Overview
Specifications describe the instrument’s warranted performance over the temperature range of 0°C to 40°C (except as noted). Supplemental characteristics are intended to provide information that is useful in applying the instrument by giving non-warranted performance parameters.

These are denoted as “typical,” “nominal,” or “approximate.” Warm-up time must be greater than or equal to 30 minutes after power on for all specifications. Specifications of the stimulus characteristics and measurement accuracy are defined at the tip of APC-7 connector on the test head connected to the instrument.
Agilent 4291B RF Impedance/Material Analyzer

Measurement Parameters
Impedance parameters
|Z|, θz, |Y|, θy, R, X, G, B, C_p, C_s, L_p, L_s, R_p, R_s, D, Q, |Γ|, θ_y, Γ_x, Γ_y

Stimulus Characteristics
Frequency Characteristics
Operating frequency ...................................................... 1 MHz to 1.8 GHz
Frequency resolution ..................................................... 1 mHz
Frequency reference
Accuracy
@ 23 ± 5°C .......................................................................... < ±10 ppm

Precision frequency reference (Option 1D5)
Accuracy
@ 0°C to 40°C ................................................................. < ±1 ppm

Source Characteristics
OSC level
Voltage range
@ 1 MHz ≤ Frequency ≤ 1 GHz (When terminal is open) ................. 0.2 mV_{rms} to 1 V_{rms}
@ 1 GHz < Frequency ≤ 1.8 GHz (When terminal is open) ................. 0.2 mV_{rms} to 0.5 V_{rms}

Current range
@ 1 MHz ≤ Frequency ≤ 1 GHz (When terminal is shorted). ............. 4 µA_{rms} to 20 mA_{rms}
@ 1 GHz < Frequency ≤ 1.8 GHz (When terminal is shorted). ............. 4 µA_{rms} to 10 mA_{rms}

Power range
@ 1 MHz ≤ Frequency ≤ 1 GHz (When terminating with 50 Ω). ......... –67 dBm to 7 dBm
@ 1 GHz < Frequency ≤ 1.8 GHz (When terminating with 50 Ω) ........ –67 dBm to 1 dBm

OSC level resolution
AC voltage resolution
0.22 V_{rms} < V_{osc} ≤ 1 V_{rms} ........................................... 2 mV
70 mV_{rms} < V_{osc} ≤ 220 mV_{rms} ..................................... 0.5 mV
22 mV_{rms} < V_{osc} ≤ 70 mV_{rms} .................................... 0.2 mV
7 mV_{rms} < V_{osc} ≤ 22 mV_{rms} ...................................... 0.05 mV
2.2 mV_{rms} < V_{osc} ≤ 7 mV_{rms} .................................... 0.02 mV
0.7 mV_{rms} < V_{osc} ≤ 2.2 mV_{rms} .................................. 0.005 mV
0.2 mV_{rms} ≤ V_{osc} ≤ 0.7 mV_{rms} .................................. 0.002 mV
Agilent 4291B RF Impedance/Material Analyzer

**AC current resolution**

\[
\begin{align*}
4.4 \text{ mA}_{\text{rms}} < I_{\text{OSC}} & \leq 20 \text{ mA}_{\text{rms}} & \rightarrow 40 \mu\text{A} \\
1.4 \text{ mA}_{\text{rms}} < I_{\text{OSC}} & \leq 4.4 \text{ mA}_{\text{rms}} & \rightarrow 10 \mu\text{A} \\
0.44 \text{ mA}_{\text{rms}} < I_{\text{OSC}} & \leq 1.4 \text{ mA}_{\text{rms}} & \rightarrow 4 \mu\text{A} \\
140 \mu\text{A}_{\text{rms}} < I_{\text{OSC}} & \leq 440 \mu\text{A}_{\text{rms}} & \rightarrow 1 \mu\text{A} \\
44 \mu\text{A}_{\text{rms}} < I_{\text{OSC}} & \leq 140 \mu\text{A}_{\text{rms}} & \rightarrow 0.4 \mu\text{A} \\
14 \mu\text{A}_{\text{rms}} < I_{\text{OSC}} & \leq 44 \mu\text{A}_{\text{rms}} & \rightarrow 0.1 \mu\text{A} \\
4 \mu\text{A}_{\text{rms}} \leq I_{\text{OSC}} & \leq 14 \mu\text{A}_{\text{rms}} & \rightarrow 0.04 \mu\text{A}
\end{align*}
\]

