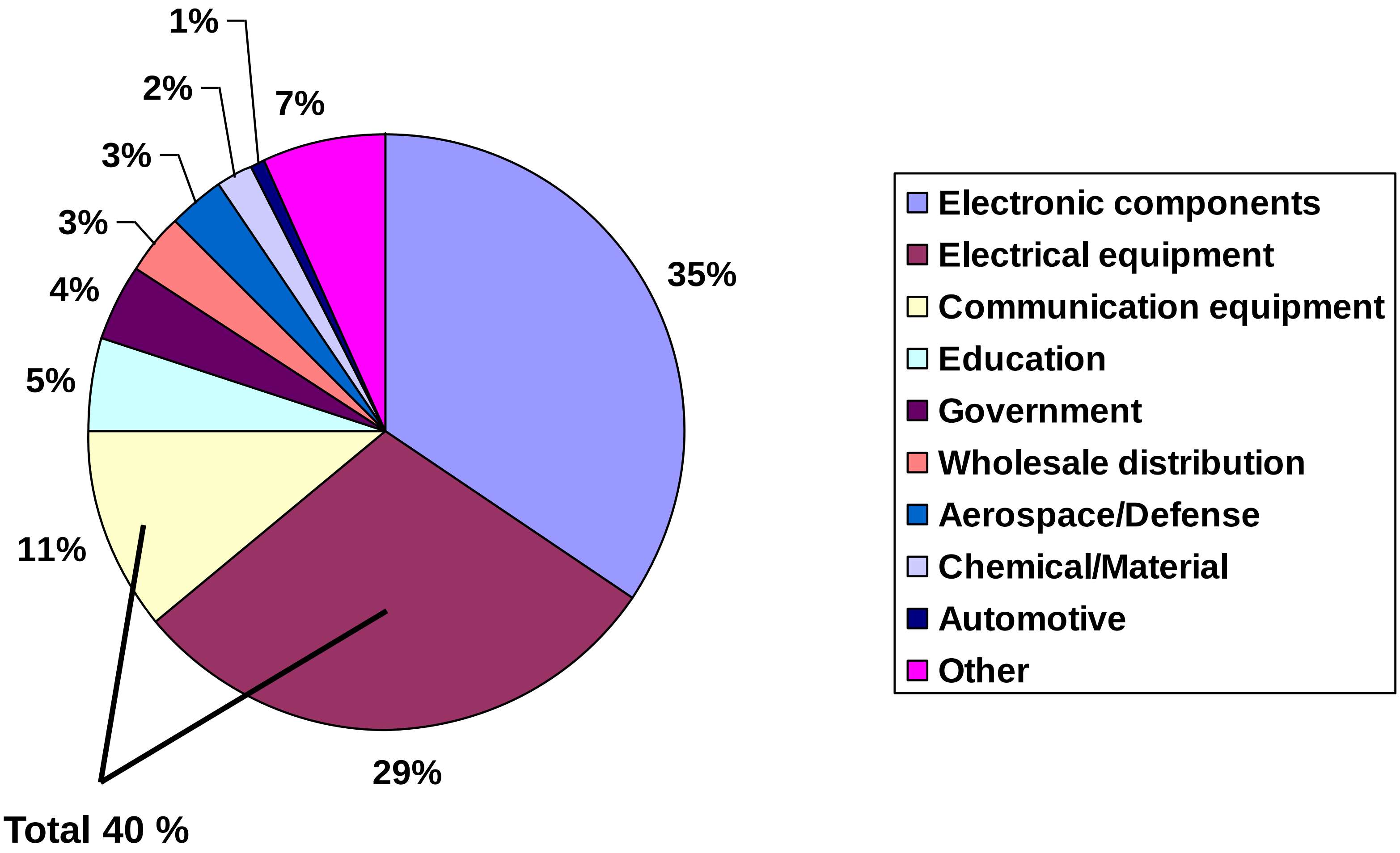
Agenda

Unlocking Measurement Insights for 75 Years

- **Introduction**
  - Impedance test environment
  - Challenges
  - Components tested

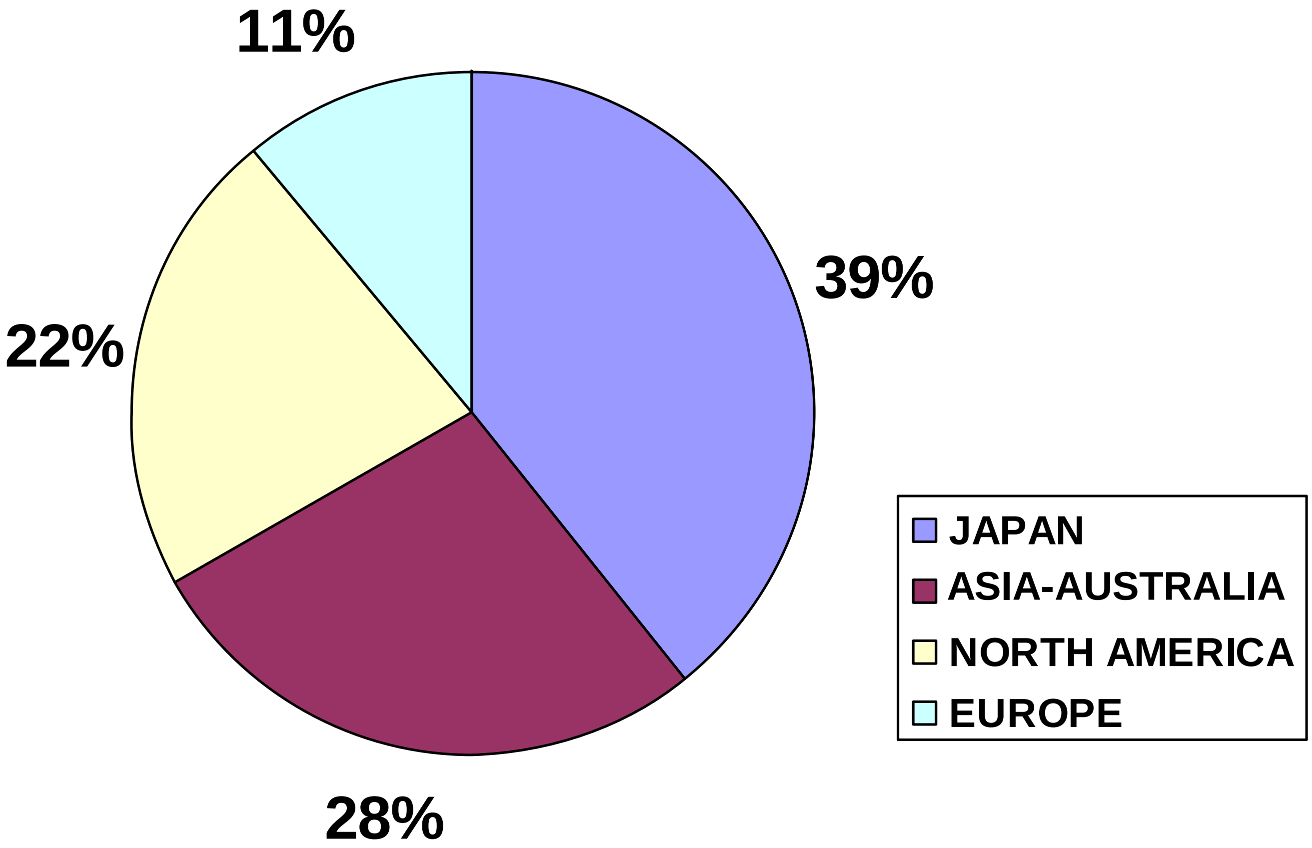
Industry Distribution

Unlocking Measurement Insights for 75 Years



Geographical Distribution

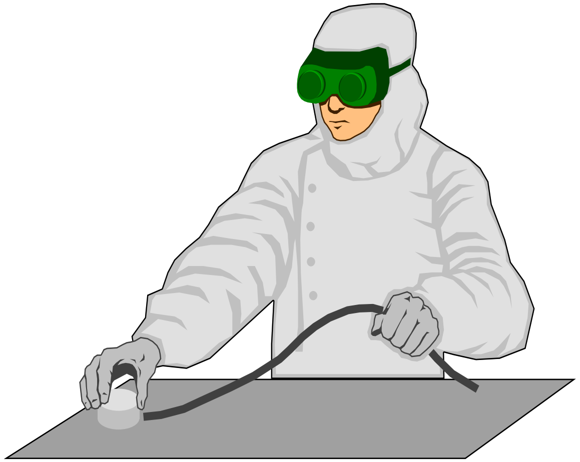
Unlocking Measurement Insights for 75 Years



Profile: Component Manufacturers

Unlocking Measurement Insights for 75 Years

- **Impedance testing is done throughout the design and manufacturing processes**
- **Material evaluation (ceramics, inductor cores)**
  - Ensures component performance and quality
- **Production test**
  - Minimizes production failure rate
  - Ensures that specifications are met
- **Accuracy and speed requirements vary**



Profile: Equipment Manufacturers

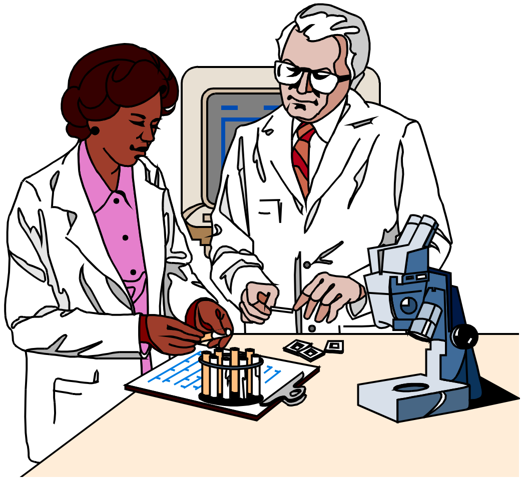
Unlocking Measurement Insights for 75 Years

- **Incoming inspection**
  - Find defective components before they are used
  - Quality assurance departments may use several types of impedance measuring instruments
- **Circuit design**
- **Circuit evaluation**
  - Check all components on the PC board
  - Probing required

Profile: Education and Research

Unlocking Measurement Insights for 75 Years

- **Measuring material and component behavior over a wide range of conditions**
- **Testing new and experimental materials**
- **Key instrument features:**
  - Wide range of capabilities
  - PC connectivity for simplified data collection and analysis



Agenda

Unlocking Measurement Insights for 75 Years

- **Introduction**
  - Impedance test environment
  - Challenges
  - Components tested

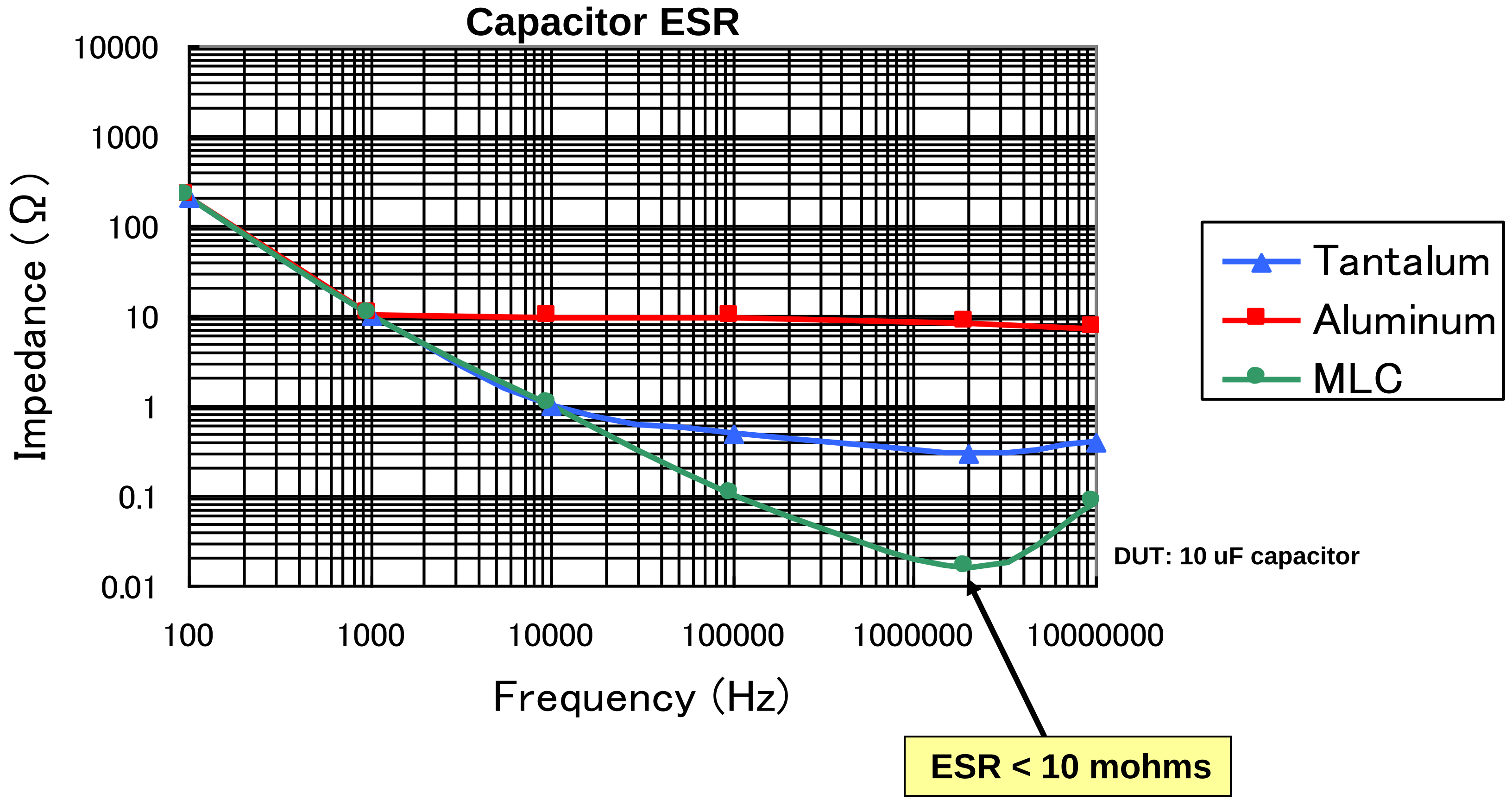
Current Trends in Test Requirements

Unlocking Measurement Insights for 75 Years

- Higher frequencies
- High quality/low loss
- Smaller size
- Lower price
- Stable performance in various environments

Higher Frequency / Lower Loss

- **Equivalent series resistance (ESR) is a key parameter**

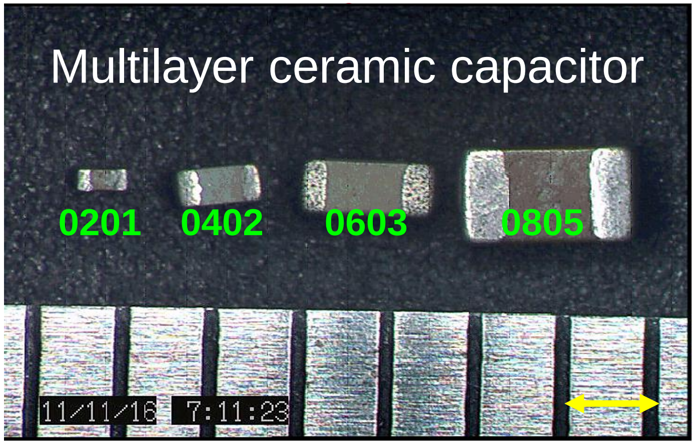


DUT: 10 uF capacitor

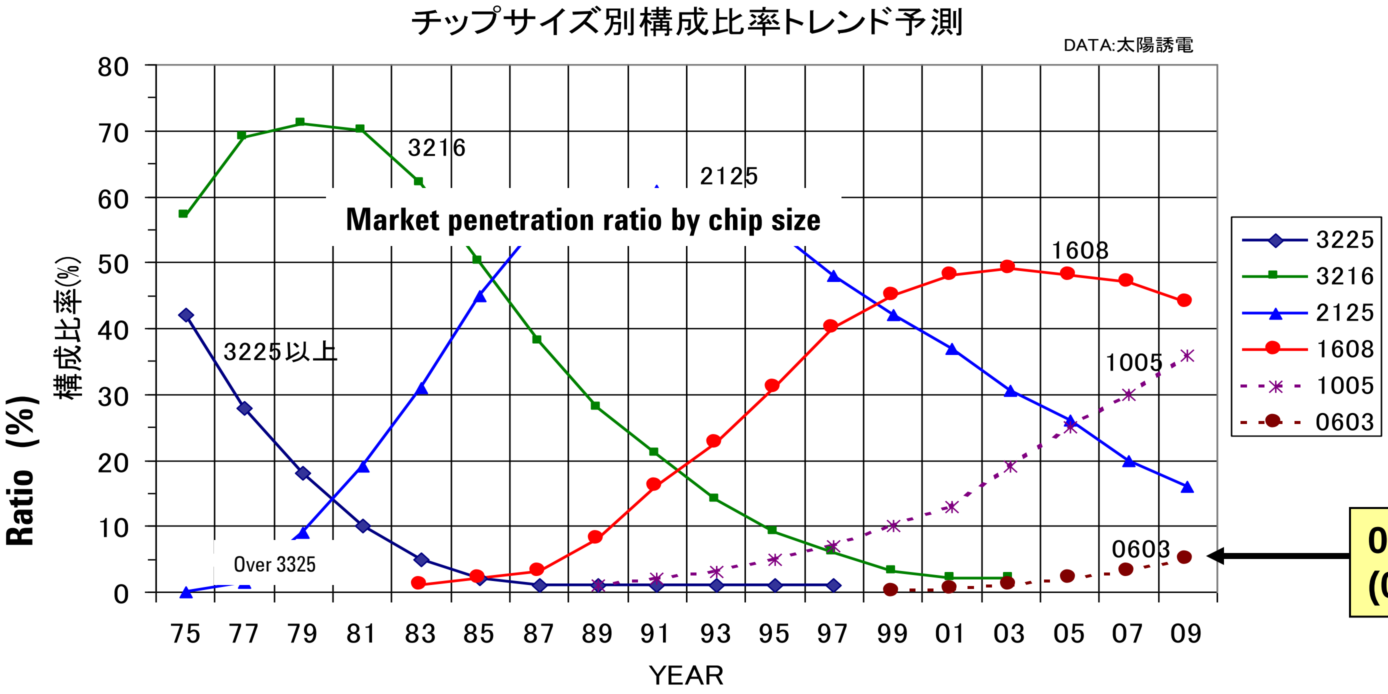
ESR < 10 mohms

Smaller SMDs

- **Extremely small packages**
  - As small as 0.02 x 0.01 inches
  - Require special test fixture



1mm



Market penetration ratio by chip size

0201 size
(0.6 mm x 0.3 mm)

Agenda

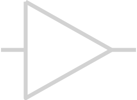
Unlocking Measurement Insights for 75 Years

- **Introduction**
  - Impedance test environment
  - Challenges
  - Components tested

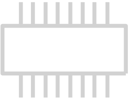
Example DUT

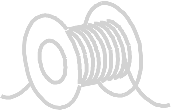
KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years



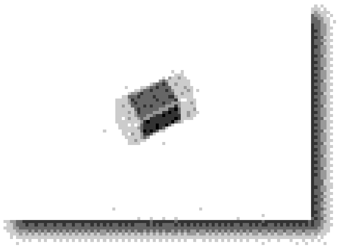
- Amplifier Circuit
- Antenna
- Battery
- Cable
- Capacitor, Ceramic
- Capacitor, Electrolytic
- Capacitor, Film
- Connector
- Diode
- IC Package
- Inductor, IF/RF
- Inductor, Ferrite Core
- Inductor, Power
- Inductor, Transformer





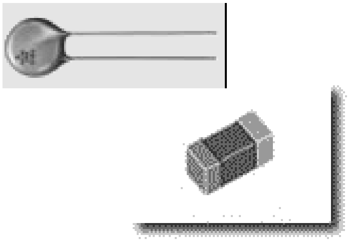
- HDD Head, Magnetic
- HDD Head, MR
- Material, Dielectric
- Material, Magnetic
- PC board
- Relay
- Resistor
- Resonator, Ceramic
- Resonator, Crystal
- RFID
- Switch
- Transistor

Capacitors



Ceramic (<10 uF)

- 0.1 pF to 10 µF
- Low D/high Q
- Wide capacitance range



Ceramic (>10 uF)

- 10 µF to 200 µF
- High capacitance

Electrolytic

- 0.1 µF to 0.1 F
- High capacitance

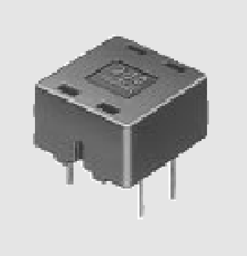
Film

- 20 pF to 400 µF
- Low D/high Q
- High stability
- High reliability

Inductors

RF/IF

- 100 kHz to 6 GHz
- Low D/high Q
- High SRF
- Small size



EMI

- 10 kHz to 1 GHz
- Noise suppression
  - Power line
  - Signal line

Power

- Switching freq.
- High current

Transformer

- Power trans. to 120 Hz
- Switching trans. to 1 MHz
- AC voltage conversion

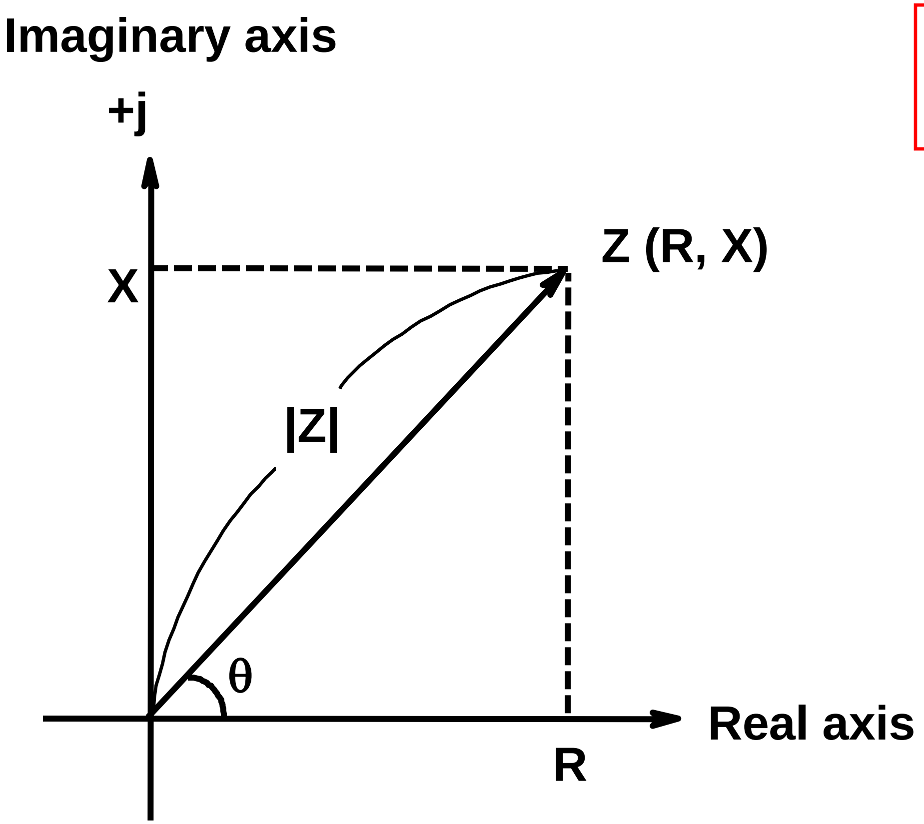
Agenda

Unlocking Measurement Insights for 75 Years

- Introduction
- **Impedance fundamentals**
  - What is impedance?
  - Parasitics
  - Ideal, real and measured values
  - Component dependency factors

Definition of Impedance (Z)

- **Total opposition a device or circuit offers to the flow of AC**



$$Z = R + jX = |Z|\angle\theta$$

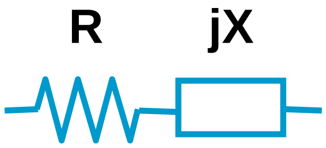
$$R = |Z|\cos\theta$$
$$X = |Z|\sin\theta$$

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

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

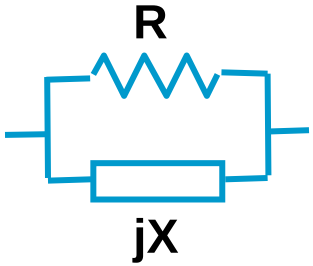
Series and Parallel Combinations

Real and imaginary components are connected in series



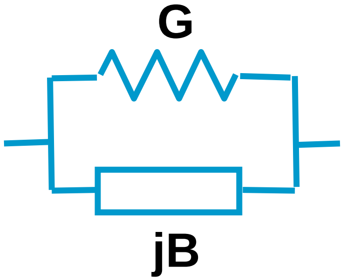
$Z = R + jX$
(Impedance is easier to express)

Real and imaginary components are connected in parallel



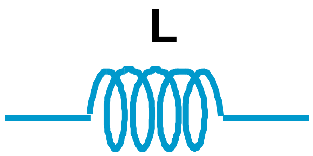
$$Z = \frac{jRX}{R + jX} = \frac{RX^2}{R^2 + X^2} + j\frac{R^2X}{R^2 + X^2}$$

