Radiofrequency Measurements

Impedance Measurements
Low-frequency Methods

Bridge method

\[ Z_x = \frac{Z_1}{Z_2} \cdot Z_3 \]

When no current flows through the detector (D), the value of the unknown impedance \( Z_x \) can be obtained by the relationship of the other bridge elements. Various types of bridge circuits, employing combinations of L, C, and R components as the bridge elements, are used for various applications.

Resonant method

When a circuit is adjusted to resonance by adjusting a tuning capacitor \( C \), the unknown impedance \( L_x \) and \( R_x \) values are obtained from the test frequency, \( C \) value, and \( Q \) value. \( Q \) is measured directly using a voltmeter placed across the tuning capacitor. Because the loss of the measurement circuit is very low, \( Q \) values as high as 1000 can be measured. Other than the direct connection shown here, series and parallel connections are available for a wide range of impedance measurements.
Low-frequency Methods

I-V method

An unknown impedance $Z_x$ can be calculated from measured voltage and current values. Current is calculated using the voltage measurement across an accurately known low value resistor, $R$. In practice a low-loss transformer is used in place of $R$ to prevent the effects caused by placing a low value resistor in the circuit. The transformer, however, limits the low end of the applicable frequency range.
Low-frequency Methods

Auto balancing bridge method

The current, flowing through the DUT, also flows through resistor R. The potential at the “L” point is maintained at zero volts (thus called a “virtual ground”), because the current through R balances with the DUT current by operation of the I-V converter amplifier. The DUT impedance is calculated using voltage measurement at High terminal and that across R.

Note: In practice, the configuration of the auto balancing bridge differs for each type of instrument. Generally LCR meters, in a low frequency range typically below 100 kHz, employ a simple operational amplifier for its I-V converter. This type of instrument has a disadvantage in accuracy, at high frequencies, because of performance limits of the amplifier. Wideband LCR meters and impedance analyzers employ the I-V converter consisting of sophisticated null detector, phase detector, integrator (loop filter) and vector modulator to ensure a high accuracy for a broad frequency range over 1 MHz. This type of instrument can attain to a maximum frequency of 110 MHz.
\[ Z_X = |Z_X| e^{i\phi} \]

\[ V_Z = A \cos (\omega t + \phi) \]

\[ V_R = B \cos \omega t \]

\[ \left| \frac{Z_X}{R_S} \right| = \frac{A}{B} \]

\[ V = V_0 \cos (\omega t + \phi) \cos (\omega t + \theta) = (V_0/2) \left[ \cos (\phi - \theta) + \cos (2\omega t + \phi + \theta) \right] + \]

\[ \langle V \rangle = (V_0/2) \cos (\phi - \theta) \]

\[ u_{Z1} = kA \cos (\phi - \theta) \]

\[ u_{Z2} = kA \cos (\phi - \theta - \pi/2) = kA \sin (\phi - \theta) \]

\[ u_{R1} = kB \cos (- \theta) \]

\[ u_{R2} = kB \cos (- \theta - \pi/2) = kB \sin (- \theta) \]
RF-IV

\[ Z_X = |Z_X| e^{j\phi} \]

\[ \left| \frac{Z_X}{R_S} \right| = \sqrt{\frac{u_{Z1}^2 + u_{Z2}^2}{u_{R1}^2 + u_{R2}^2}} = \frac{A}{B} \]

\[ \cos \phi = \frac{B}{A} \frac{u_{R1} u_{Z1} + u_{R2} u_{Z2}}{u_{R1}^2 + u_{R2}^2} \]

\[ \sin \phi = \frac{B}{A} \frac{u_{R1} u_{Z2} - u_{R2} u_{Z1}}{u_{R1}^2 + u_{R2}^2} \]
Network analysis method

The reflection coefficient is obtained by measuring the ratio of an incident signal to the reflected signal. A directional coupler or bridge is used to detect the reflected signal and a network analyzer is used to supply and measure the signals. Since this method measures reflection at the DUT, it is usable in the higher frequency range.
High-frequency Methods

(a) Theoretical measurement sensitivity

Impedance (Log scale)

Network analysis for resistive DUT

RF I-V method

Impedance measurement sensitivity

High

Low Z

Zo

High Z

(b) Practical measurement sensitivity

Impedance (Log scale)

Network analysis for reactive DUT

RF I-V method

Impedance measurement sensitivity

High

Low Z

Zo

High Z

Reflection coefficient $\Gamma$

The graph applies to $Z = R_{x} + j \omega L$
High-frequency Methods

![Graph showing Q factor accuracy vs frequency. The graph compares the accuracy of Network analysis and RF I-V method.]

Note: The Q accuracy is compared at Q factor of 100 at 50Ω impedance.
## Measurement Methods

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<th>Advantages</th>
<th>Disadvantages</th>
<th>Applicable frequency range</th>
<th>Typical Agilent products</th>
<th>Common application</th>
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<tbody>
<tr>
<td><strong>Bridge method</strong></td>
<td>High accuracy (0.1% typ.). Wide frequency coverage by using different types of bridges. Low cost.</td>
<td>Need to be manually balanced. Narrow frequency coverage with a single instrument.</td>
<td>DC to 300 MHz</td>
<td>None</td>
<td>Standard lab</td>
</tr>
<tr>
<td><strong>Resonant method</strong></td>
<td>Good Q accuracy up to high Q.</td>
<td>Need to be tuned to resonance. Low impedance measurement accuracy.</td>
<td>10 kHz to 70 MHz</td>
<td>None</td>
<td>High Q device measurement.</td>
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<td><strong>I-V method</strong></td>
<td>Grounded device measurement. Suitable to probe type test needs.</td>
<td>Operating frequency range is limited by transformer used in probe.</td>
<td>10 kHz to 100 MHz</td>
<td>None</td>
<td>Grounded device measurement.</td>
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<tr>
<td><strong>RF I-V method</strong></td>
<td>High accuracy (1% typ.) and wide impedance range at high frequencies.</td>
<td>Operating frequency range is limited by transformer used in test head.</td>
<td>1 MHz to 3 GHz</td>
<td>4287A, 4395A, 43961A, 4396B, 43961A, E4991A</td>
<td>RF component measurement.</td>
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<tr>
<td><strong>Network analysis method</strong></td>
<td>High frequency Range. Good accuracy when the unknown impedance is close to the characteristic impedance</td>
<td>Recalibration required when the measurement frequency is changed. Narrow impedance measurement range.</td>
<td>300 kHz and above</td>
<td>8753E, 4395A</td>
<td>RF component measurement.</td>
</tr>
<tr>
<td><strong>Auto balancing bridge method</strong></td>
<td>Wide frequency coverage from LF to HF. High accuracy over a wide impedance measurement range. Grounded device measurement</td>
<td>Higher frequency ranges not available.</td>
<td>20 Hz to 110 MHz</td>
<td>4284A, 4294A, 4294A+42941A (*1), 4294A+42942A (*1)</td>
<td>Generic component measurement (*1) Grounded device measurement</td>
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