**AC power resolution**

\[
A + B + 6_{[\text{dB}]} \times f_{[\text{MHz}]} \frac{\text{dB}}{1800}
\]

where,

- \( A \) depends on temperature conditions as follows:
  - @ within referenced to 23±5°C: 2 dB
  - @ other environmental temperature conditions: 4 dB

- \( B \) depends on OSC level as follows:
  - @ \( V_{\text{OSC}} \geq 250 \text{ mV}_{\text{rms}} \):
    - \( I_{\text{OSC}} \geq 5 \text{ mA}_{\text{rms}} \):
      - \( P_{\text{OSC}} \geq -5 \text{ dBm} \):
    - \( 250 \text{ mV}_{\text{rms}} > V_{\text{OSC}} \geq 2.5 \text{ mV}_{\text{rms}} \):
      - \( 5 \text{ mA}_{\text{rms}} > I_{\text{OSC}} \geq 50 \text{ \mu A}_{\text{rms}} \):
        - \( -5 \text{ dBm} > P_{\text{OSC}} \geq -45 \text{ dBm} \):
    - @ other OSC level: 2 dB

**Definition of OSC level**

- Voltage level: 2 × voltage level across the 50 Ω which is connected to the output terminal (This level is approximately equal to the level when a terminal is open.)
- Current level: 2 × current level through the 50 Ω which is connected to the output terminal (This level is approximately equal to the level when a terminal is shorted.)
- Power level: when terminating with 50 Ω

**OSC level accuracy**

\[
\frac{1}{2} \text{ of specification value (typical)}
\]

**Connector**

- APC-7

**Output impedance**

- 50 Ω (Nominal value)

**DC bias (Option 001)**

- DC voltage level: 0 to ±40V
- DC current level: 20 μA to 100 mA and –20 μA to –100 mA
- DC level resolution: 1 mV, 20 μA

**DC level accuracy**

- @ 23±5°C:
  - Voltage: 0.1 % + 4 mV + \( (I_{\text{dc (mA)}} \times 5 [\Omega]) \) mV
  - Current: 0.5 % + 30 μA + \( (V_{\text{dc (v)}} / 10 [\text{kΩ}]) \) mA
- @ 8 to 18°C and 28 to 38°C:
  - Voltage: 0.2 % + 8 mV + \( (I_{\text{dc (mA)}} \times 10 [\text{kΩ}]) \) mV
  - Current: 1 % + 60 μA + \( (V_{\text{dc (v)}} / 5 [\text{kΩ}]) \) mA
- @ 0 to 8°C and 38 to 40°C:
  - Voltage: 0.3 % + 12 mV + \( (I_{\text{dc (mA)}} \times 15 [\text{kΩ}]) \) mV
  - Current: 1.5 % + 90 μA + \( (V_{\text{dc (v)}} \times 3/10 [\text{kΩ}]) \) mA
Agilent 4291B RF Impedance/Material Analyzer

Level monitor

Monitor parameters ........................................ OSC level (voltage, current), DC bias (voltage, current)
Monitor accuracy ........................................ Same as OSC level accuracy (typical)
DC bias ..................................................... Twice as bad as specifications of dc level accuracy (typical)

Sweep Characteristics

Figure 1-2. DC Voltage and Current Level Range (Typical)