(Impedance is too complex)

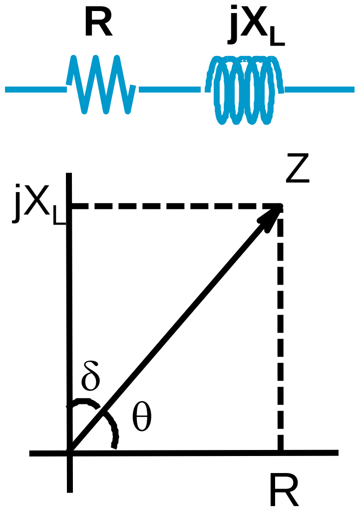


$Y = G + jB$
(Admittance is easier)

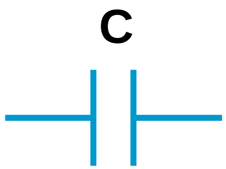
Impedance Plane



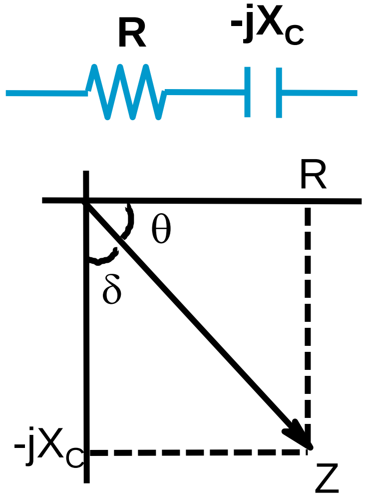
$$X_L = 2\pi f L = \omega L$$



(a) Inductive vector on impedance plane



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



(b) Capacitive vector on impedance plane

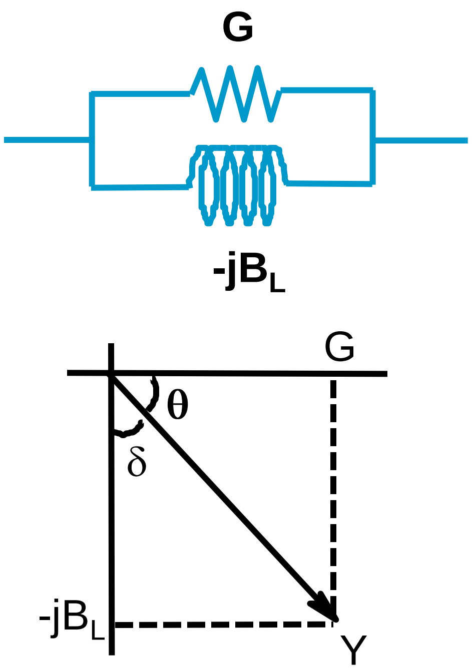
Q = quality factor $= \dfrac{X_L}{R} = \dfrac{-X_C}{R}$

$= \tan\theta$

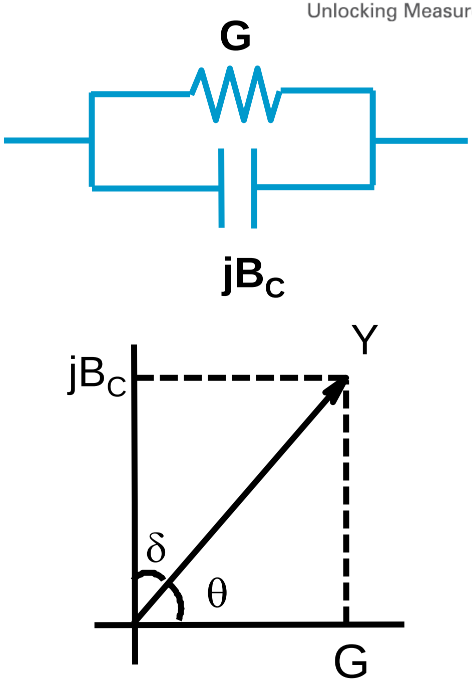
D = dissipation factor $= \dfrac{1}{Q}$

$= \tan\delta$

Admittance Plane



(c) Inductive vector
on admittance plane



(d) Capacitive vector
on admittance plane

$$Q = \frac{-B_L}{G} = \frac{B_C}{G} = \tan\theta$$

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

Quality and Dissipation Factors

- $Q = \dfrac{\text{Energy stored}}{\text{Energy lost}} = \dfrac{X_L}{R}$ **(inductors)**
- **As** $R \Rightarrow 0$, $Q \Rightarrow \infty$ **(better component)**
- $D = \dfrac{1}{Q} = \dfrac{R}{-X_C}$ **(capacitors)**
- **As** $R \Rightarrow 0$, $D \Rightarrow 0$ **(better component)**

Agenda

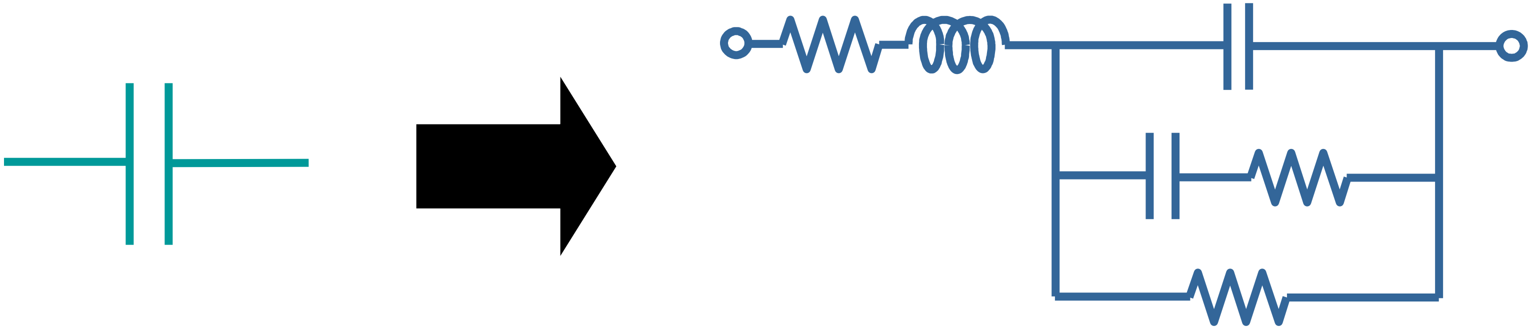
Unlocking Measurement Insights for 75 Years

- Introduction
- **Impedance fundamentals**
  - What is impedance?
  - Parasitics
  - Ideal, real and measured values
  - Component dependency factors

Parasitics

Unlocking Measurement Insights for 75 Years

- **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**

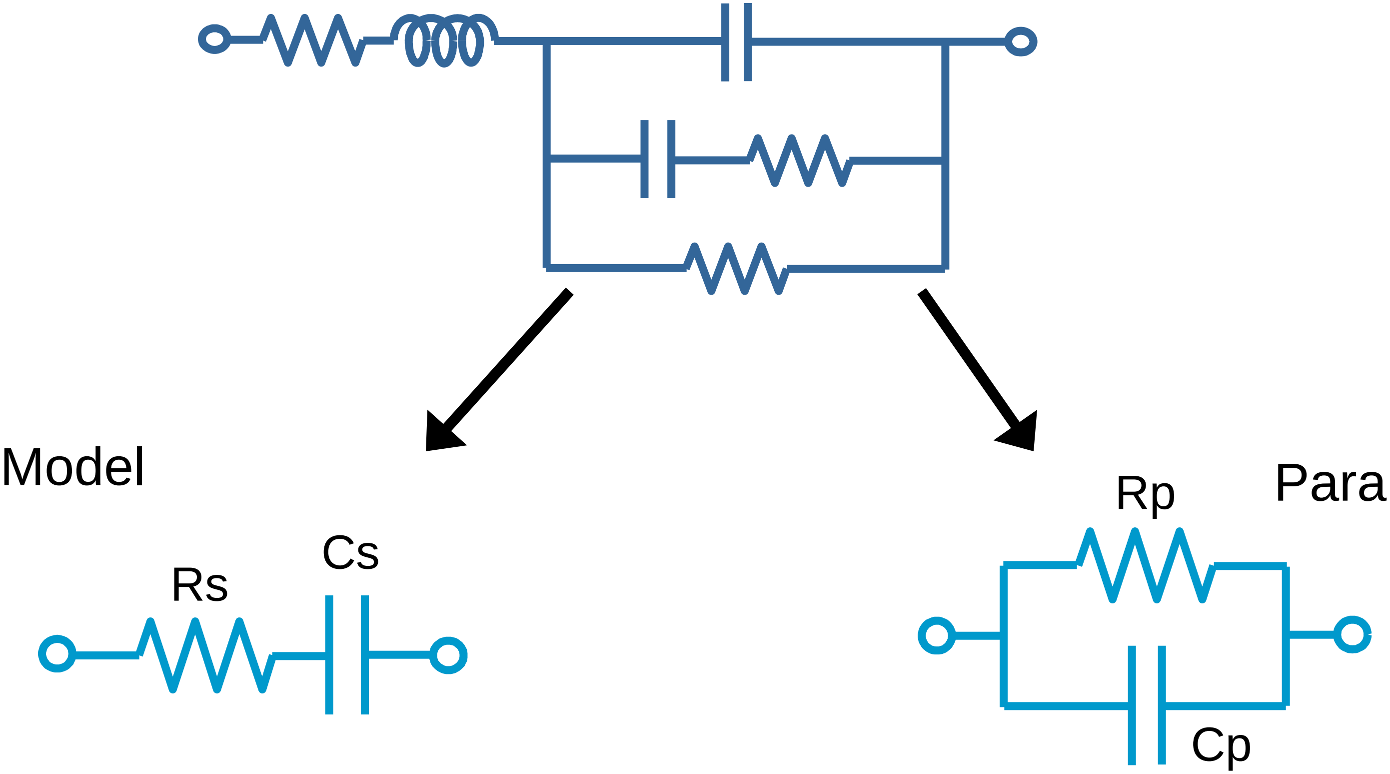


Capacitor Equivalent Circuit

Series and Parallel Models

Unlocking Measurement Insights for 75 Years

Capacitor Equivalent Circuit



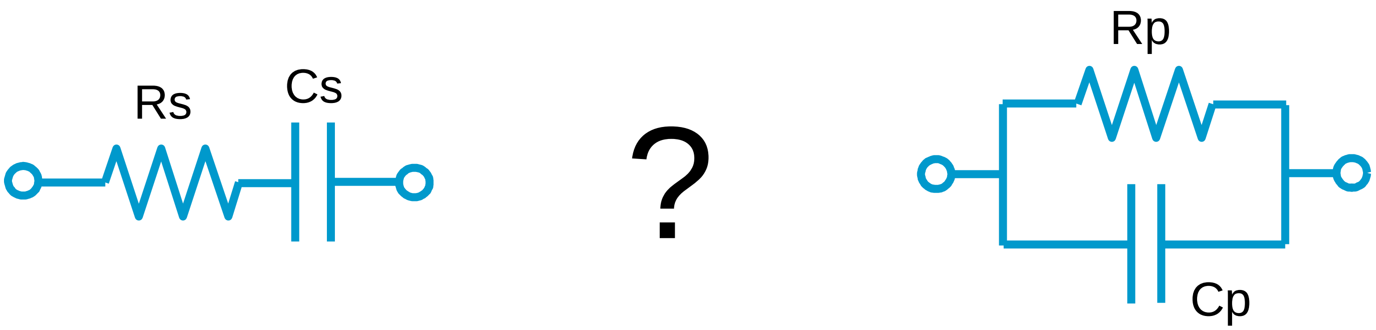
Series Model

Parallel Model

Low-Impedance Device
(Large C, Small L)

High-Impedance Device
(Small C, Large L)

Which Model is Correct?



Series model

Parallel model

- **Both are correct:**

$$C_S = C_P\,(1 + D^2)$$

- **For a low Q (high D) device, one model will be more accurate**

- **For a high Q (low D) device, $C_S \approx C_P$**

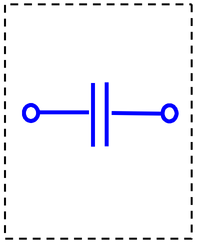
Agenda

Unlocking Measurement Insights for 75 Years

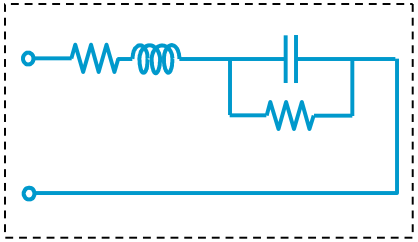
- Introduction
- **Impedance fundamentals**
    - What is impedance?
    - Parasitics
    - Ideal, real and measured values
    - Component dependency factors

Ideal, Real, and Measured Values

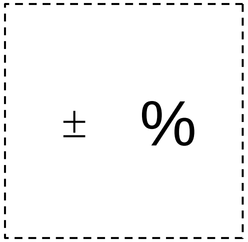
- **Ideal value**
  - Excludes effects of parasitics
  - Academic interest only



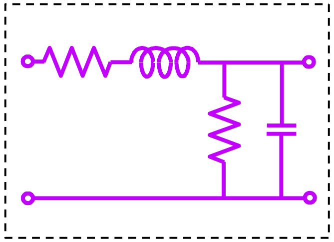
- **Real value**
  - Takes into consideration the parasitics
  - Frequency dependent



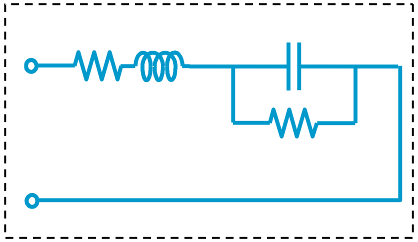
- **Measured value**
  - The value obtained with and displayed by the measuring instrument.



Instrument



Test fixture



Real-world device

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

Agenda

Unlocking Measurement Insights for 75 Years

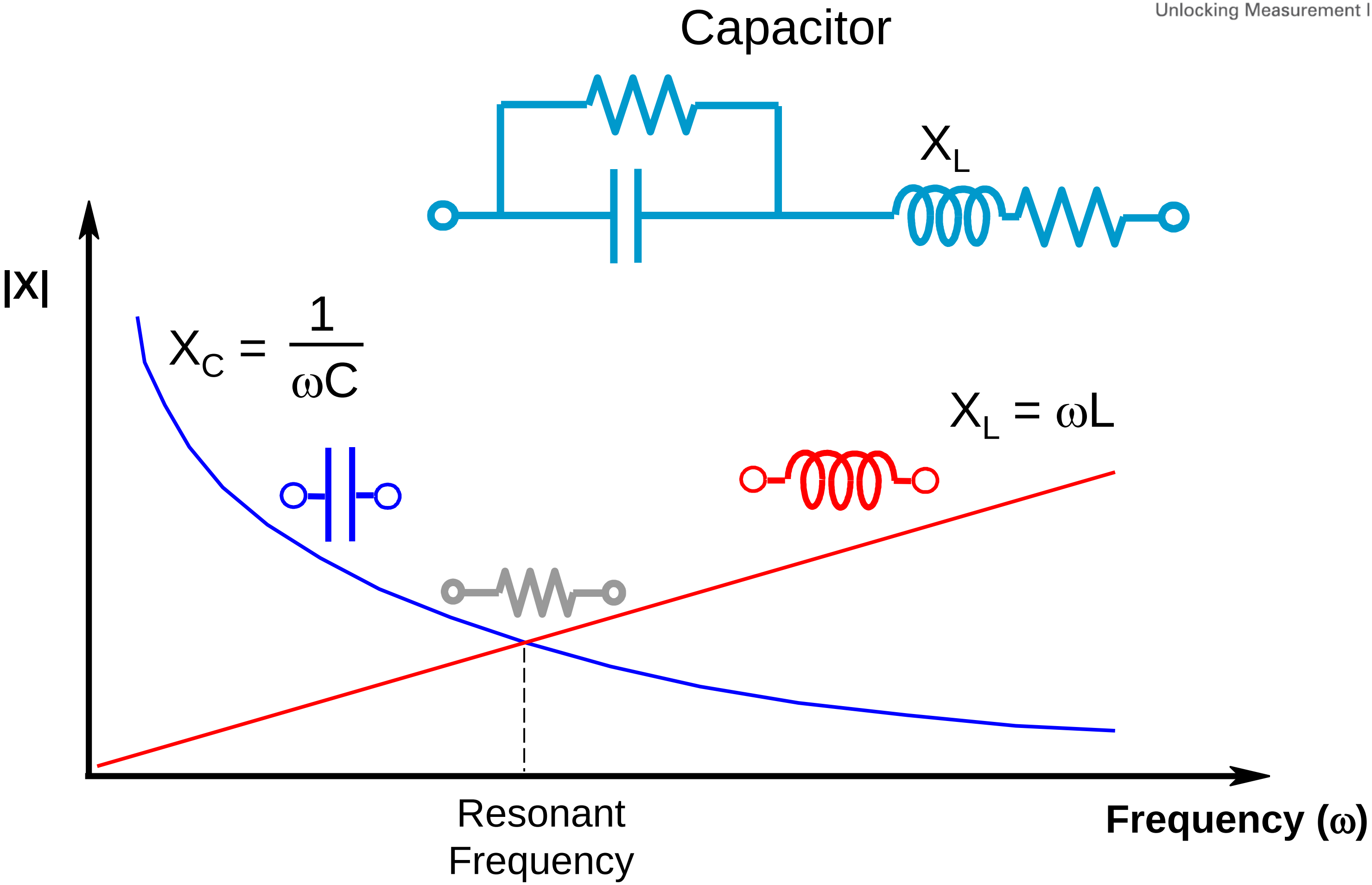
- Introduction
- **Impedance fundamentals**
  - What is impedance?
  - Parasitics
  - Ideal, real and measured values
  - Component dependency factors

Component Dependency Factors

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

X versus Test Signal Frequency

Unlocking Measurement Insights for 75 Years

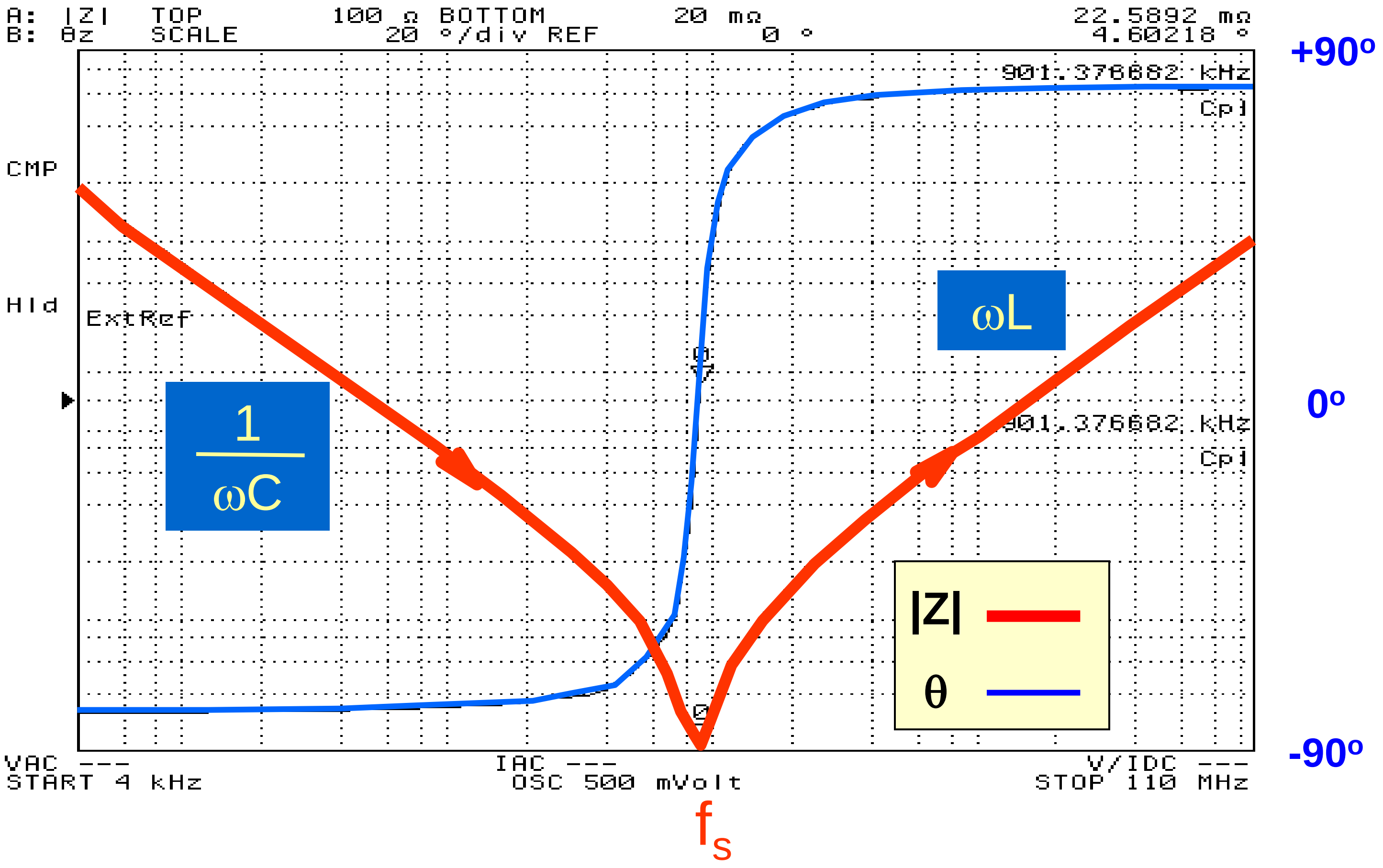


Example: Capacitor Resonance

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

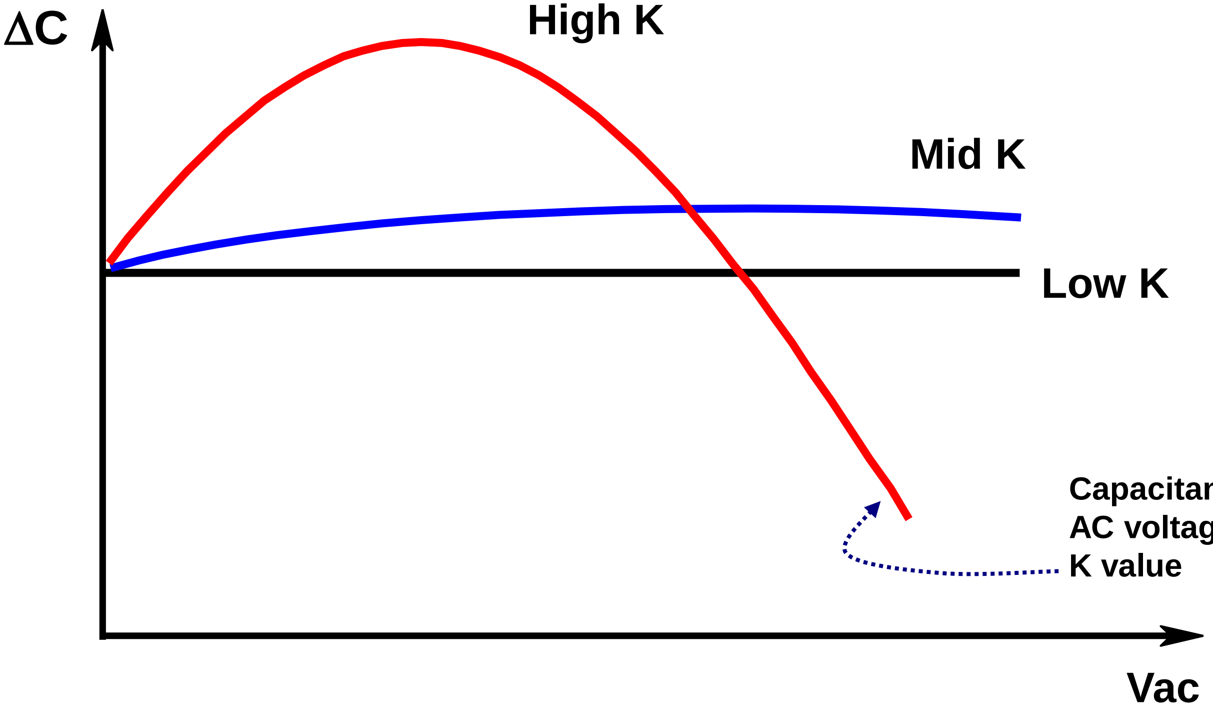
Impedance versus Frequency



C versus Test Signal Level

Unlocking Measurement Insights for 75 Years

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

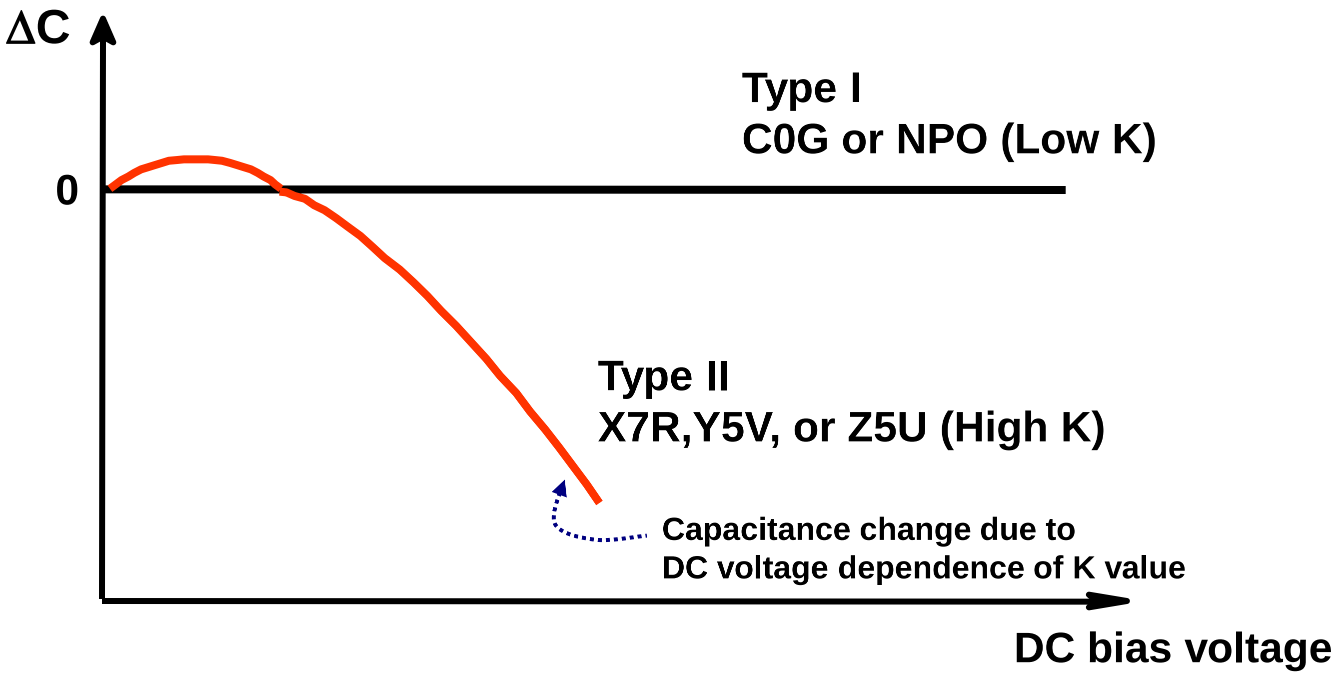


Capacitance change due to AC voltage dependence of K value

C versus DC Voltage Bias

Unlocking Measurement Insights for 75 Years

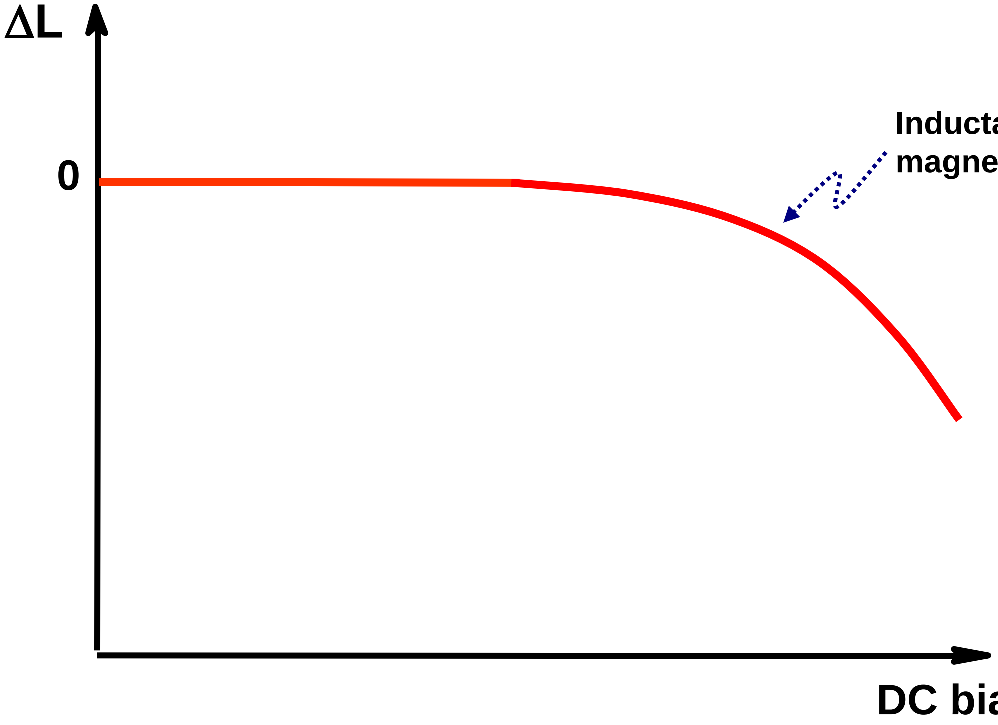
DC bias voltage dependency of type I and II SMD capacitors



L versus DC Current Bias

Unlocking Measurement Insights for 75 Years

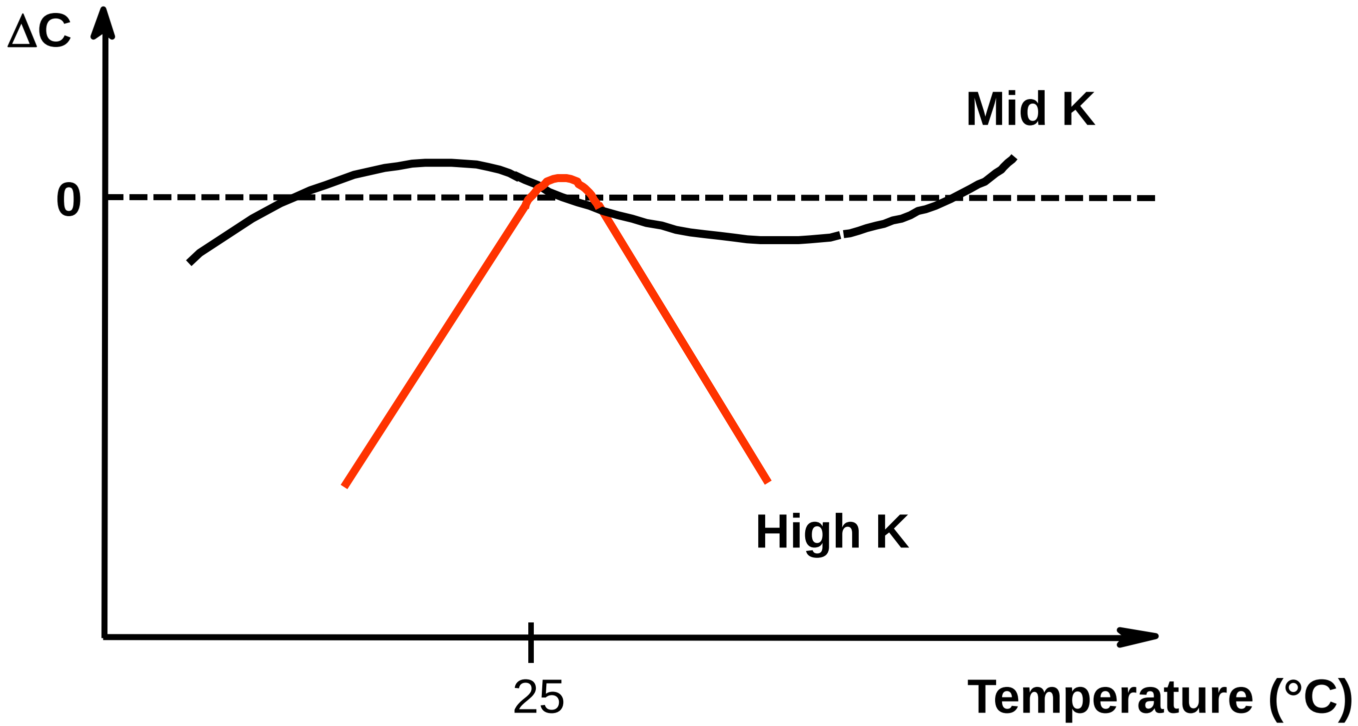
DC bias current dependency of cored inductors



Inductance roll-off due to magnetic saturation of inductor core

C versus Temperature

Temperature dependency of ceramic capacitors for different K values



Agenda

- Introduction
- Impedance fundamentals
- **Measurement methods**
  - Popular methods
  - Instrument functions

Popular Measurement Methods

- **Auto-balancing bridge**
- **RF I-V**
- **Network analysis (reflection coefficient)**
- **Less popular methods**
    - Bridge
    - Resonant (Q meter)
    - I-V (probe)

Measurement Method Considerations

Unlocking Measurement Insights for 75 Years

- **Method and instrument selection criteria**
- Theory of operation
- Advantages and disadvantages

Method and Instrument Selection Criteria

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

These determine the most suitable method

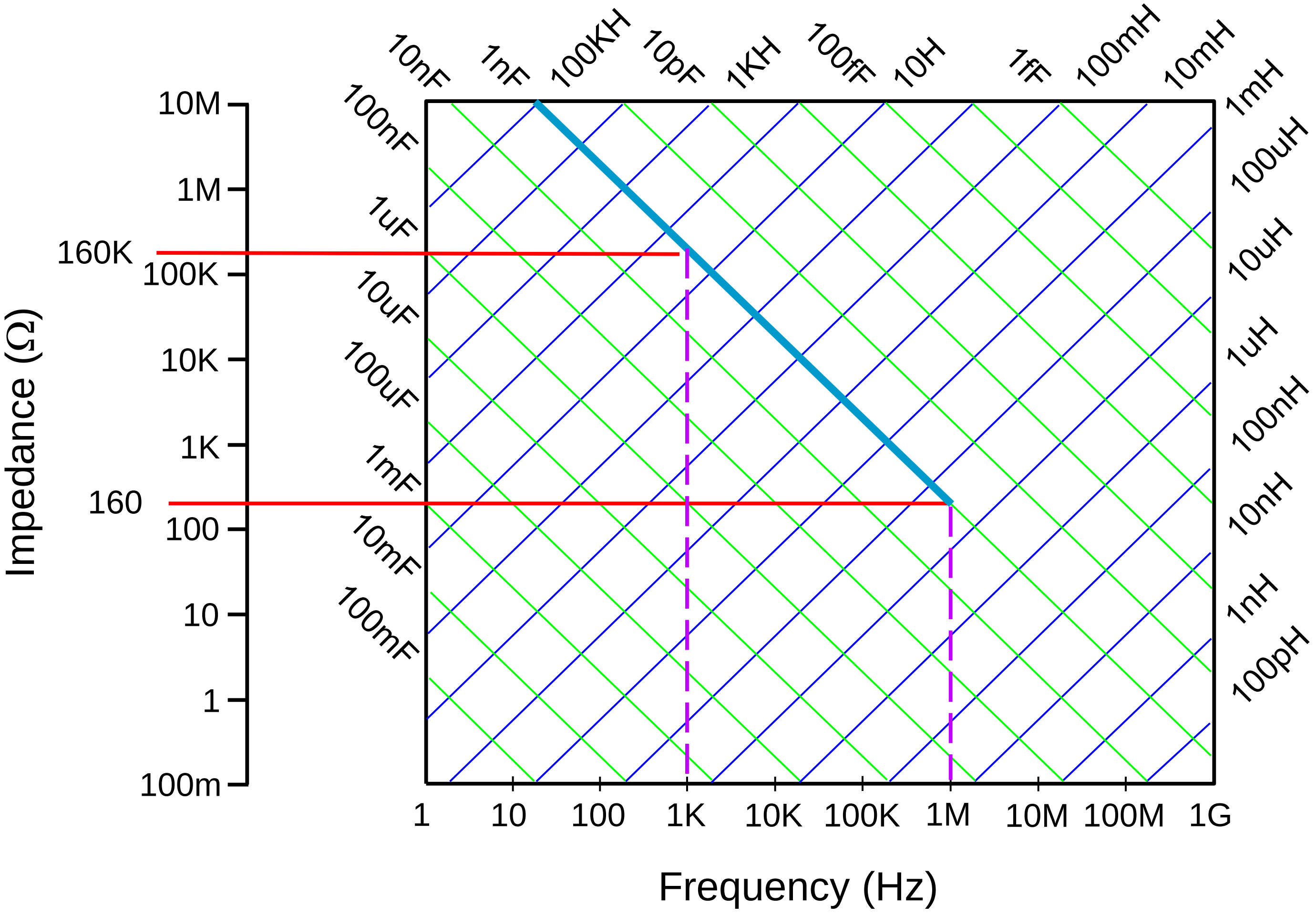
4) Electrical test conditions
5) Measurement parameters
6) Physical characteristics of DUT

These determine the proper instrument and test fixture

Finding Impedance from Frequency

Unlocking Measurement Insights for 75 Years

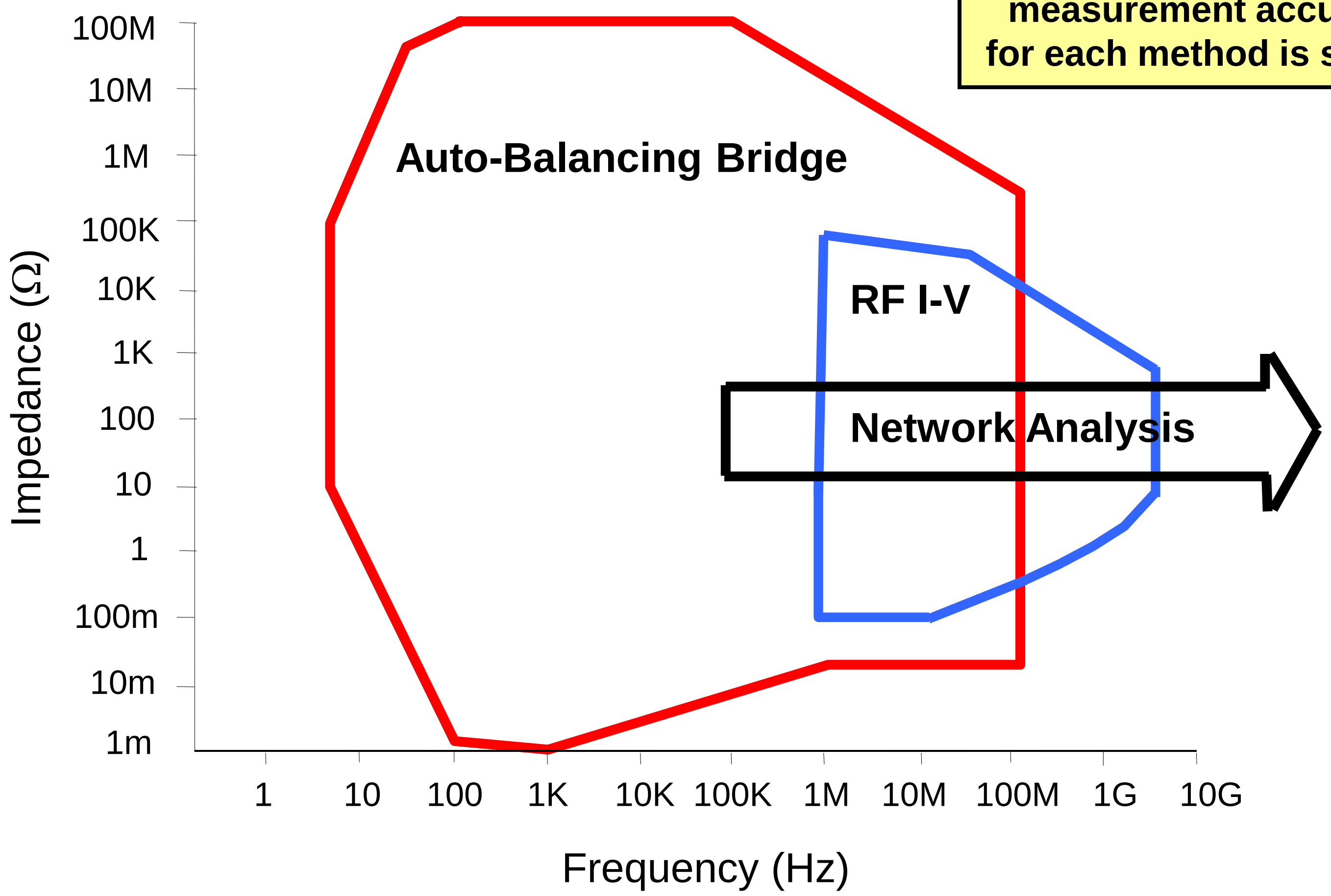
Reactance Chart



Frequency and DUT Impedance

Unlocking Measurement Insights for 75 Years

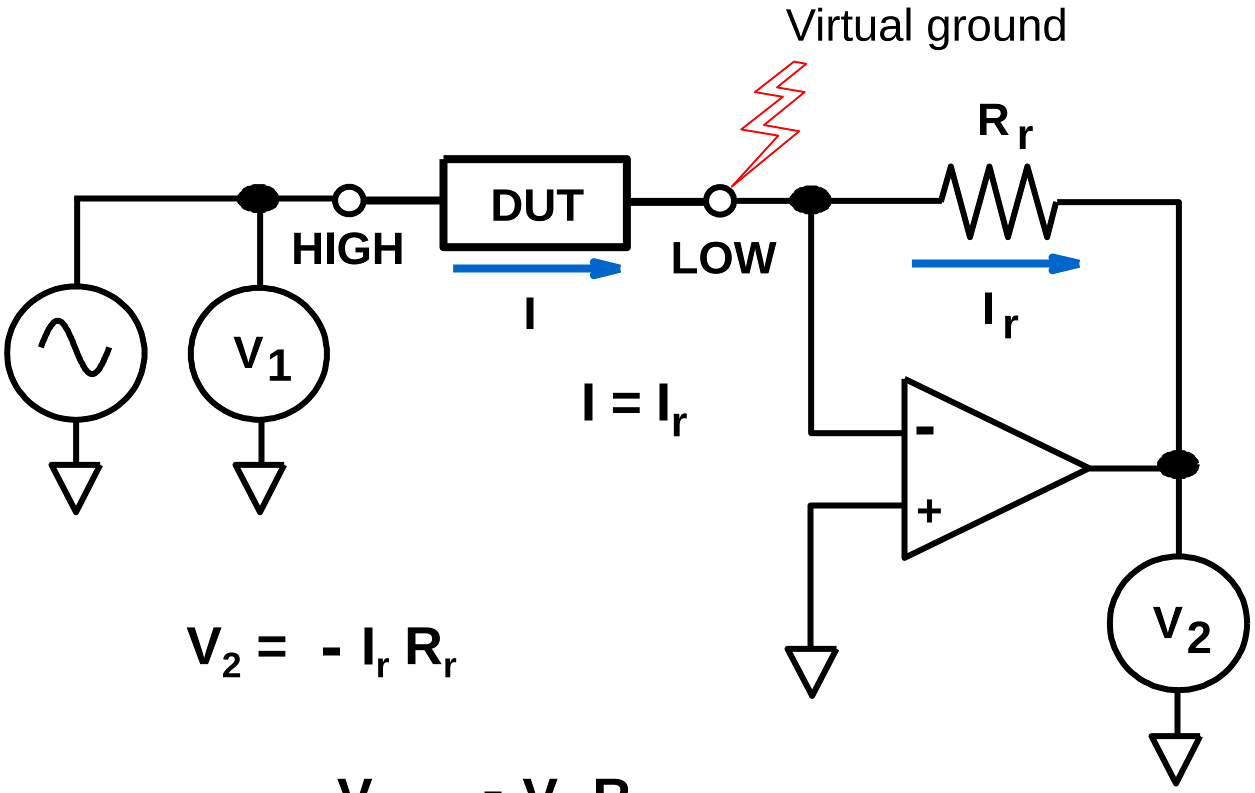
The area of 10% measurement accuracy for each method is shown



Measurement Method Considerations

- Method and instrument selection criteria
- **Theory of operation**
- Advantages and disadvantages

Auto-Balancing Bridge Method (1 of 2)

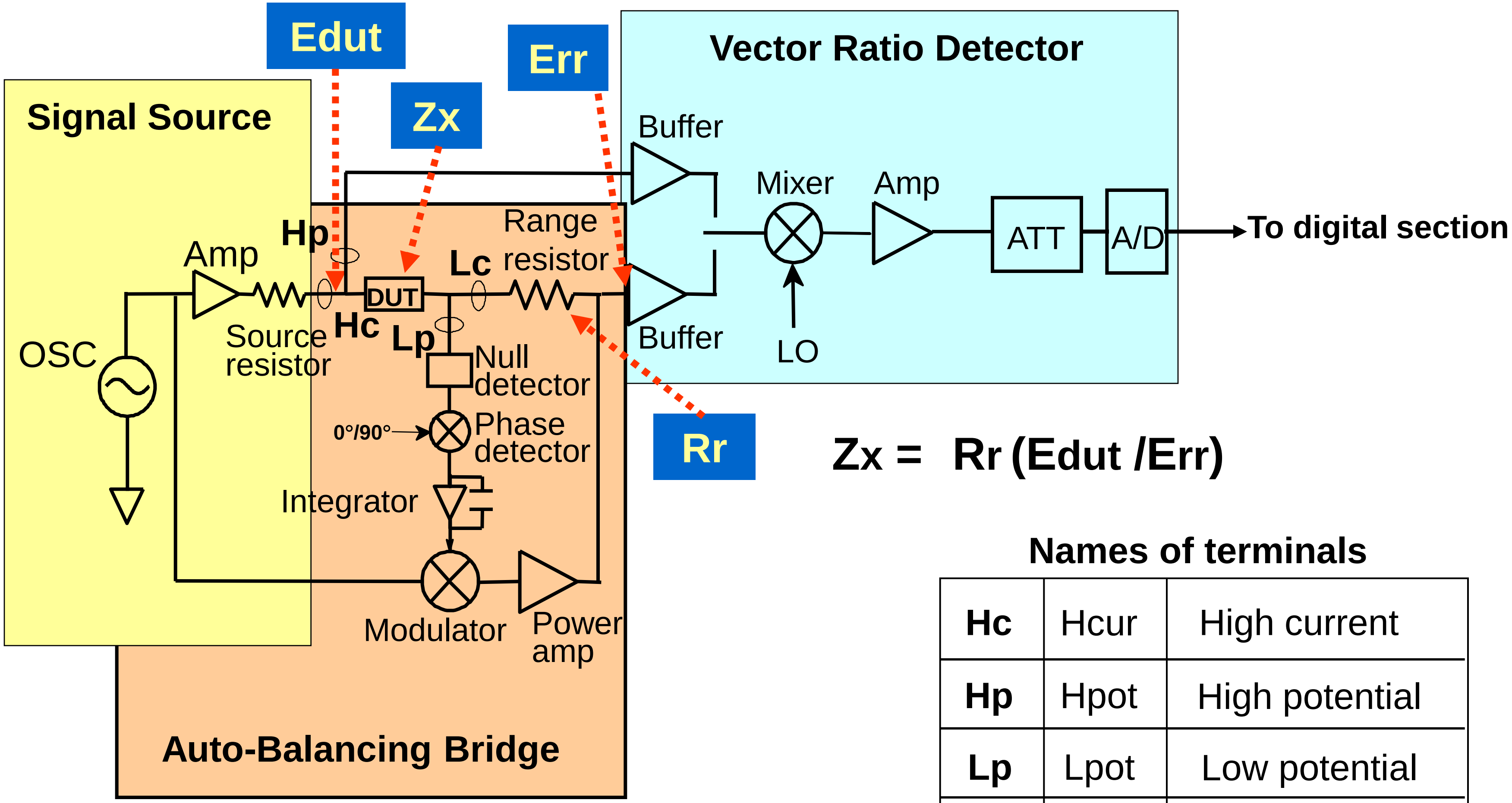


$I = I_r$

$$V_2 = -I_r R_r$$

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

Auto-Balancing Bridge Method (2 of 2)



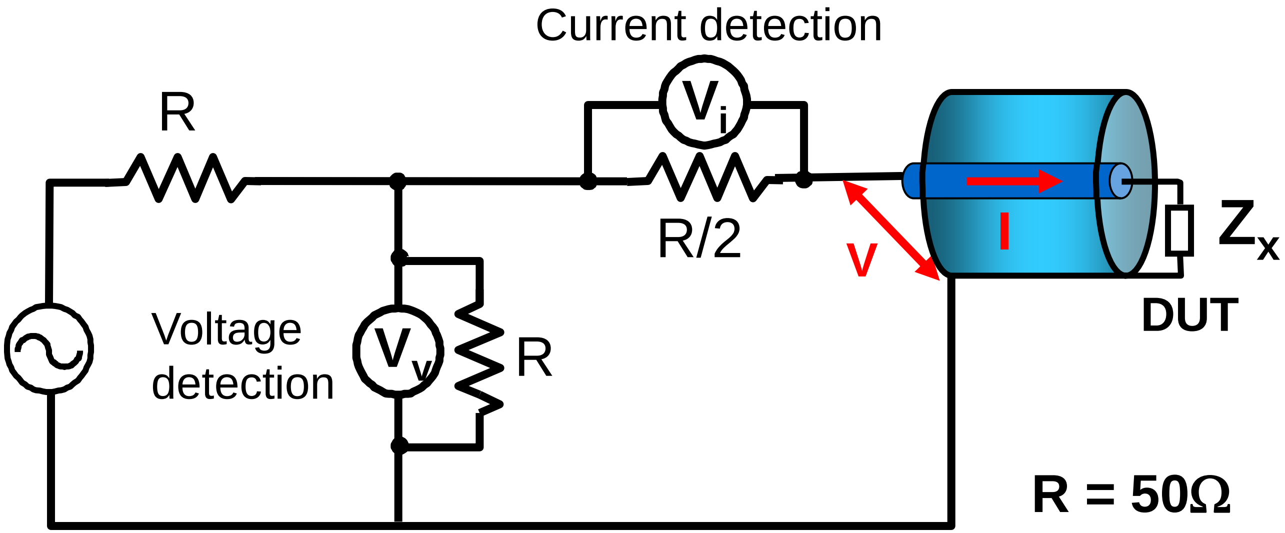
$$Zx = Rr\,(Edut\,/Err)$$

Names of terminals

Hc	Hcur	High current
Hp	Hpot	High potential
Lp	Lpot	Low potential
Lc	Lcur	Low current