Sweep parameters ........................................ Frequency, OSC level (voltage), DC bias voltage/current
Sweep setup .................................................. Start Stop, or Center Span
Sweep type .................................................... Linear, Log, Zero-span, List
Other sweep parameters ................................ Linear, Log, Zero-span
Sweep mode .................................................. Continuous, Single, Manual, Number of groups
Sweep direction .............................................. Up sweep, Down sweep
AC level, DC bias (voltage and current) .................. Up sweep
Other sweep parameters ................................ Up sweep
Number of measurement points ......................... 2 to 801 points
Averaging ..................................................... Sweep average, Point average
Delay time ................................................... Point delay time, Sweep delay time
Measurement circuit mode .............................. Series circuit mode, parallel circuit mode

Calibration/Compensation
Calibration function ...................................... Open/Short/50 Ω calibration, Low loss calibration
Compensation function .................................. Open/Short/Load compensation, Port extension, Electric length
Agilent 4291B RF Impedance/Material Analyzer

Measurement Accuracy

Conditions of accuracy specifications

• Open/Short/50 Ω calibration must be done. Calibration ON.
• Averaging (on point) factor is larger than 32 at which calibration is done if Cal points is set to USER DEF.
• Measurement points are same as the calibration points.
• Environmental temperature is within ±5°C of temperature at which calibration is done, and within 13°C to 33°C. Beyond this environmental temperature condition, accuracy is twice as bad as specified.

|Z|, |Y| Accuracy ...................................................... ±(Ea + Eb) [%]

The illustrations of |Z| and |Y| accuracy are shown in Figures 1-3 to 1-6.

θ Accuracy ...................................................... ±(Ea + Eb) [rad]

L, C, X, B Accuracy ...................................................... ±(Ea + Eb) × θ[1 + Dx²] [%]

R, G Accuracy ...................................................... ±(Ea + Eb) × θ[1 + Qx²] [%]

D Accuracy (∆D)

\[ @ |D_x \tan \left( \frac{E_a + E_b}{100} \right) | < 1 \] ...................................................... ± \left( \frac{1 + D_x^2 \tan \left( \frac{E_a + E_b}{100} \right)}{1 + D_x \tan \left( \frac{E_a + E_b}{100} \right)} \right)

Especially, @ D_x ≤ 0.1. ...................................................... ± \frac{(E_a + E_b)}{100}

Q Accuracy (∆Q)

\[ @ |Q_x \tan \left( \frac{E_a + E_b}{100} \right) | < 1 \] ...................................................... ± \left( \frac{1 + Q_x^2 \tan \left( \frac{E_a + E_b}{100} \right)}{1 + Q_x \tan \left( \frac{E_a + E_b}{100} \right)} \right)

Especially, @ \frac{10}{(E_a + E_b)} ≥ Q_x ≥ 10 ...................................................... ±Q_x \frac{(E_a + E_b)}{100}

Where,

\( D_x \): Measured value of D

\( E_a \): depends on measurement frequency as follows:

- @ 1 MHz ≤ Frequency ≤ 100 MHz ........................................ 0.6
- @ 100 MHz < Frequency ≤ 500 MHz ........................................ 0.8
- @ 500 MHz < Frequency ≤ 1000 MHz ...................................... 1.2
- @ 1000 MHz < Frequency ≤ 1800 MHz .................................... 2.0

\( E_b = \frac{|Z_x|}{|Z_a|} + \frac{|Y_x|}{|Z_a|} \times 100 \)

\( Q_x \): Measured value of Q

\( Z_x \): impedance measurement value [Ω]

\( Z_x \) and \( Y_x \) depend on number of point averaging (N_av), OSC level (VOSC), impedance measurement value (Zx) and the test head used as follows:
### Agilent 4291B RF Impedance/Material Analyzer