RF-IV Method (1 of 2)

Unlocking Measurement Insights for 75 Years

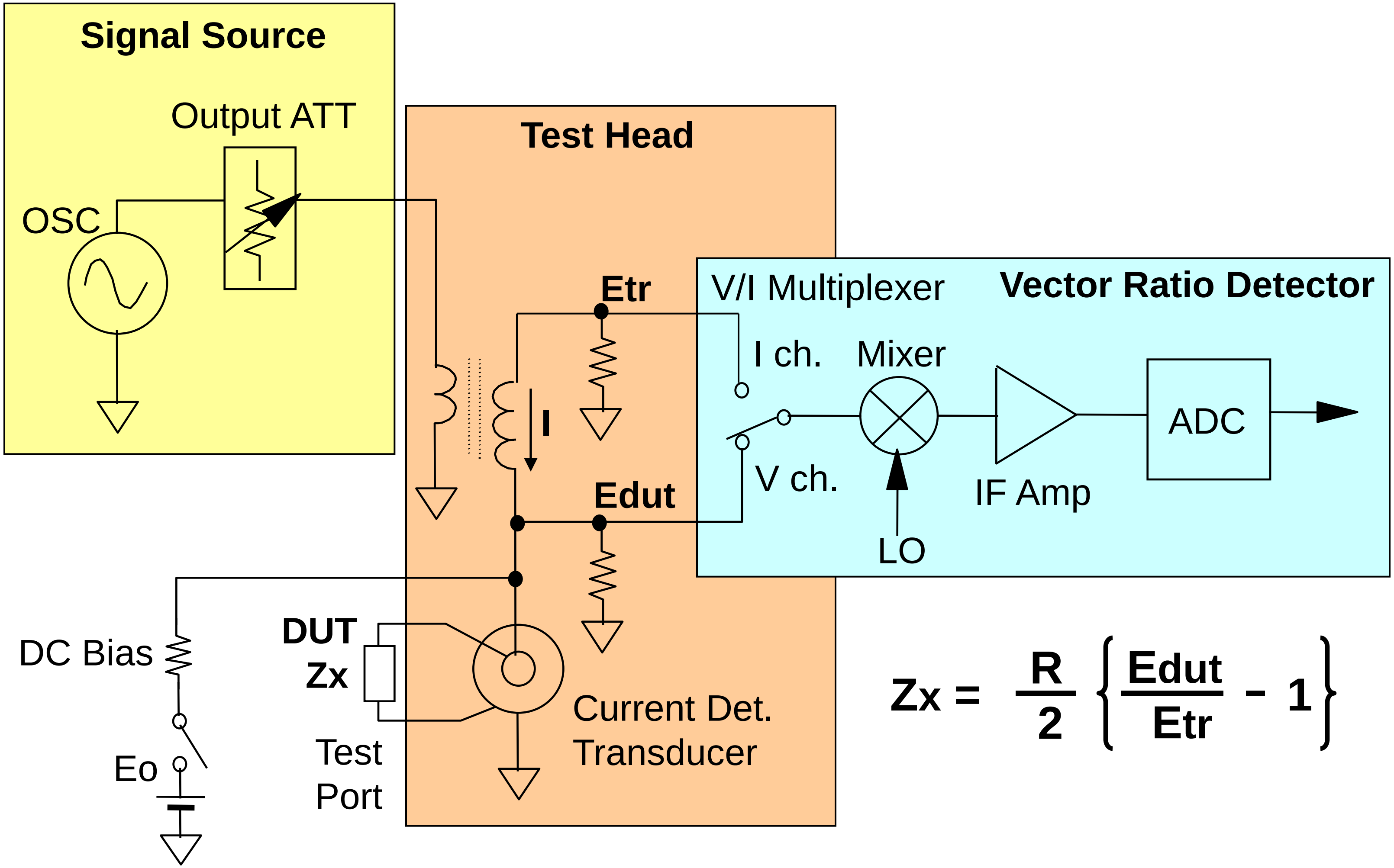


High-Impedance Test Head

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

RF I-V Method (2 of 2)

Unlocking Measurement Insights for 75 Years

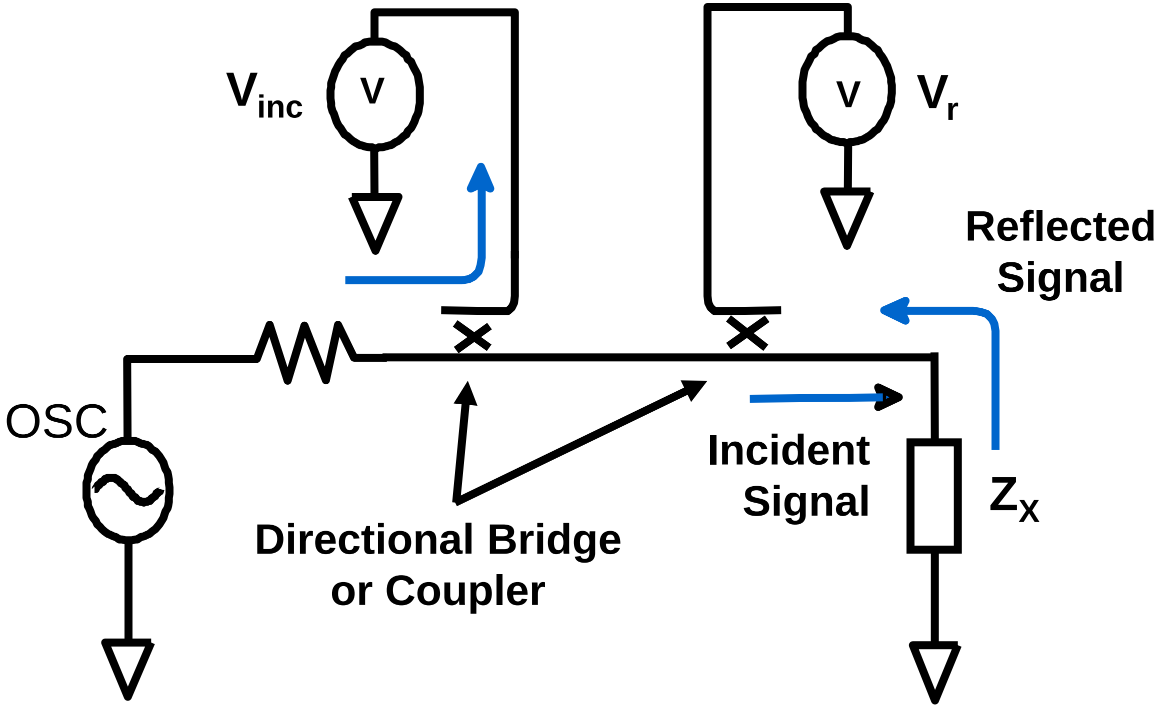


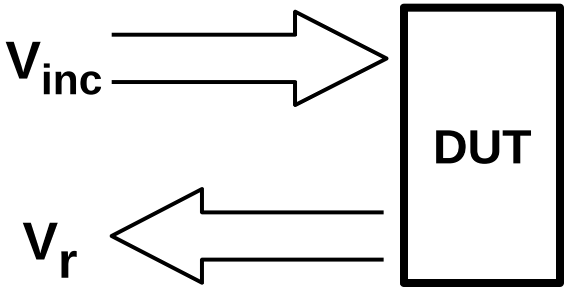
$$Zx = \frac{R}{2}\left\{\frac{Edut}{Etr} - 1\right\}$$

Network Analysis Method

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years



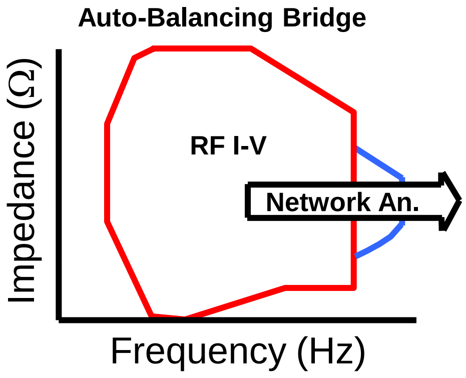


$$\Gamma = \frac{V_r}{V_{inc}} = \frac{Z_X - Z_0}{Z_X + Z_0}$$

Measurement Method Considerations

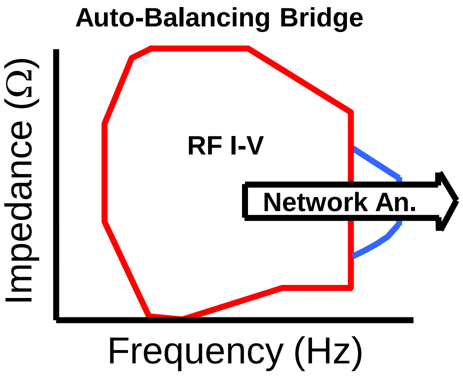
- Method and instrument selection criteria
- Theory of operation
- **Advantages and disadvantages**

Auto-Balancing Bridge



- **Advantages**
  - High accuracy over a wide impedance range
  - Wide frequency coverage (LF to HF)
  - Variety of fixture selections
- **Disadvantages**
  - Higher frequency ranges (>110 MHz) not available

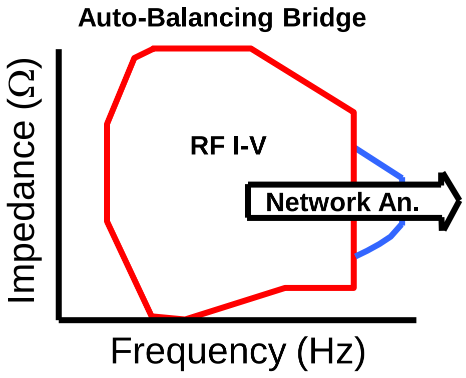
RF-IV



- **Advantages**
  - Excellent HF and RF performance (≤ 3 GHz)
  - High accuracy and wide impedance range
  - Variety of fixture selections

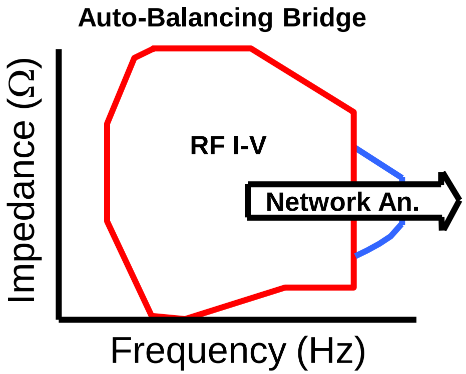
- **Disadvantages**
  - Lower frequency range is limited by the transformer used in the test head

Network Analysis



- **Advantages**
  - Covers highest frequencies (≥ 3 GHz)
  - High accuracy around the characteristic impedance of the analyzer (Z_o)
  - Only method able to measure multiport devices
- **Disadvantages**
  - Recalibration required when measurement frequency is changed
  - Narrow impedance measurement range

Summary of Measurement Methods



Method	Frequency Range	Impedance Range	Terminal Connections	# of Ports
Auto-Balancing Bridge	$20 \leq f \leq 110$ MHz	$1\ m\Omega \leq Z \leq 100\ M\Omega$ (10% acc)	4-terminal pair, BNC	1
RF I-V	$1\ MHz \leq f \leq 3\ GHz$	$0.2 \leq Z \leq 20\ k\Omega$ (10% acc)	7 mm	1
Network Analysis	$f \geq 300$ kHz	$Z \cong Z_0$	7 mm, N-type	$N \geq 1$

Measurement Methods and Agilent Products

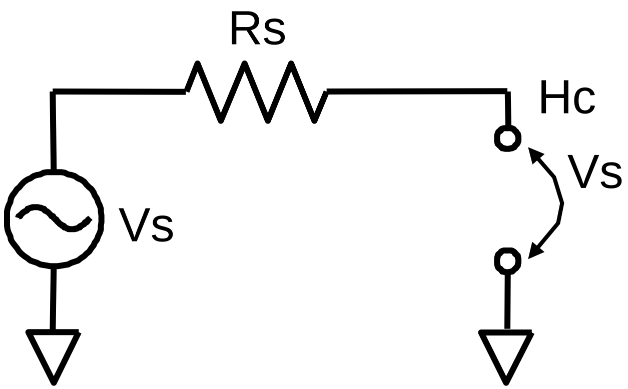
Unlocking Measurement Insights for 75 Years

Measurement Method	Agilent Product	Frequency Range
Auto-Balancing Bridge	4263B LCR Meter E4981A C Meter E4980A Precision LCR Meter 4285A Precision LCR Meter 4294A Precision Impedance Analyzer	100 Hz to 100 kHz spot 120 Hz, 1kHz, 1 MHz spot 20 Hz to 2 MHz 75 kHz to 30 MHz 40 Hz to 110 MHz
RF I-V	E4982A RF LCR Meter E4991A Impedance/Material Analyzer	1 MHz to 3 GHz 1 MHz to 3 GHz
Network Analysis	ENA Series Vector Network Analyzers PNA Series Microwave Vector Network Analyzers	5 Hz to 20 GHz 300 kHz to 1.1 THz

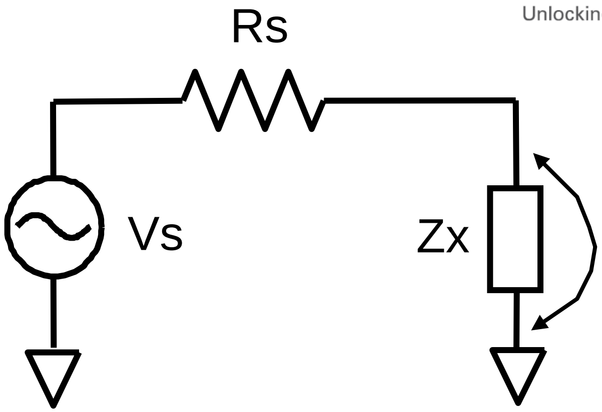
Agenda

- Introduction
- Impedance fundamentals
- **Measurement methods**
  - Popular methods
  - Instrument functions

OSC Level



(a) High terminal is open

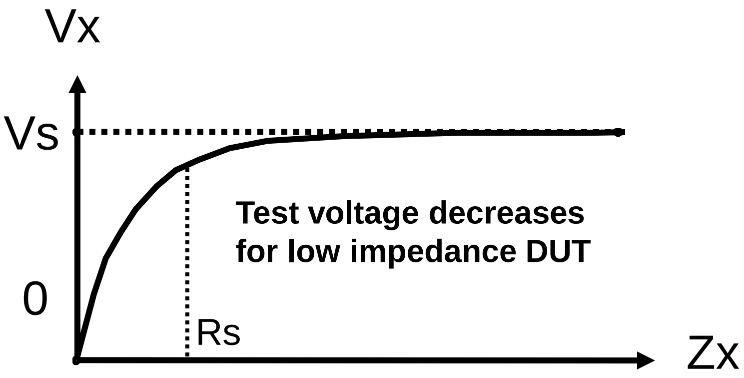


$$V_x = \frac{Z_x}{R_s + Z_x} V_s$$

(b) DUT is connected to the high terminal

Vs = OSC level

Rs = source resistor

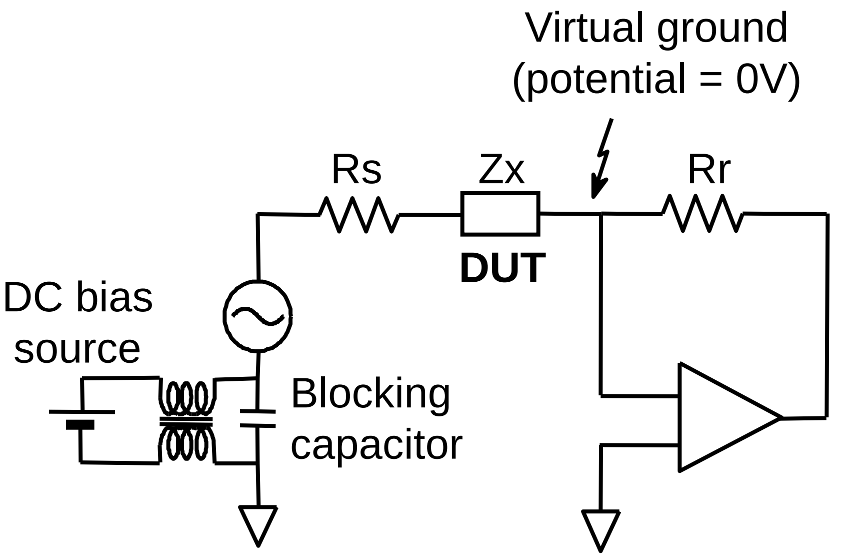


Test voltage decreases for low impedance DUT

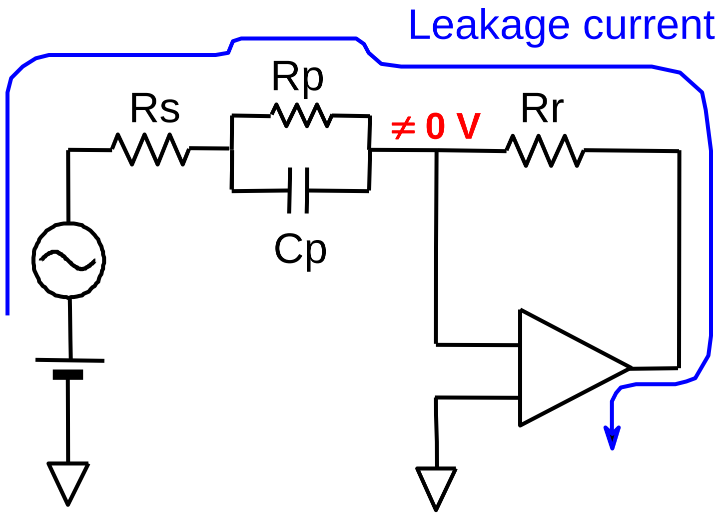
(c) Vx versus Zx

DC Bias

Unlocking Measurement Insights for 75 Years



(a) Simplified diagram of measurement with DC bias

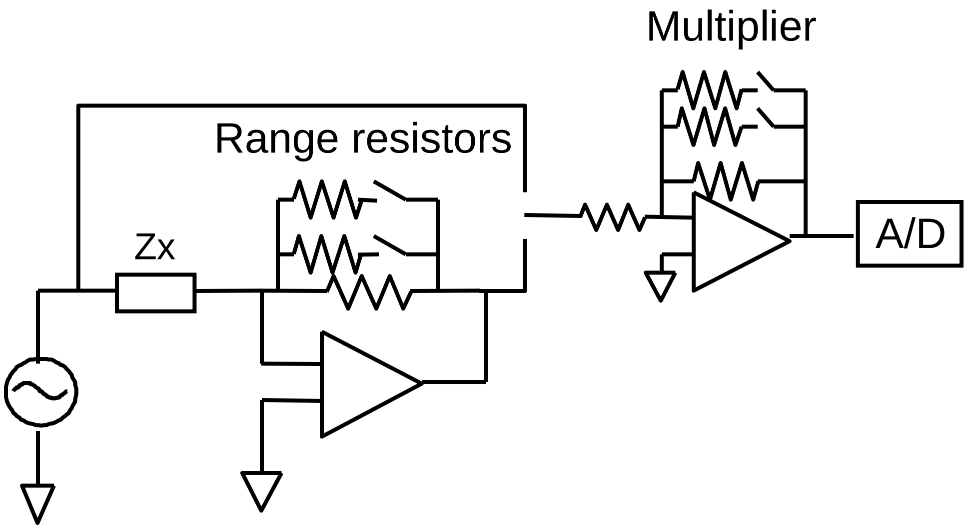


(b) When the DUT's Rp is low, leakage current decreases the DC voltage applied to the DUT

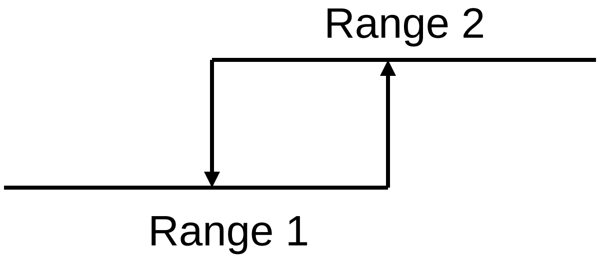
The 4294A and some impedance analyzers can automatically regulate DC bias voltage or current across DUT according to the monitored bias levels.

Ranging

Unlocking Measurement Insights for 75 Years



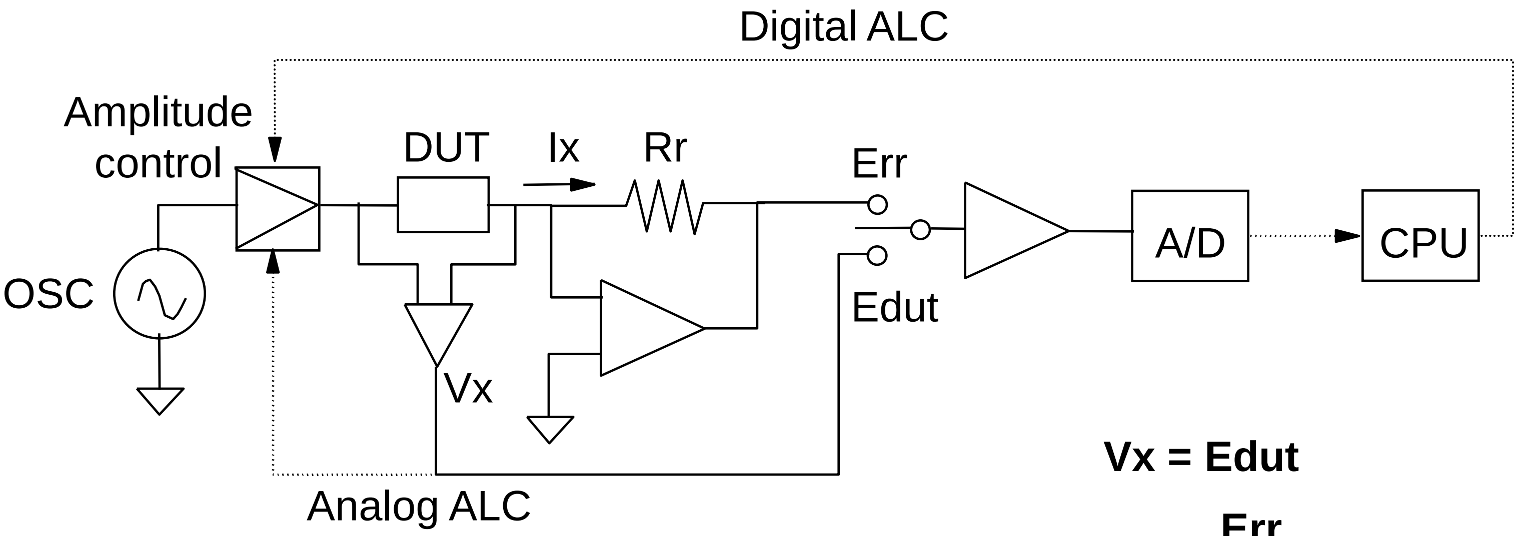
(a) Ranging is done by changing the range resistor and multiplier of the vector ratio detector.



(b) Hysteresis in the range boundary prevents frequent range changes caused by noise

Level Monitor

Unlocking Measurement Insights for 75 Years

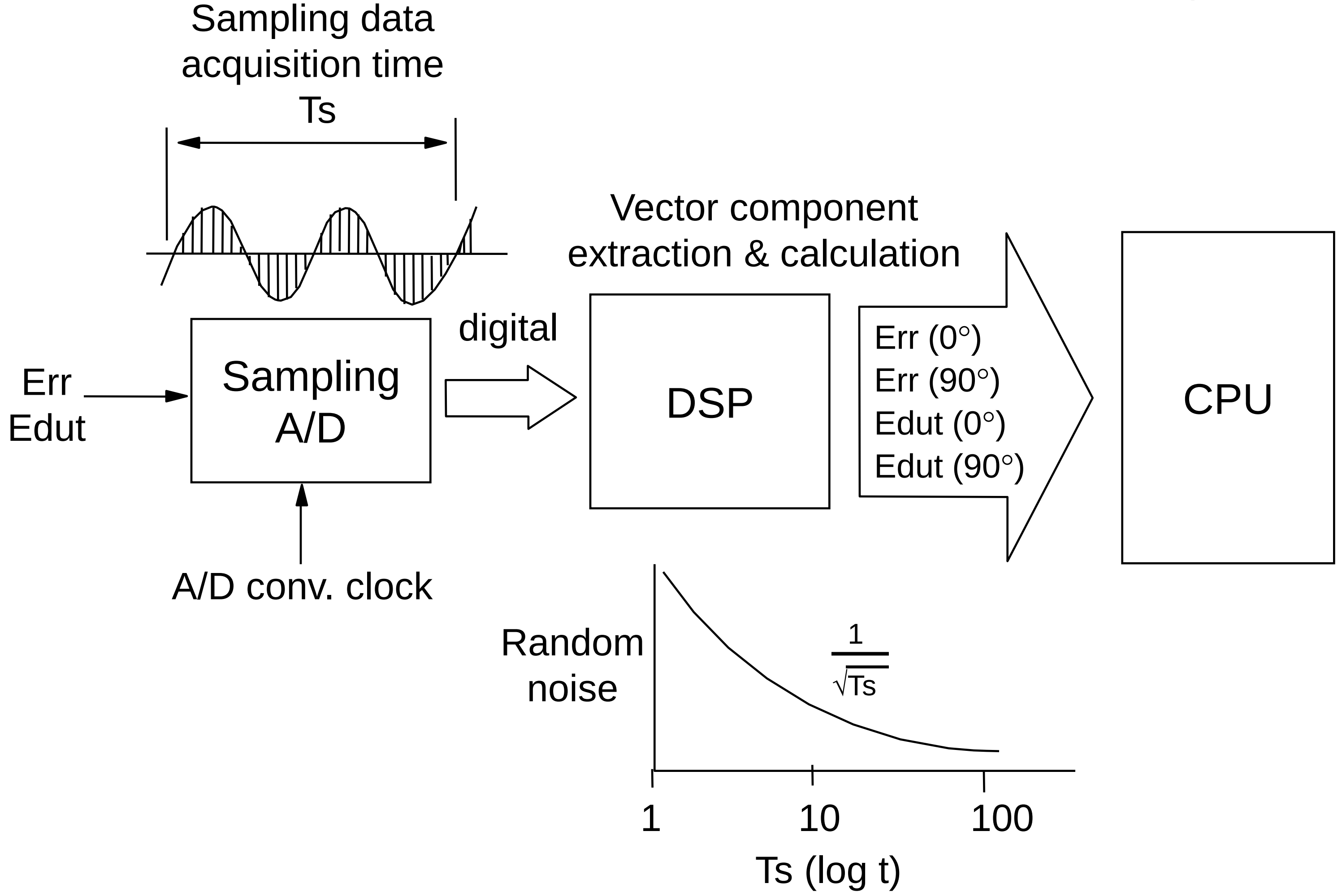


$$\mathbf{Vx = Edut}$$

$$\mathbf{Ix = \frac{Err}{Rr}}$$

Measurement Time and Averaging

Unlocking Measurement Insights for 75 Years



Sampling data acquisition time Ts

Vector component extraction & calculation

Err

Edut

Sampling A/D

digital

DSP

Err (0°)

Err (90°)

Edut (0°)

Edut (90°)

CPU

A/D conv. clock

Agenda

Unlocking Measurement Insights for 75 Years

- Introduction
- Impedance fundamentals
- Measurement methods
- **Fixturing and cabling**
- Calibration and compensation
- Solution selection process