#### Table 1-1. $Z_s$ and $Y_s$ When High Impedance Test Head Is Used

<table>
<thead>
<tr>
<th>Number of Point Averaging ($N_{av}$)</th>
<th>OSC Signal Level ($V_{osc}$)</th>
<th>Meas. Impedance ($Z_s$)</th>
<th>$Z_s$ [Ω]</th>
<th>$Y_s$ [S]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>( \frac{0.02}{V_{osc}} \times (0.2 + 0.001 \times f_{MHz}) )</td>
<td>( \frac{0.02}{V_{osc}} \times (5 \times 10^{-4} + 2 \times 10^{-7} \times f_{MHz}) )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( Z_s \geq 500 \Omega )</td>
<td>( 0.2 + 0.001 \times f_{MHz} )</td>
<td>( 5 \times 10^{-6} + 2 \times 10^{-7} \times f_{MHz} )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( Z_s &lt; 500 \Omega )</td>
<td>( 0.2 + 0.001 \times f_{MHz} )</td>
<td>( 2 \times 10^{-6} + 2 \times 10^{-7} \times f_{MHz} )</td>
</tr>
<tr>
<td>( 1 \leq N_{av} \leq 7 )</td>
<td>( V_{osc} &lt; 0.02V )</td>
<td>–</td>
<td>( 0.02 )</td>
<td>( 0.02 )</td>
</tr>
<tr>
<td></td>
<td>( 0.02V \leq V_{osc} &lt; 0.12V)</td>
<td>–</td>
<td>( 0.1 + 5 \times 10^{-4} \times f_{MHz} )</td>
<td>( 2 \times 10^{-6} + 1 \times 10^{-7} \times f_{MHz} )</td>
</tr>
<tr>
<td></td>
<td>( V_{osc} \geq 500 \Omega )</td>
<td>( \frac{0.02}{V_{osc}} \times (0.1 + 5 \times 10^{-4} \times f_{MHz}) )</td>
<td>( 0.1 )</td>
<td>( 0.02 )</td>
</tr>
<tr>
<td></td>
<td>( V_{osc} &lt; 0.02V )</td>
<td>–</td>
<td>( 0.02 )</td>
<td>( 0.02 )</td>
</tr>
<tr>
<td>( N_{av} \geq 8 )</td>
<td>( V_{osc} &lt; 0.02V )</td>
<td>–</td>
<td>( 0.02 )</td>
<td>( 0.02 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( V_{osc} \geq 500 \Omega )</td>
<td>( 0.01 + 5 \times 10^{-4} \times f_{MHz} )</td>
<td>( 3 \times 10^{-6} + 1 \times 10^{-7} \times f_{MHz} )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( Z_s \geq 5 \Omega )</td>
<td>( 0.05 + 0.001 \times f_{MHz} )</td>
<td>( 1 \times 10^{-6} + 2 \times 10^{-7} \times f_{MHz} )</td>
</tr>
</tbody>
</table>

At the following frequency points, instrument spurious characteristics could occasionally cause measurement errors to exceed specified value because of instrument spurious characteristics:

- 10.71 MHz
- 17.24 MHz
- 21.42 MHz
- 42.84 MHz
- 514.645 MHz
- 686.19333 MHz
- 1029.29 MHz
- 1327.38666 MHz

See “EMC” under “Others” in “General Characteristics.”
Agilent 4291B RF Impedance/Material Analyzer

Figure 1-3. Impedance Measurement Accuracy Using High Impedance Test Head (@ Low OSC Level)

Figure 1-4. Impedance Measurement Accuracy Using High Impedance Test Head (@ High OSC Level)
Agilent 4291B RF Impedance/Material Analyzer

Figure 1-5. Impedance Measurement Accuracy Using Low Impedance Test Head (@ Low OSC Level)

Figure 1-6. Impedance Measurement Accuracy Using Low Impedance Test Head (@ High OSC Level)
Agilent 4291B RF Impedance/Material Analyzer

Typical measurement accuracy when open/short/50 Ω/low-loss-capacitor calibration is done

Conditions
- Averaging on point factor is larger than 32 at which calibration is done.
- Cal Points is set to USER DEF.
- Environmental temperature is within ±5°C of temperature at which calibration is done, and within 13°C to 33°C. Beyond this environmental temperature condition, accuracy is twice as bad as specified.

|Z|, |Y| Accuracy .................................................. ±(E_a + E_b) [%]