Fixturing and Cabling

LF impedance measurement

- Terminal configuration
- Guarding

RF impedance measurement

- Terminal configuration in the RF range
- Test port extension in the RF range

Terminal Configuration

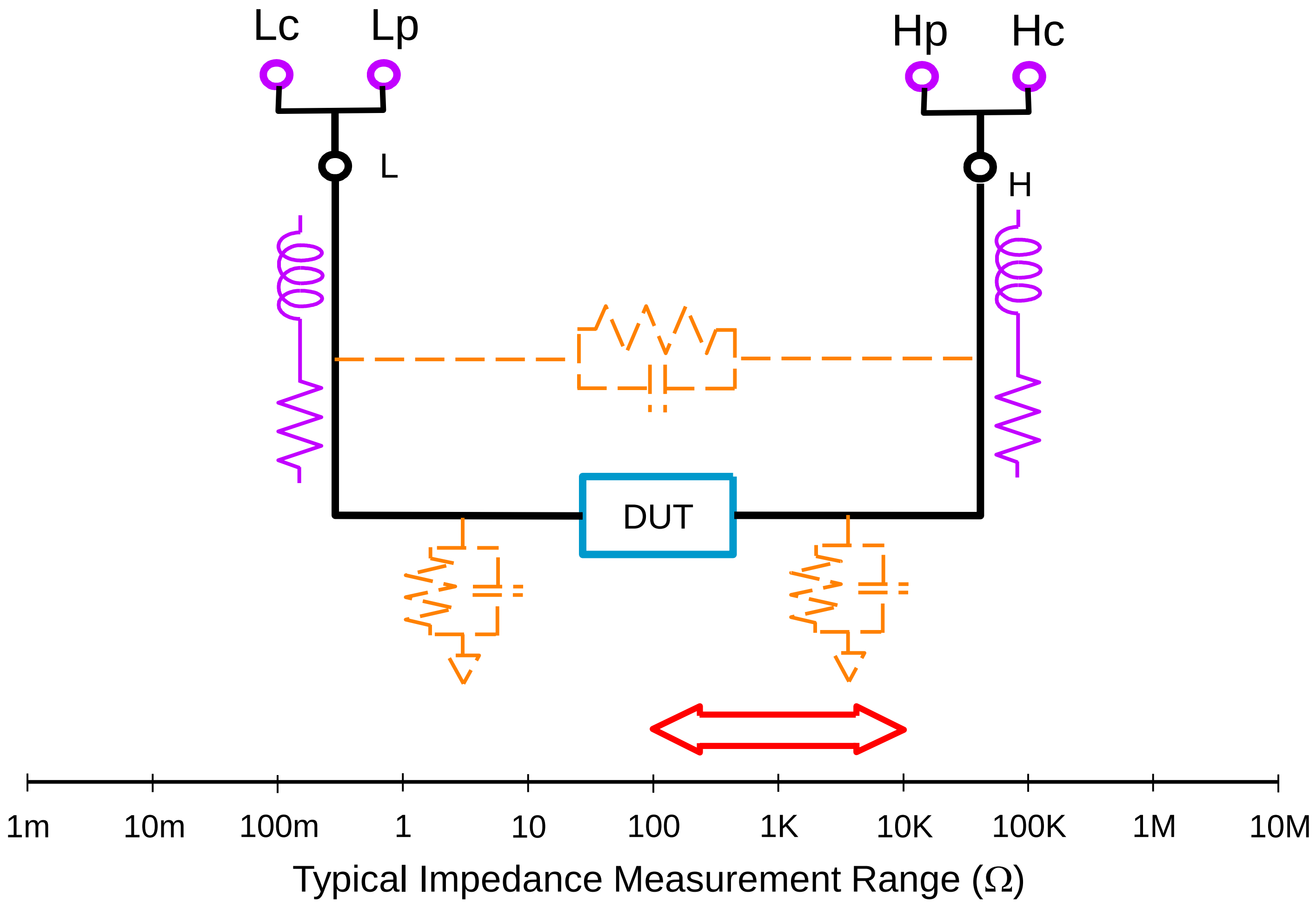
Types of configuration

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

Terminal Configuration

Unlocking Measurement Insights for 75 Years

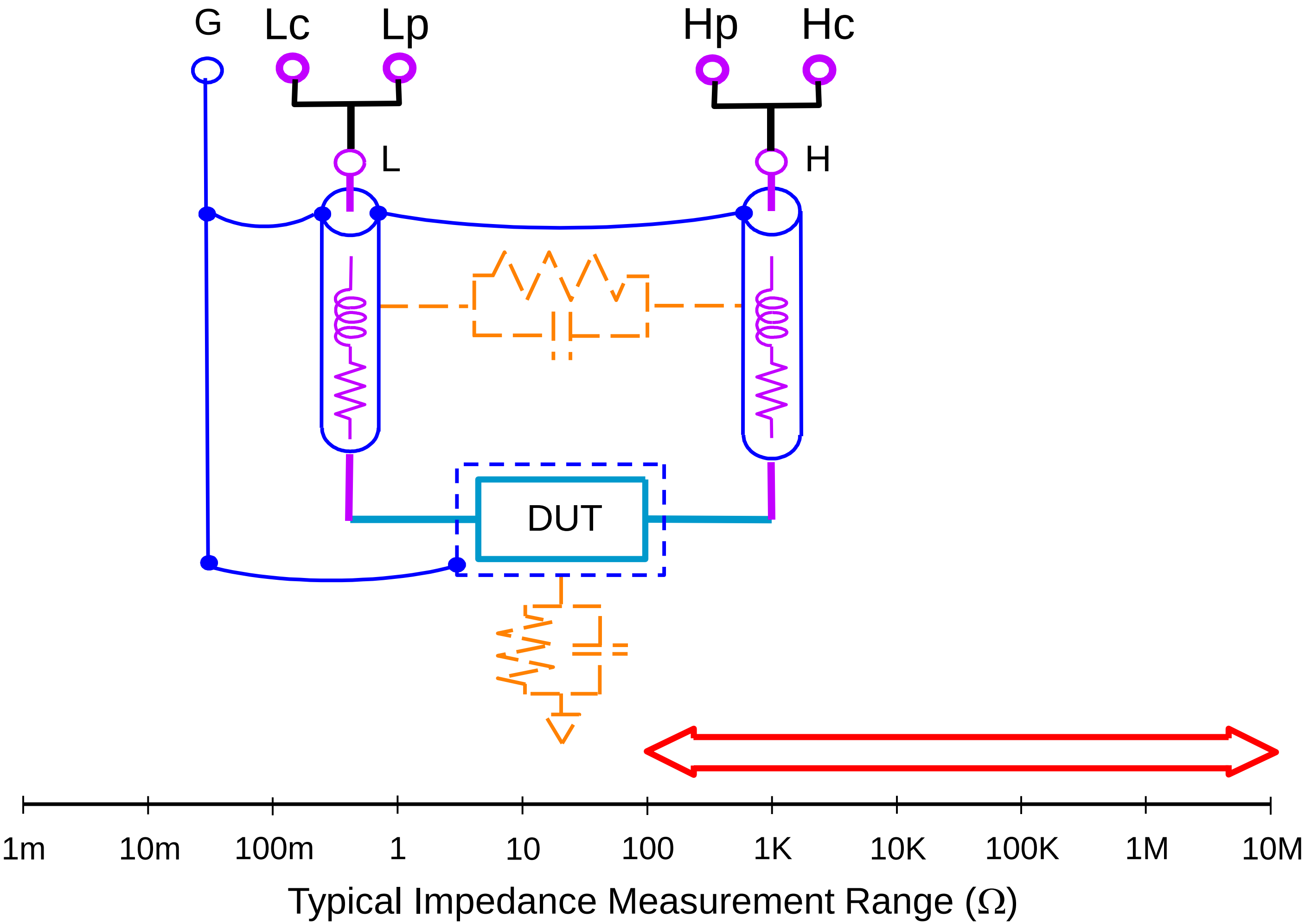
Two-terminal (2T) method



Terminal Configuration

Unlocking Measurement Insights for 75 Years

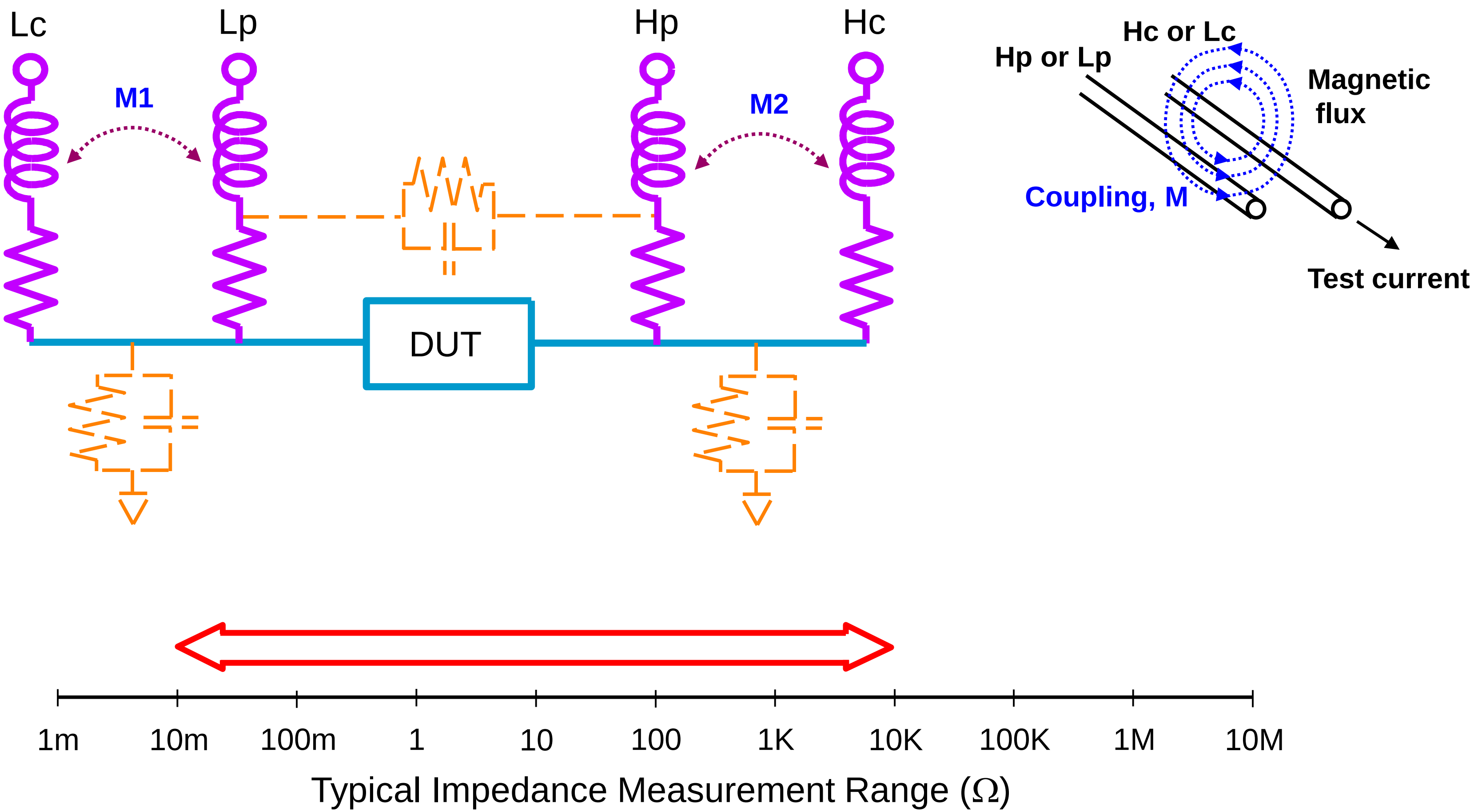
Three-terminal (3T) method



Terminal Configuration

Unlocking Measurement Insights for 75 Years

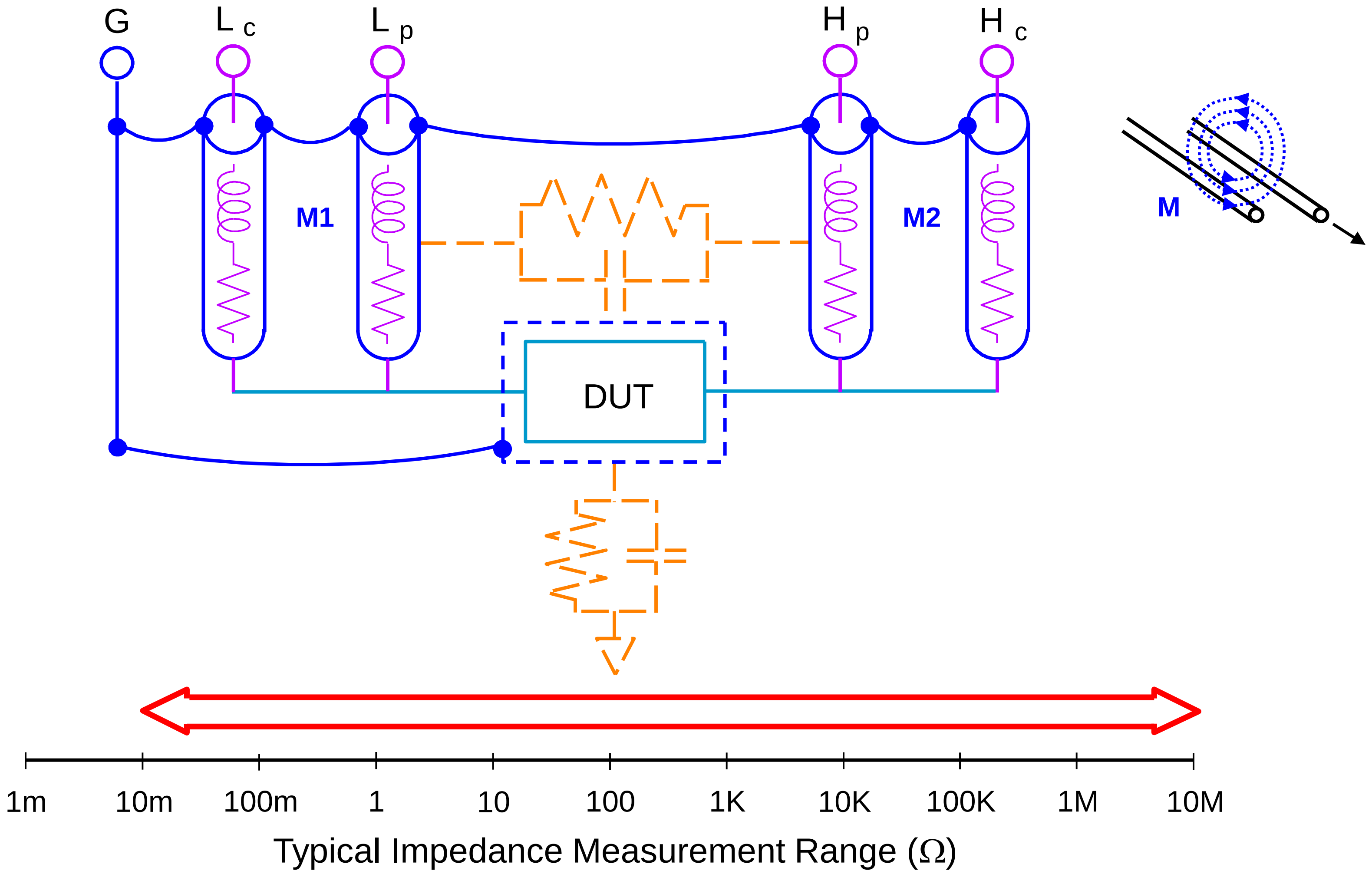
Four-terminal (Kelvin, 4T) method



Terminal Configuration

Unlocking Measurement Insights for 75 Years

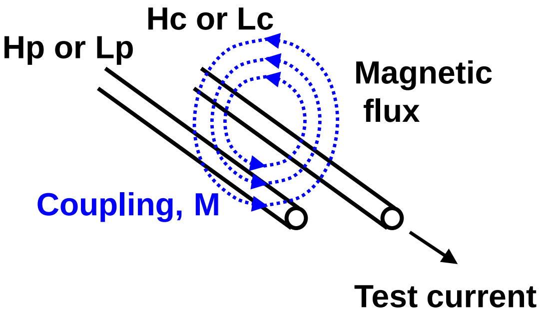
Five-terminal (5T) method



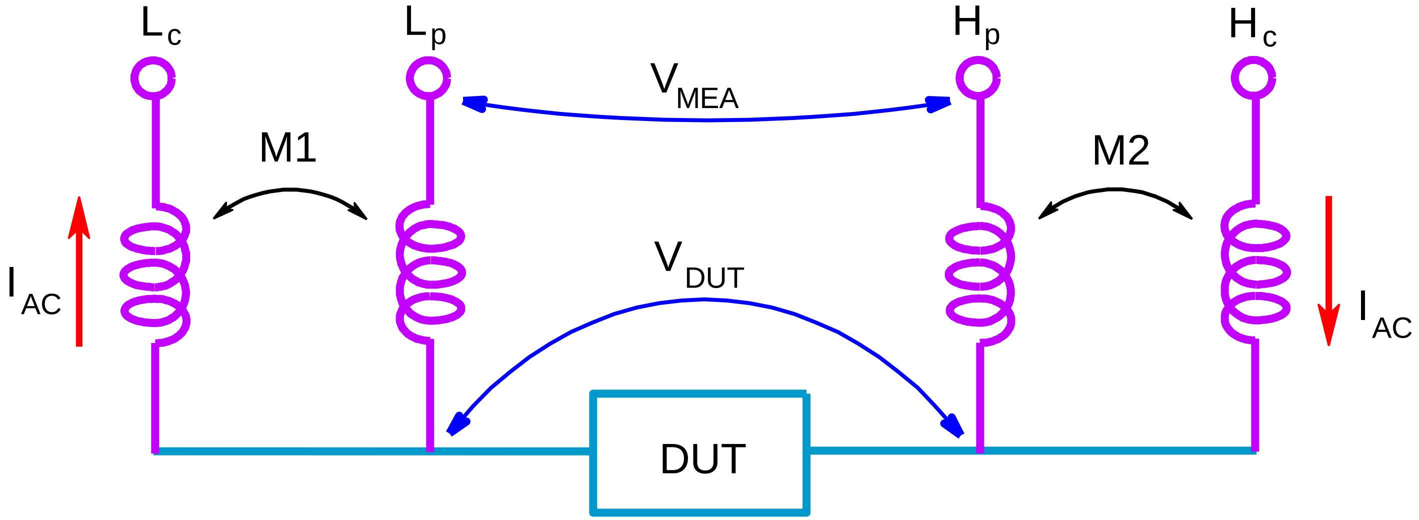
Terminal Configuration

Unlocking Measurement Insights for 75 Years

Mutual inductance error



For mΩ DUT

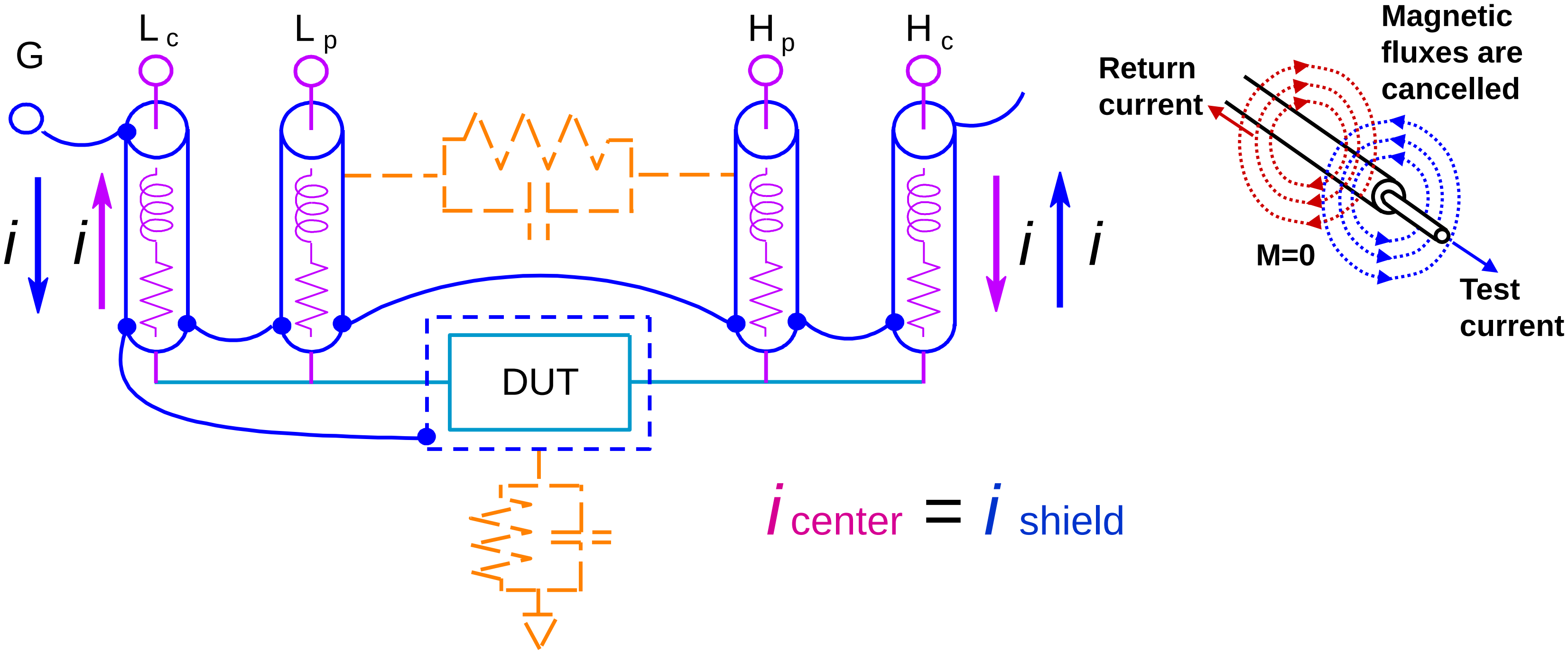


$V_{MEA} \neq V_{DUT}$

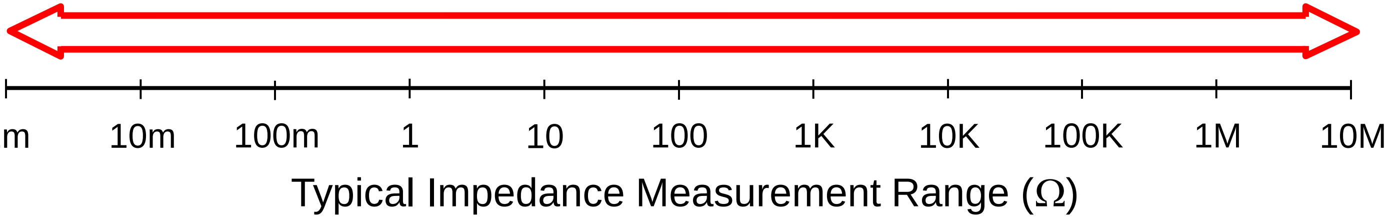
Terminal Configuration

Unlocking Measurement Insights for 75 Years

Four-terminal pair (4TP) method



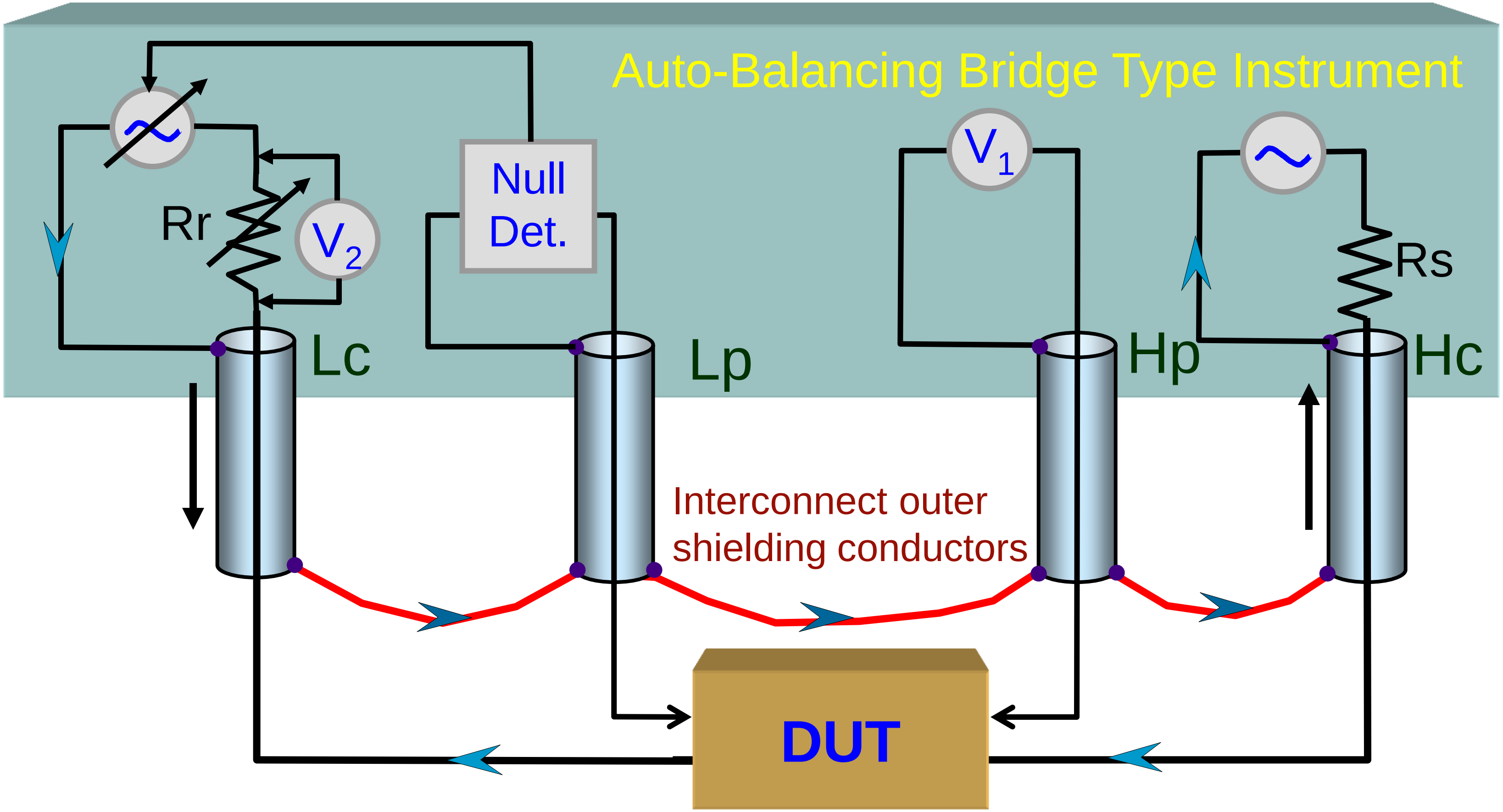
$i_{\text{center}} = i_{\text{shield}}$



Terminal Configuration

Four-terminal pair (4TP) simplified schematic

Unlocking Measurement Insights for 75 Years



Fixturing and Cabling

Unlocking Measurement Insights for 75 Years

LF impedance measurement

- Terminal configuration
- Guarding

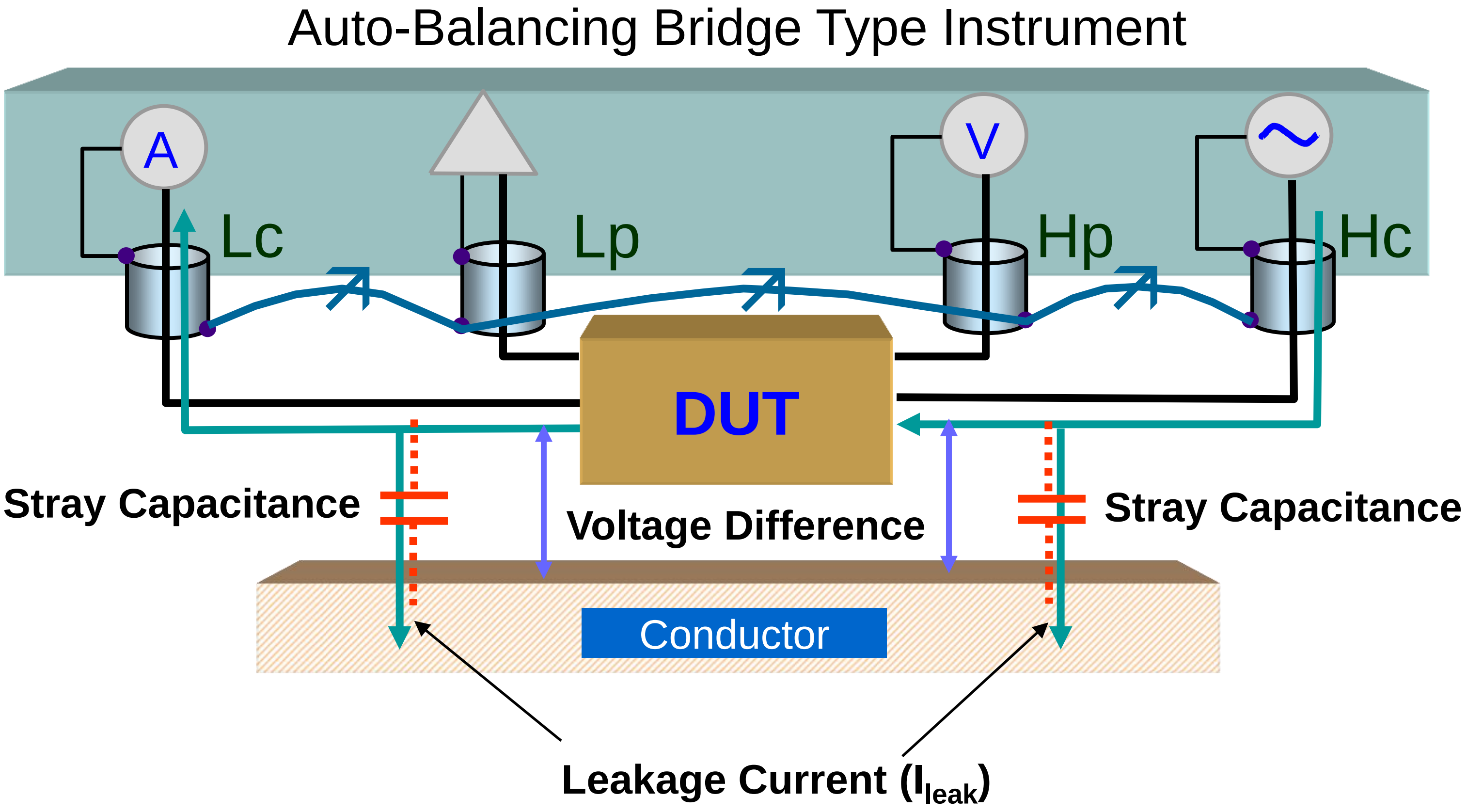
RF impedance measurement

- Terminal configuration in the RF range
- Test port extension in the RF range

Guarding (1 of 3)

Unlocking Measurement Insights for 75 Years

Stray capacitance and leakage current



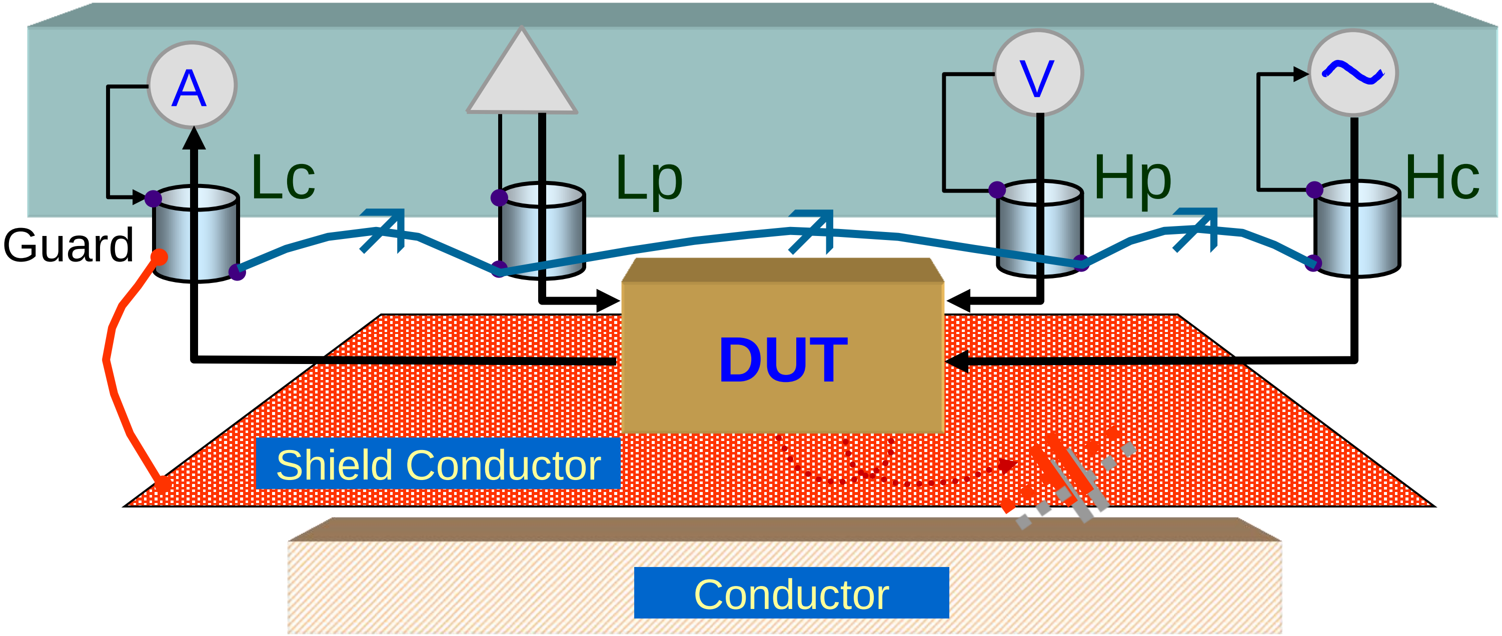
$I_{dut} = I_{meas} + I_{leak}$

Guarding (2 of 3)

Unlocking Measurement Insights for 75 Years

Guard Mechanism and Solution

Auto-Balancing Bridge Type Instrument



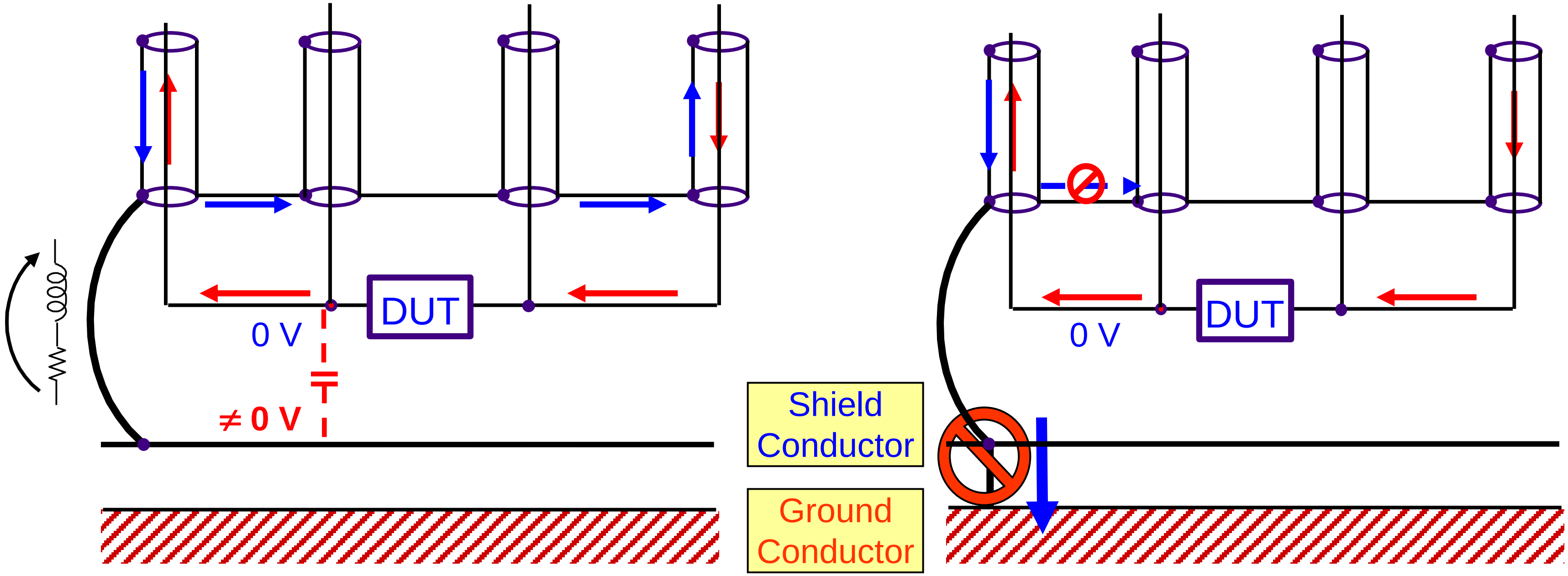
Guarding (3 of 3)

Unlocking Measurement Insights for 75 Years

Key Points to Consider

(a) Minimize impedance of guard line.

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



Fixturing and Cabling

Unlocking Measurement Insights for 75 Years

LF impedance measurement

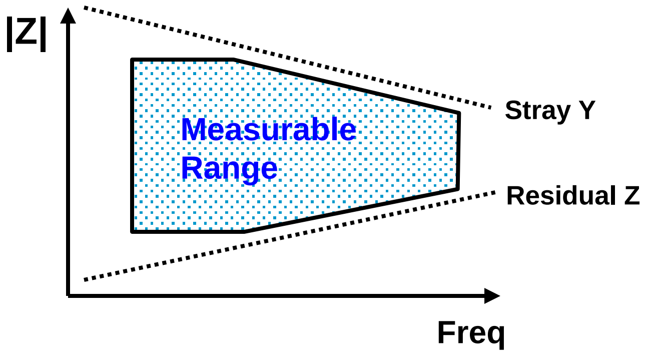
- Terminal configuration
- Guarding

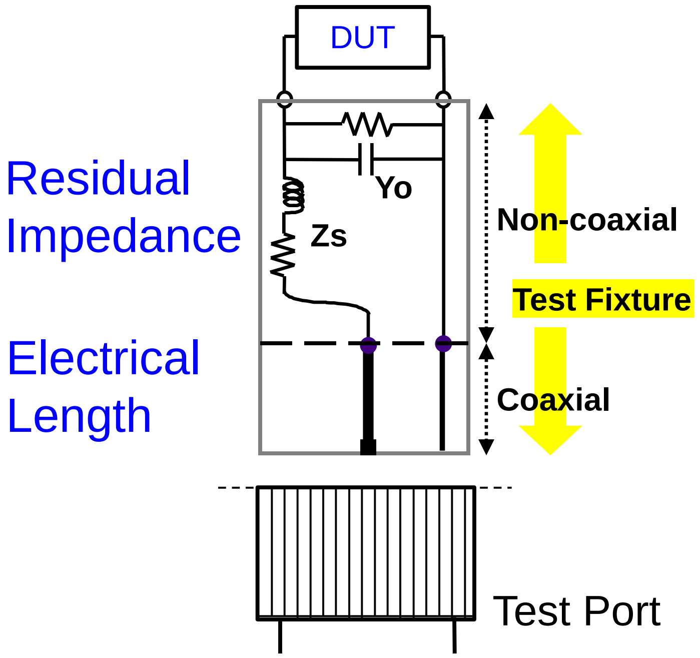
RF impedance measurement

- Terminal configuration in the RF range
- Test port extension in the RF range

Terminal Configuration in the RF Range

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

Fixturing and Cabling

LF impedance measurement

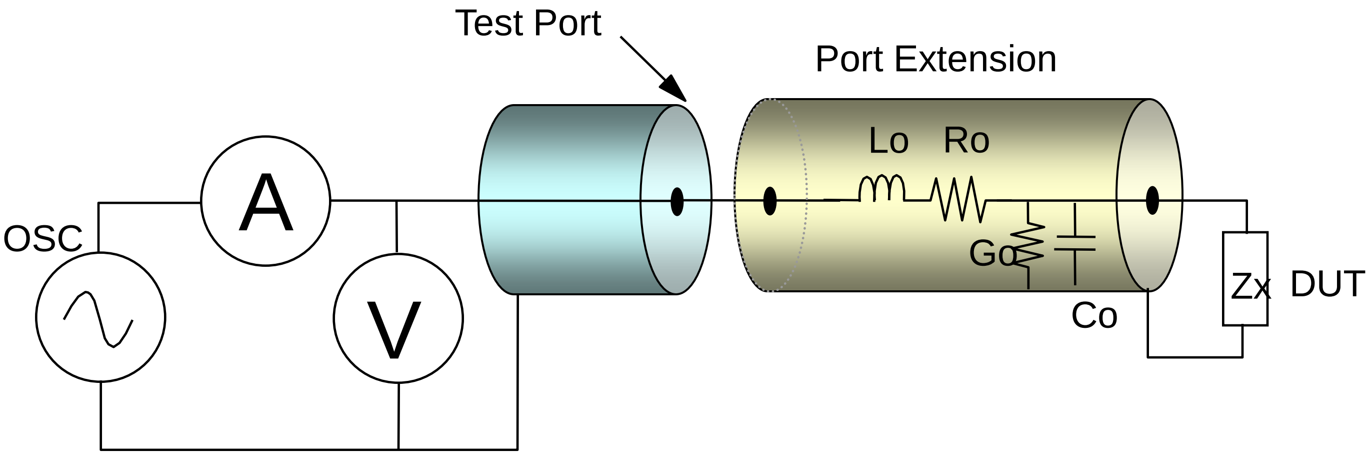
- Terminal configuration
- Guarding

RF impedance measurement

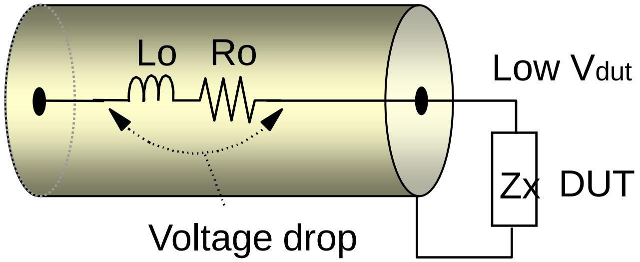
- Terminal configuration in the RF range
- Test port extension in the RF range

Test Port Extension in the RF Range

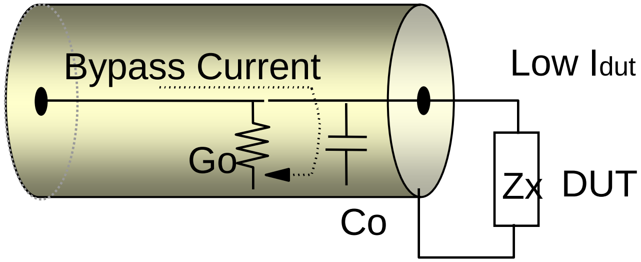
Calibration plane extension



(a) Port Extension



(b) Low impedance DUT



(c) High impedance DUT

Agenda

Unlocking Measurement Insights for 75 Years

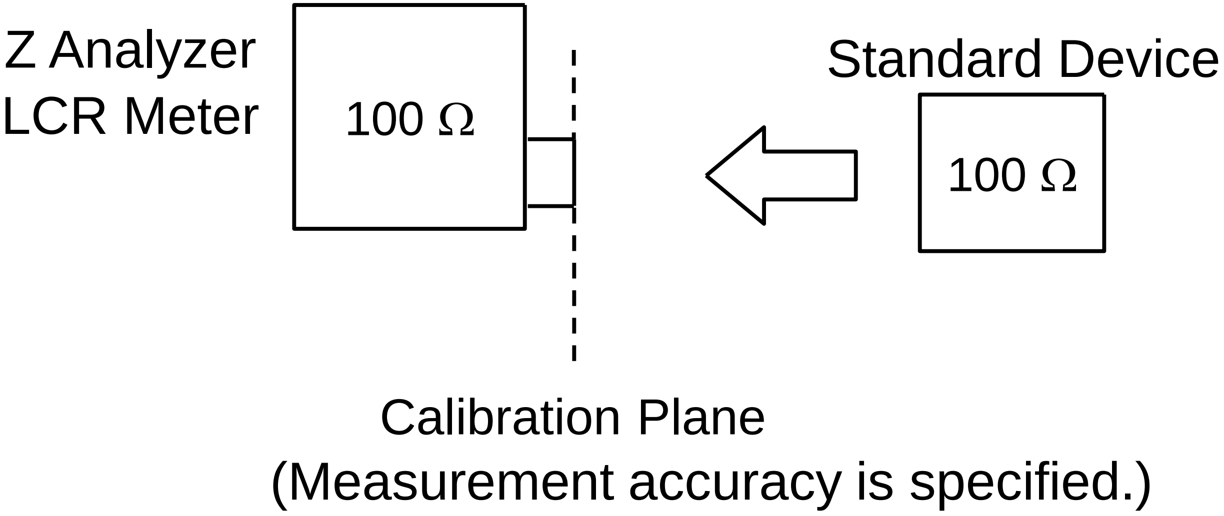
- Introduction
- Impedance fundamentals
- Measurement methods
- Fixturing and cabling
- **Calibration and compensation**
- Solution selection process

Calibration

Unlocking Measurement Insights for 75 Years

Compensation ≠ Calibration

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

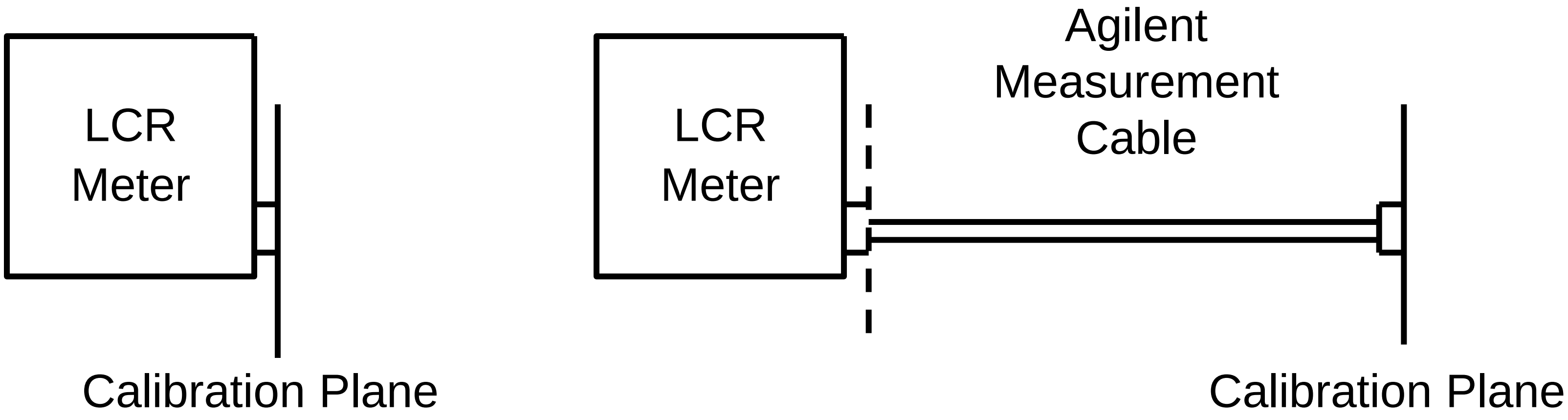


Calibration

Unlocking Measurement Insights for 75 Years

Cable Correction

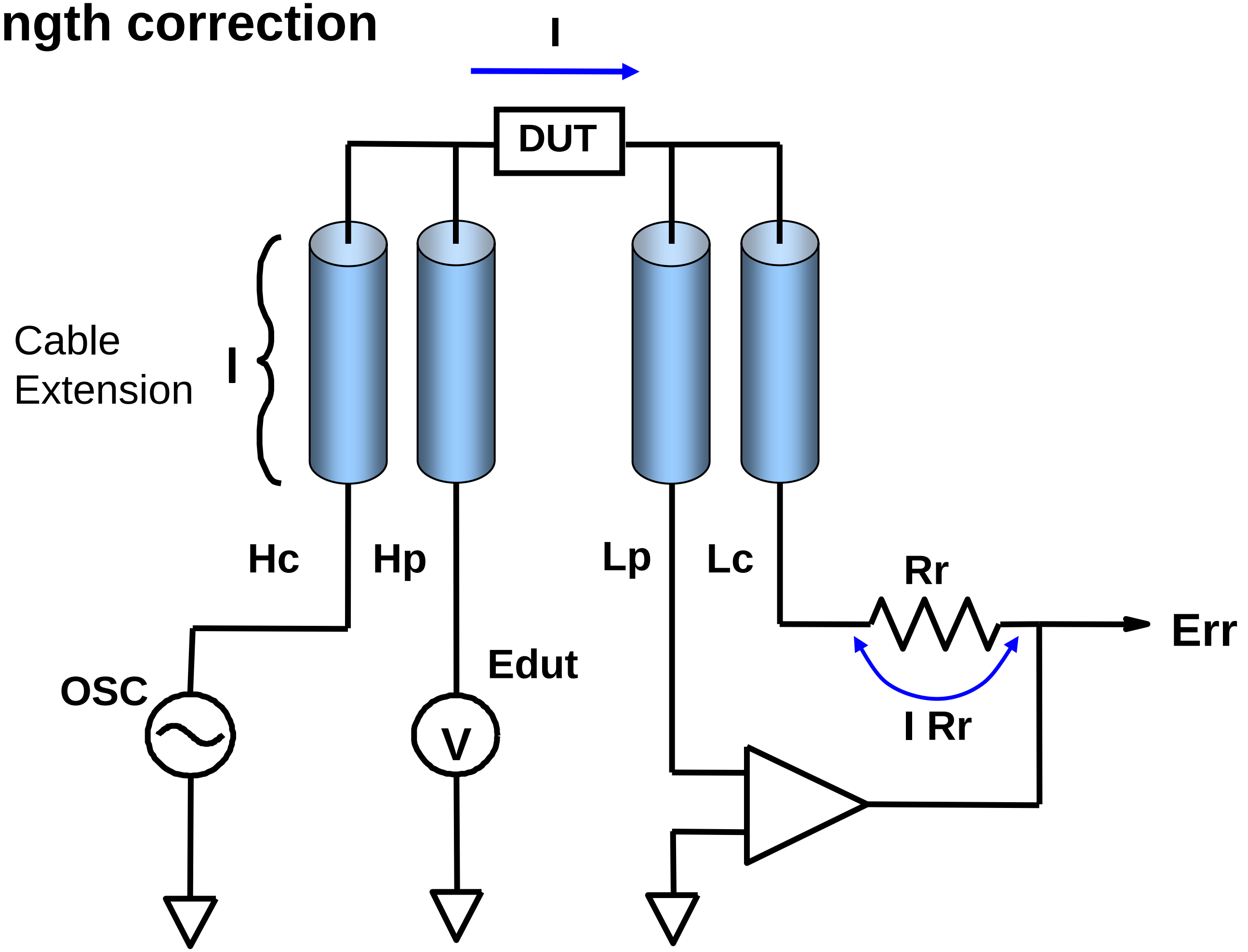
Extending the Calibration Plane using specified Agilent cables. (Agilent 16048A/B/D/E)



Measurement Cable Extension Induced Error

Unlocking Measurement Insights for 75 Years

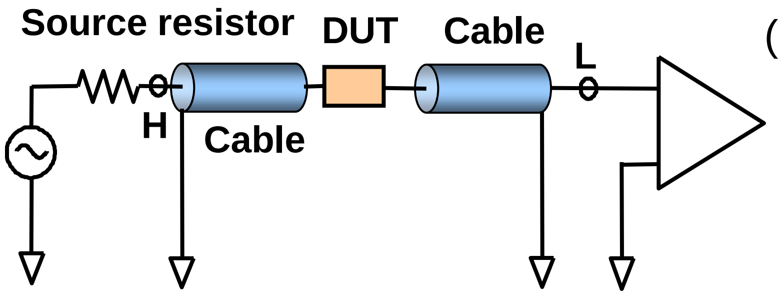
Cable length correction



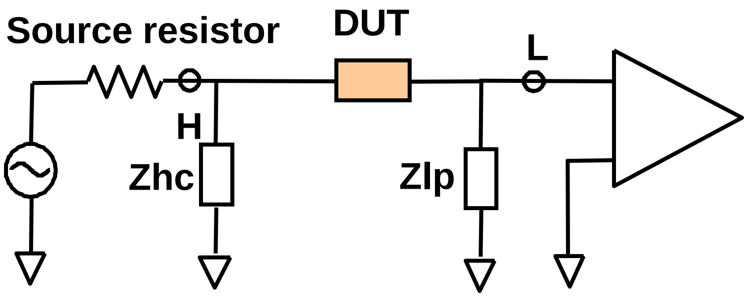
Measurement Cable Extension Induced Error

Unlocking Measurement Insights for 75 Years

Cable length extension in the low frequency range



(a) Extended cables connected to High and Low terminals



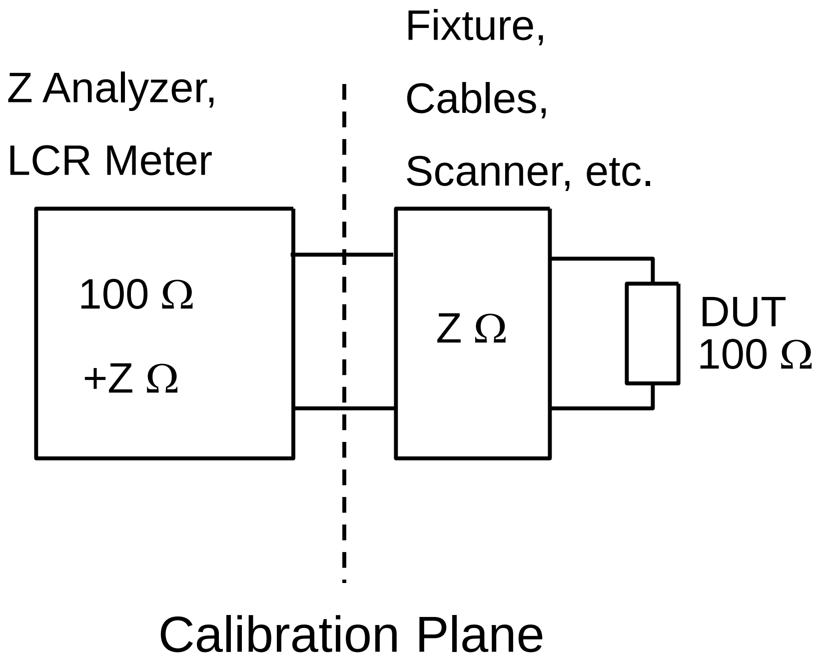
(b) Effects of cable extension

Zhc: An impedance determined by the capacitance connected to the High terminal (H). This impedance decreases the test signal level and degrades accuracy.

Zlp: An impedance determined by the cable connected to the Low terminal (L). This impedance decreases the input impedance of the amplifier and decreases the measurement accuracy.

Compensation

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



Z Analyzer,
LCR Meter

100 Ω
+Z Ω

Fixture,
Cables,
Scanner, etc.

Z Ω

DUT
100 Ω

Calibration Plane

- 2 types of compensation:

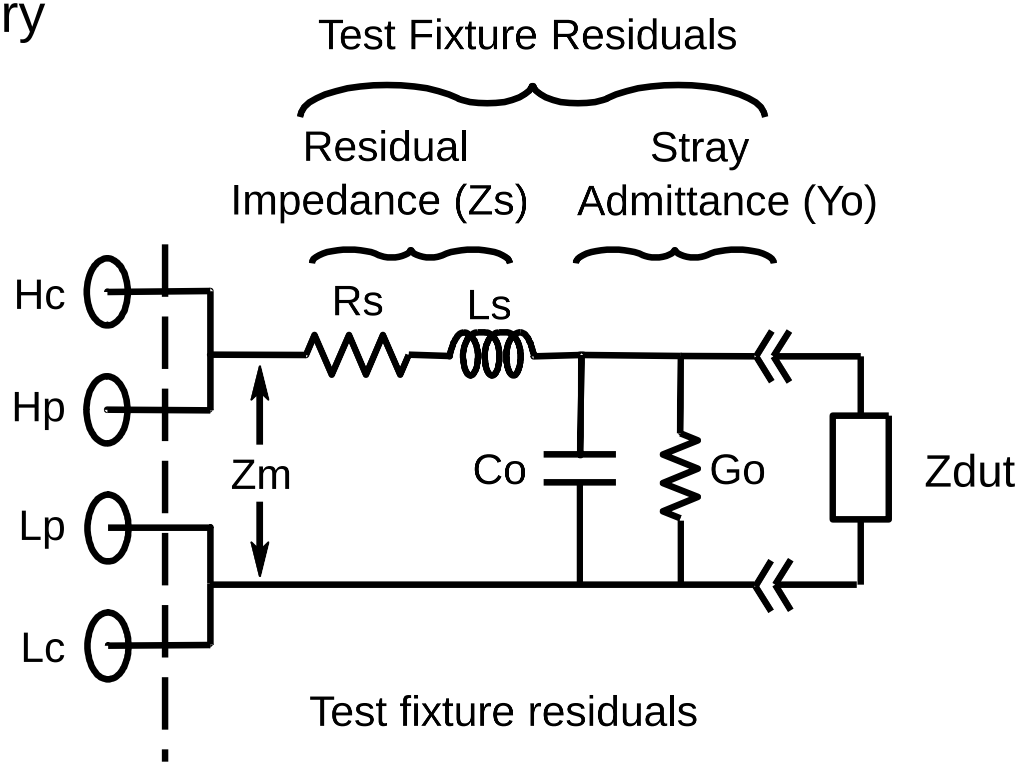
  - OPEN/SHORT compensation

  - OPEN/SHORT/LOAD compensation

Compensation

OPEN/SHORT Compensation

Basic Theory

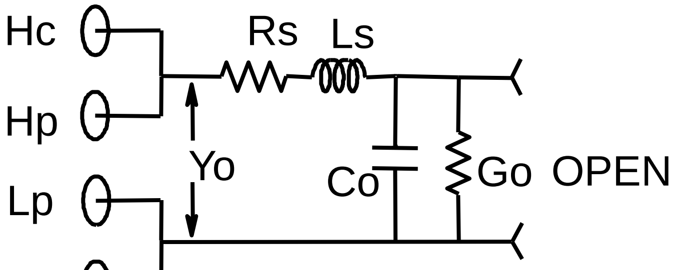


Test fixture residuals

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

Compensation

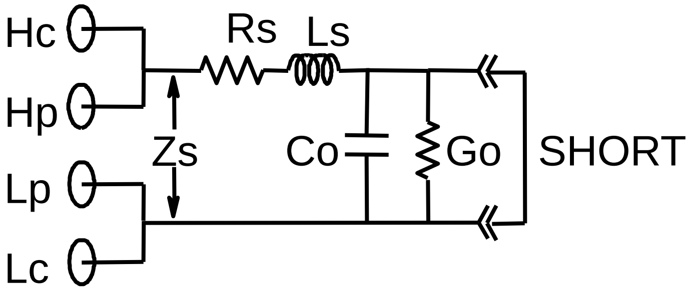
OPEN/SHORT Compensation



$$Yo = Go + j\omega Co$$

$$\left(Rs + j\omega Ls << \frac{1}{Go + j\omega Co}\right)$$

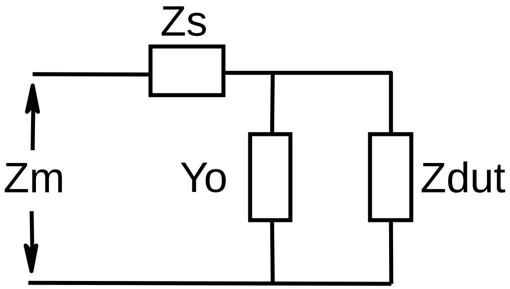
(a) OPEN measurement



$$Zs = Rs + j\omega Ls$$

SHORT Impedance << Rs + jωLs

(b) SHORT measurement



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

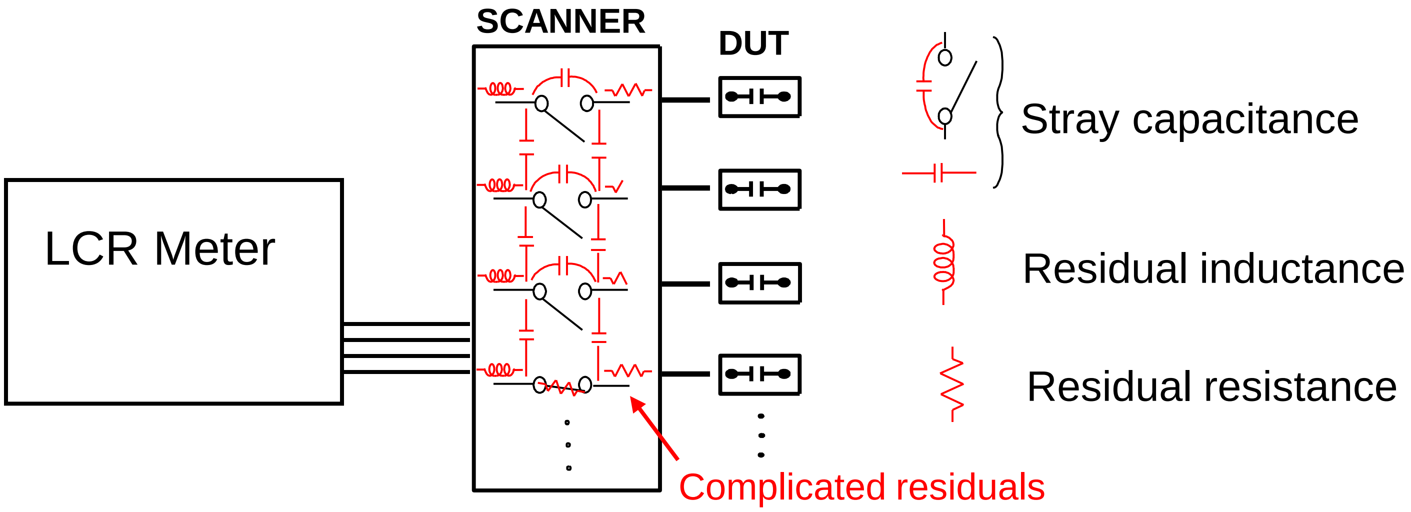
(c) Compensation formula

Compensation

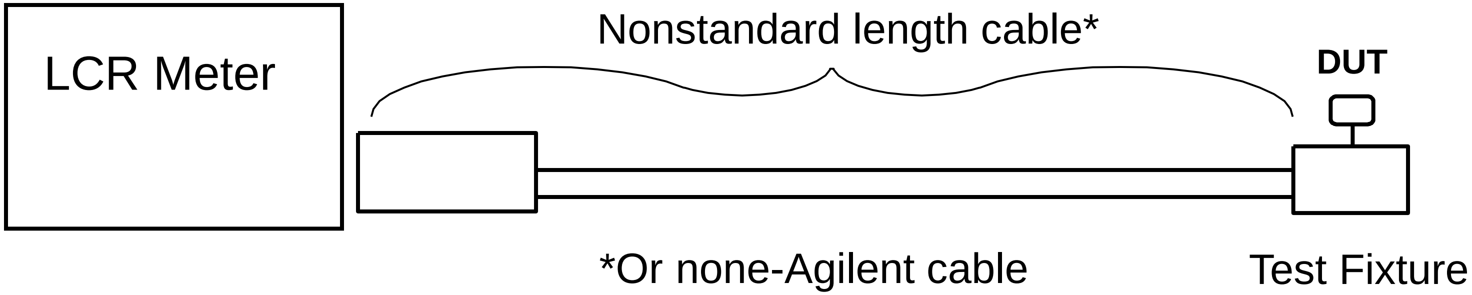
Unlocking Measurement Insights for 75 Years

OPEN/SHORT Compensation Issues

Problem 1: Difficulty in eliminating complicated residuals



Problem 2: Difficulty in eliminating Phase Shift Error



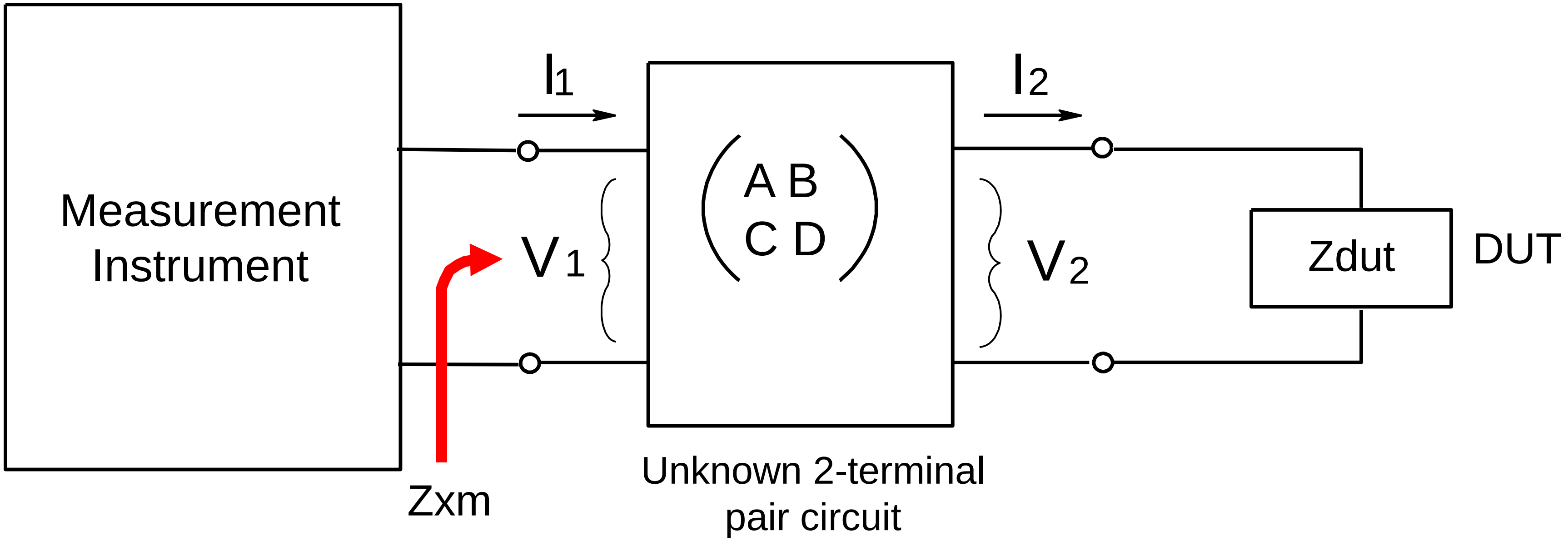
*Or none-Agilent cable

Compensation

OPEN/SHORT/LOAD Compensation

Unlocking Measurement Insights for 75 Years

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 $Zxm = V_2/I_2$

Compensation

OPEN/SHORT/LOAD Compensation

Basic Theory

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

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

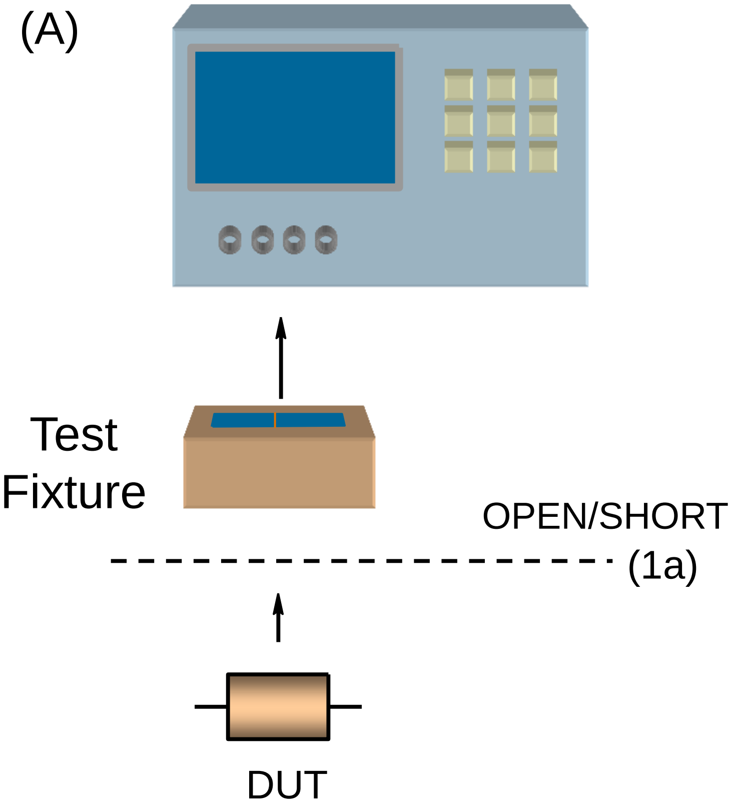
*These are complex vectors. Conversions to real and imaginary components are necessary