θ Accuracy .................................................. ± \( \frac{E_c}{100} \) [rad]

L, C, X, B Accuracy .................................................. ± \( \sqrt{(E_a + E_b)^2 + (E_cD_x)^2} \) [%]

R, G Accuracy .................................................. ± \( \sqrt{(E_a + E_b)^2 + (E_cQ_x)^2} \) [%]

D Accuracy
@ \(|D_x \tan(E_c/100)| < 1\) .................................................. ± \( \frac{(1 + D_x^2) \tan(E_c/100)}{1 + D_x \tan(E_c/100)} \) [%]

Especially, \( D_x \leq 0.1 \) .................................................. ± \( \frac{E_c}{100} \) [%]

Q Accuracy
@ \(|Q_x \tan(E_c/100)| < 1\) .................................................. ± \( \frac{(1 + Q_x^2) \tan(E_c/100)}{1 + Q_x \tan(E_c/100)} \) [%]

Especially, \( \frac{10}{E_c} \geq Q_x \geq 10 \) .................................................. ± \( Q_x^2 \frac{E_c}{100} \) [%]

Where,
- \( D_x \): Actual D value of DUT
- \( E_a, E_b \): are as same as \( E_a \) and \( E_b \) of the measurement accuracy when OPEN/SHORT/50 Ω calibration is done.
- \( E_c = 0.06 + 0.14 \times \frac{F}{1800} \) (Typical)

- \( F \): measurement frequency [MHz]
- \( Q_x \): Actual Q value of DUT
Figure 1-7. Typical measurement accuracy when open/short/50 Ω/low-loss-capacitor calibration is done
Options 013 and 014 High Temperature Test Heads

Specification for Option 013 and 014 High Temperature Test Heads

Frequency Characteristics

Operating frequency .............................................. 1 MHz to 1.8 GHz

Source Characteristics

OSC level

Voltage Range
@ 1 MHz ≤ Frequency < 1 GHz ........................................ 0.2 mV<sub>rms</sub> to 500 mV<sub>rms</sub>
@ 1 GHz ≤ Frequency ≤ 1.8 GHz ................................. 0.2 mV<sub>rms</sub> to 250 mV<sub>rms</sub>

OSC level resolution

@ 110 mV<sub>rms</sub> < V<sub>OSC</sub> ≤ 500 mV<sub>rms</sub> ........................................ 2 mV
@ 11 mV<sub>rms</sub> < V<sub>OSC</sub> ≤ 110 mV<sub>rms</sub> ................................. 0.2 mV
@ 1.1 mV<sub>rms</sub> < V<sub>OSC</sub> ≤ 11 mV<sub>rms</sub> ........................................ 20 µV
@ 0.2 mV<sub>rms</sub> ≤ V<sub>OSC</sub> ≤ 1.1 mV<sub>rms</sub> ................................. 2 µV

AC current resolution

@ 2.75 mArms < I<sub>OSC</sub> ≤ 12.5 mA<sub>rms</sub> ................................. 50 µA
@ 0.275 mArms < I<sub>OSC</sub> ≤ 2.75 mA<sub>rms</sub> ................................. 5 µA
@ 27.5 µA<sub>rms</sub> < I<sub>OSC</sub> ≤ 275 µA<sub>rms</sub> ................................. 0.5 µA
@ 5 µA ≤ I<sub>OSC</sub> ≤ 27.5 µA ............................................. 0.05 µA

AC power resolution

@ –66.1 dBm ≤ P<sub>OSC</sub> ≤ 1.9 dBm ................................. 0.2 dBm max

OSC level accuracy

@ 1 MHz ≤ Frequency ≤ 1 GHz, V<sub>OSC</sub> ≤ 0.25 V<sub>rms</sub> (I<sub>OSC</sub> ≤ 6.3 mA, P<sub>OSC</sub> ≤ –4.1 dBm) 
A + B + S<sub>dB</sub> × frequency[MHz] dB