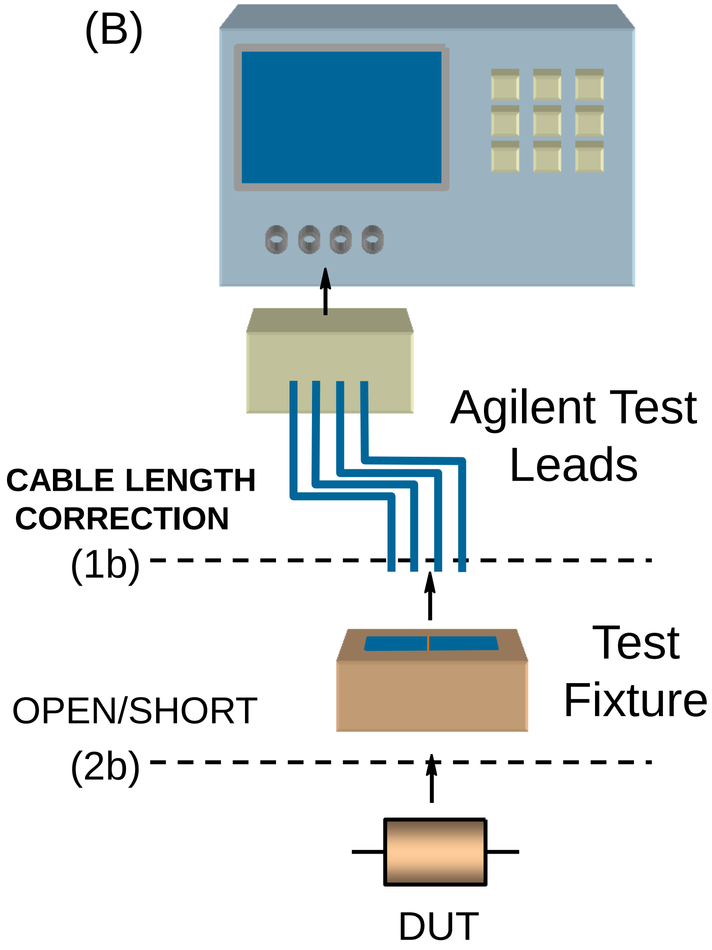
Practical Compensation Examples

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights for 75 Years

Practical Examples

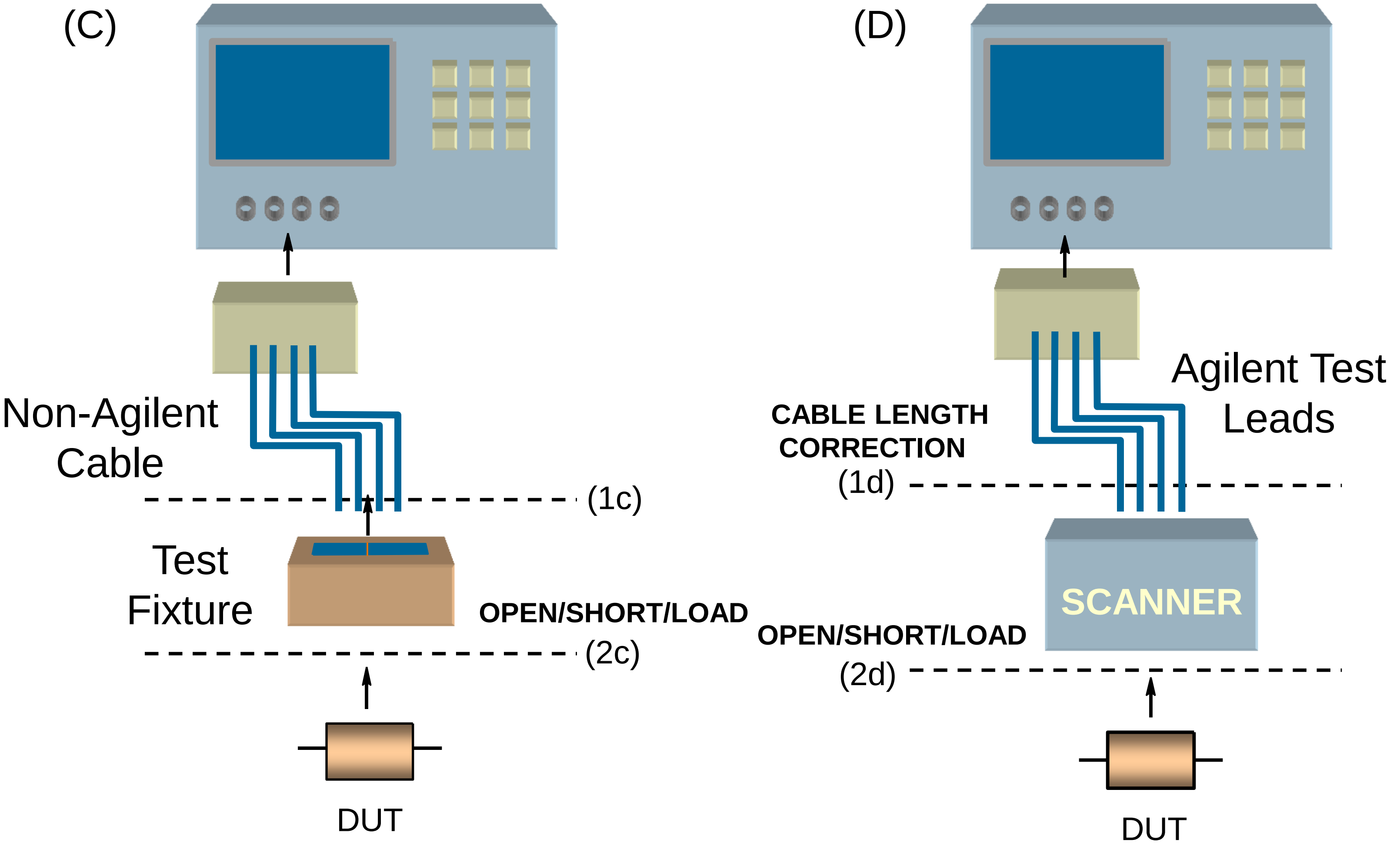




Practical Compensation Examples

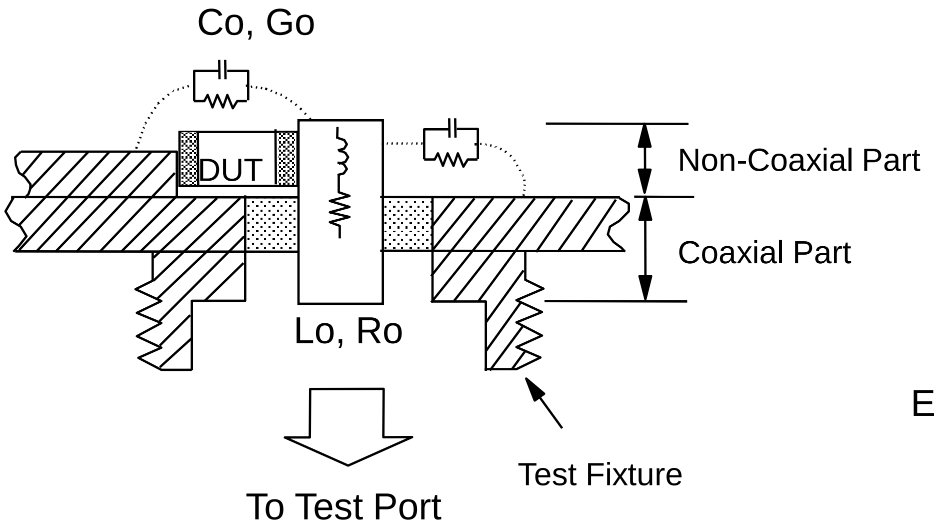
Unlocking Measurement Insights for 75 Years

Practical Examples

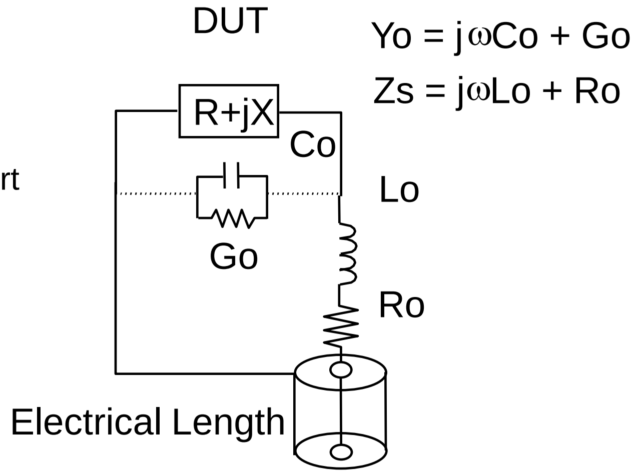


Compensation in RF Range

Error Source Model



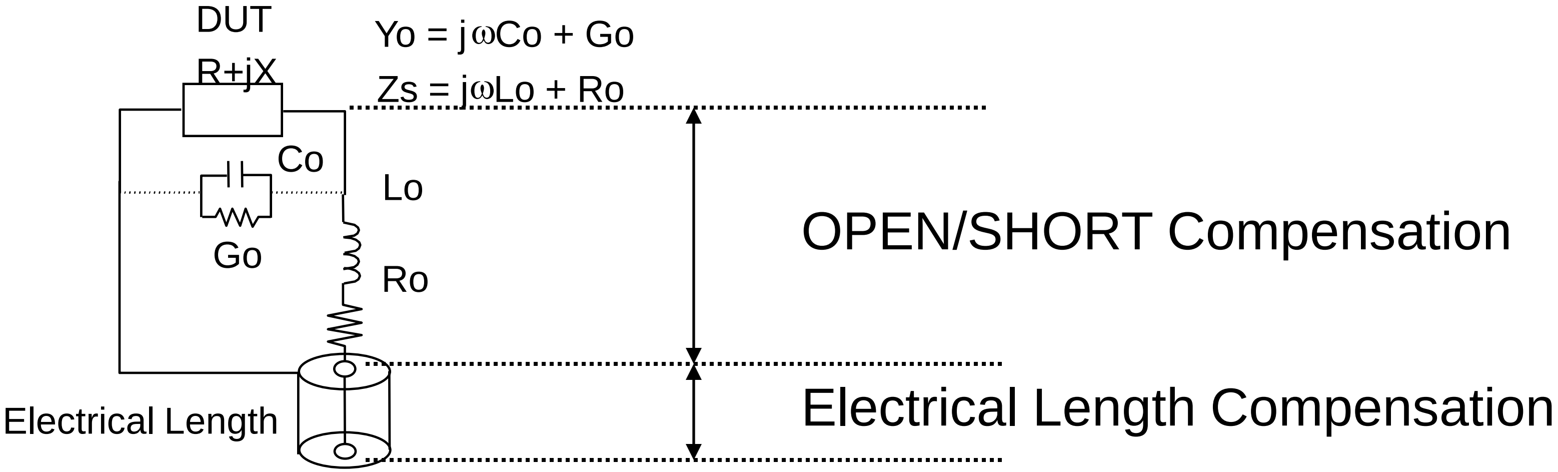
(a) Typical test fixture configuration



(b) Simplified equivalent circuit model

Compensation in RF Range

Compensation for coaxial and non-coaxial portions



Yo = jωCo + Go

Zs = jωLo + Ro

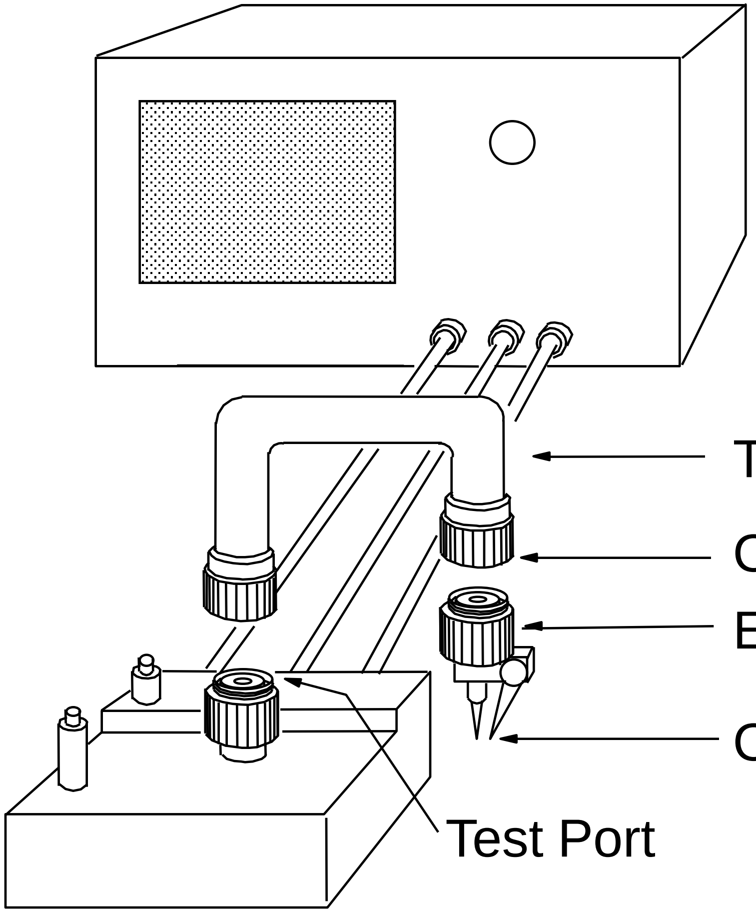
OPEN/SHORT Compensation

Electrical Length Compensation

Simplified Equivalent Circuit Model

Port Extension

Unlocking Measurement Insights for 75 Years



Test Port Extension Cable

OPEN/SHORT/LOAD Calibration

Electrical Length Compensation

OPEN/SHORT Compensation

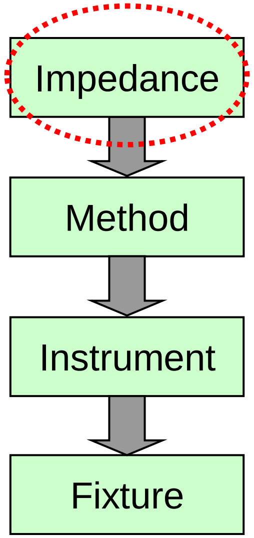
Test Port

Agenda

Unlocking Measurement Insights for 75 Years

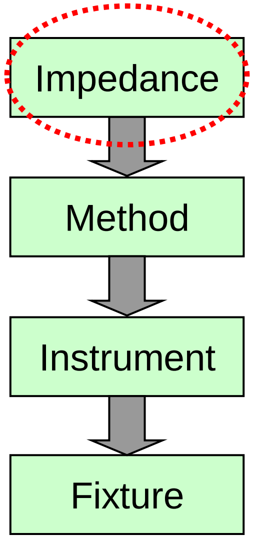
- Introduction
- Impedance fundamentals
- Measurement methods
- Fixturing and cabling
- Calibration and compensation
- **Solution selection process**

Step 1: Find Impedance (1 of 2)

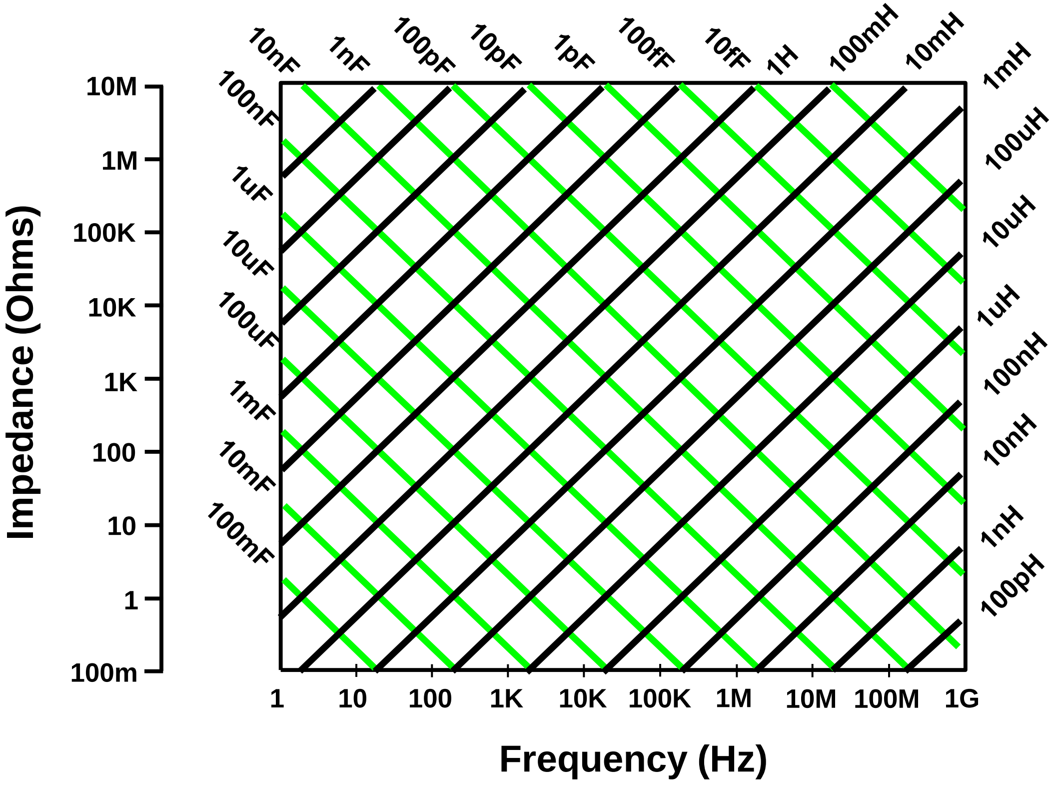


- **Determine:**
  - Approximate C or L value of DUT
  - Typical measurement frequency
- **Find impedance using an admittance chart**

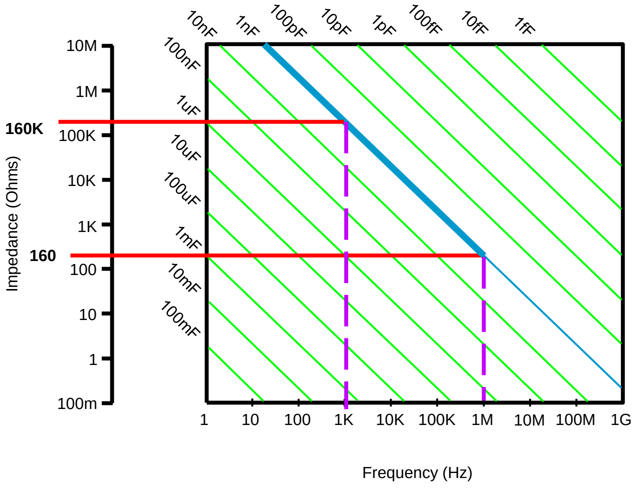
Step 1: Find Impedance (2 of 2)



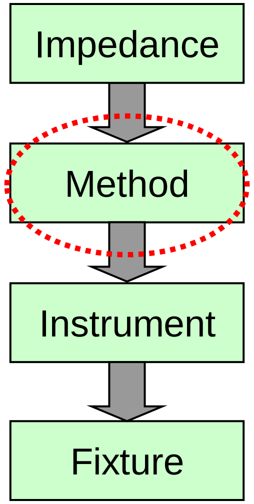
- **Use this admittance chart to find impedance from capacitance or inductance value**



Example: a 1 nF capacitor at 1 MHz has an impedance of about 160 ohms



Step 2: Choose Measurement Method

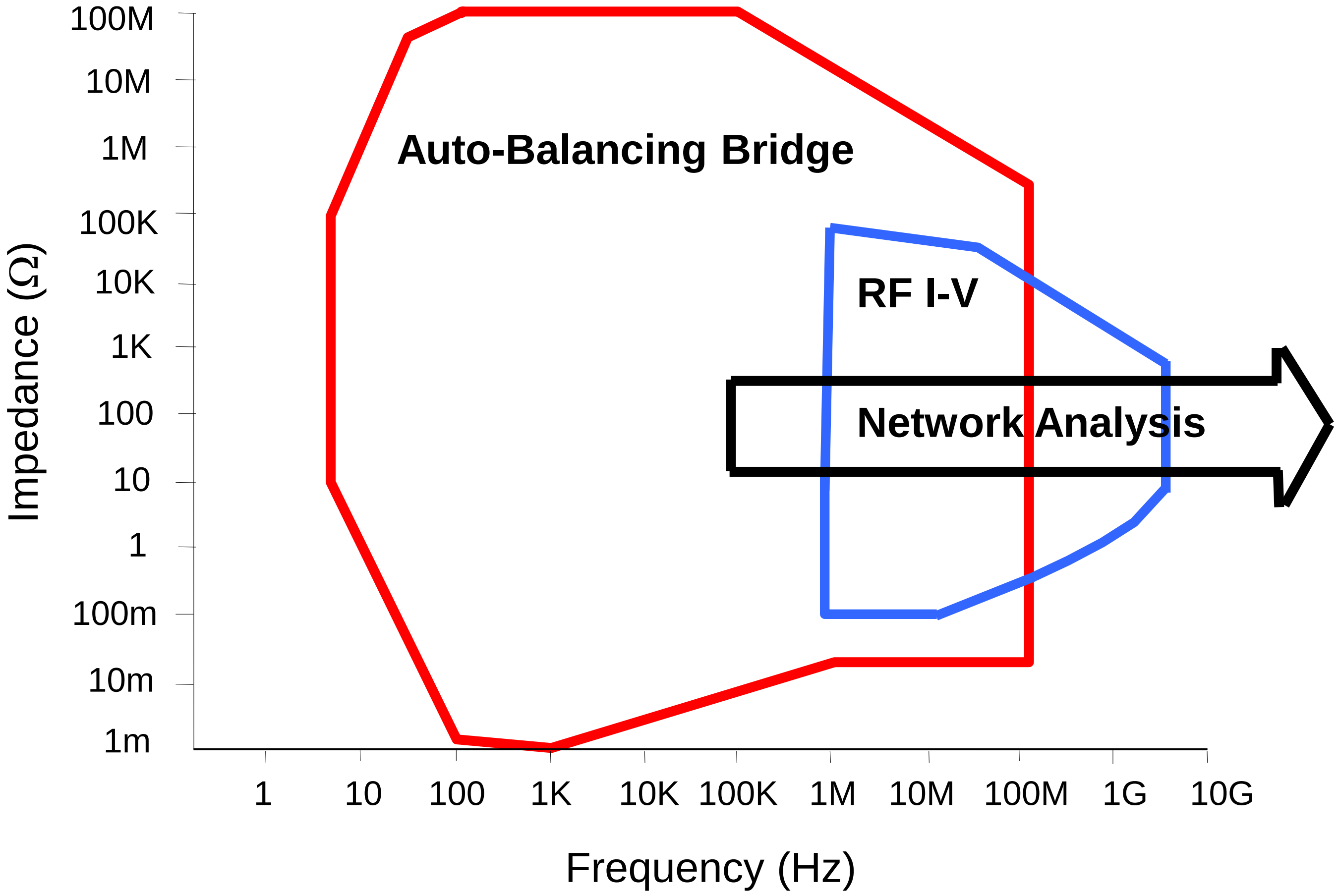


Impedance

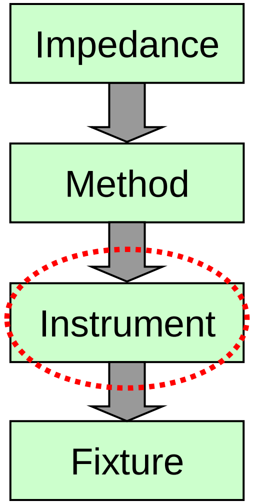
Method

Instrument

Fixture



Step 3: Select Instrument



Impedance

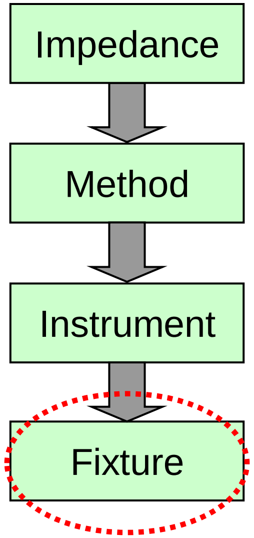
Method

Instrument

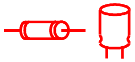
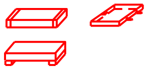
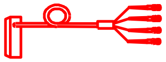
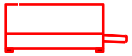
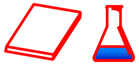
Fixture

- **Determine test conditions:**
  - Measurement parameters (R, C, L, Z, D and Q)
  - Frequency (range, swept or fixed)
  - AC signal (voltage/current, range, swept or fixed)
  - DC bias (voltage/current, range, swept or fixed)
- **Identify desired display and analysis functions:**
  - Display: graph?
  - Analysis: market, limit lines, equivalent circuit analysis?
- **Identify other needs (speed, interface, price)**
- **Refer to selection guide to choose best instrument (*Agilent LCR Meters, Impedance Analyzers and Test Fixtures*, P/N 5952-1430E)**

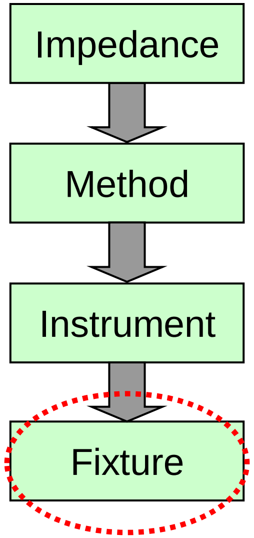
Step 4: Select Test Fixture (1 of 2)



- **Determine fixture model number group by knowing DUT type and instrument connector type:**

DUT Type	Instrument Connector Type	
	BNC (≤ 110 MHz)	7 mm (≤ 3 GHz)
Lead Component 	16047A/D/E, 16060A	16092A
SMD Component 	16034E/G/H, 16044A 16334A	16192A, 16194A, 16196A/B/C/D、16197A
Other Shape or Size	16089A/B/C/D/E	None
Extension Cable 	16048A/D/E/G/H	None
DC Bias 	16065A/C, 42841A, 42842A/B/C, 42843A	16200B
Probe 	16095A, 42941A	16094-65000
Material 	16451B, 16452A	16453A, 16454A
Others	16314-60011 (Balun)	None

Step 4: Select Test Fixture (2 of 2)


Impedance

Method

Instrument

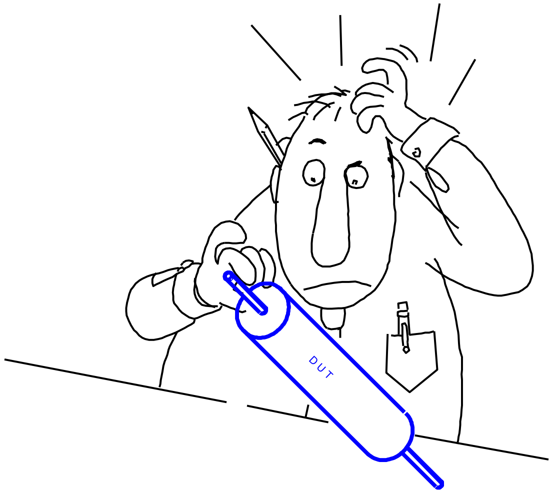
Fixture

- **Determine additional conditions:**
  - Frequency range
  - Impedance range
  - DUT shape and size
  - Location of electrodes
  - DC bias
  - Cable extension
  - Temperature
- **Refer to selection guide to choose suitable fixture (Accessories Selection Guide for Impedance Measurements, P/N 5965-4792E)**

Product Selection Process Summary

Unlocking Measurement Insights for 75 Years

- **Step 1: Find impedance**
  - Frequency
  - DUT value
- **Step 2: Choose method**
  - Frequency range
  - Impedance range
  - Accuracy
- **Step 3: Select instrument**
  - Frequency range
  - Impedance range
  - Accuracy
- **Step 4: Select test fixture**
  - DUT and connector types
  - Test conditions



For More Information

Unlocking Measurement Insights for 75 Years

- **Literature**
  - *Impedance Measurement Handbook*, Lit. No. 5950-3000
  - *Agilent Impedance Analyzers, LCR Meters and Test Fixtures*, Selection Guide, Lit. No. 5952-1430E
  - *Accessories Selection Guide for Impedance Measurements*, Lit. No. 5965-4792E
  - *8 Hints for Successful Impedance Measurements*, Lit. No. 5968-1947E
  - *Solutions for Measuring Permittivity and Permeability with LCR Meters and Impedance Analyzers*, Lit. No. 5980-2862E
- **Internet**
  - http://www.agilent.com/find/impedance
  - http://www.agilent.com/find/impedance-accessory

Thank you!

Adolfo Del Solar

Application Engineer
adolfo_del-solar@agilent.com