Where,

A depends on temperature conditions as follows:
within referenced to 23±5°C ............................................. 4 dB
@ 0°C to 18°C, 28°C to 40°C .............................................. 6 dB

B depends on OSC level as follows:
@ 0.5 V<sub>rms</sub> ≥ V<sub>OSC</sub> ≥ 120 mV<sub>rms</sub> ............................................. 0 dB
(12.5 mA<sub>rms</sub> ≥ I<sub>OSC</sub> ≥ 3 mA<sub>rms</sub>)
(1.9 dBm ≥ P<sub>OSC</sub> ≥ –10 dBm)

@ 120 mV<sub>rms</sub> > V<sub>OSC</sub> ≥ 1.2 mV<sub>rms</sub> ............................................. 1 dB
(3 mA<sub>rms</sub> > I<sub>OSC</sub> ≥ 30 µA<sub>rms</sub>)
(–10 dBm > P<sub>OSC</sub> ≥ –50 dBm)

@ 1.2 mV<sub>rms</sub> > V<sub>OSC</sub> ≥ 0.2 mV<sub>rms</sub> ............................................. 2 dB
(30 µA<sub>rms</sub> > I<sub>OSC</sub> ≥ 5 µA<sub>rms</sub>)
(–50 dBm > P<sub>OSC</sub> ≥ –66.1 dBm)

Output impedance ........................................... 40 Ω (Nominal value)

Level Monitor

Monitor accuracy

OSC level .......................................................... Same as OSC level accuracy (typical)
DC bias .......................................................... Twice as bad as specifications of dc level accuracy (typical)
Options 013 and 014 High Temperature Test Heads

Basic Measurement Accuracy

Conditions of accuracy specifications

- OPEN/SHORT/50 Ω calibration must be done. Calibration ON.
- Averaging (on point) factor must be larger than 32 at which calibration is done.
- Measurement points are same as the calibration points.
- Environmental temperature is within ±5°C of temperature at which calibration is done, and within 13°C to 33°C. Beyond this environmental temperature condition, and within 0°C to 40°C, accuracy is twice as bad as specified.
- Bending cable should be smooth and the bending angle is less than 30°.
- Cable position should be kept in the same position after calibration measurement.
- OSC level must be same as level at which calibration is done.
- OSC level is less than or equal to 0.25 V, or OSC level is greater than 0.25 V and frequency range is within 1 MHz to 1 GHz.

\[ |Z| \text{ Accuracy} \quad \pm (E_a + E_b) \% \]

\[ \theta \text{ Accuracy} \quad \pm \frac{(E_a + E_b)}{100} \text{ [rad]} \]

Where,

- \( E_a \): depends on measurement frequency as follows:
  - @ 1 MHz ≤ frequency ≤ 100 MHz \( \quad \pm 0.6 \% \)
  - @ 100 MHz < frequency ≤ 500 MHz \( \quad \pm 0.8 \% \)
  - @ 500 MHz < frequency ≤ 1 GHz \( \quad \pm 1.5 \% \)
  - @ 1 GHz < frequency ≤ 1.8 GHz \( \quad \pm 3.0 \% \)

- \( E_b = \left( \frac{Z_s}{Z_x} + Y_o \right) \times 100 [\%] \)

- \( Z_s \) and \( Y_o \) depend on number of point averaging (\( N_{av} \)) and OSC level (\( V_{osc} \)) as follows:

\[ Z_s: \text{Impedance measurement value [\( \Omega \)]} \]
## Options 013 and 014 High Temperature Test Heads

### Table 1-3. $Z_s$ and $Y_o$ When High Impedance Test Head Is Used

<table>
<thead>
<tr>
<th>Measurement Conditions</th>
<th>$Z_s$ [$\Omega$]</th>
<th>$Y_o$ [$S$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{osc} &lt; 0.02$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1 \leq N_{av} \leq 7$</td>
<td>$0.02V \leq V_{osc} &lt; 0.12$</td>
<td>$0.2 + 0.001 \times f_{(MHz)}$</td>
</tr>
<tr>
<td></td>
<td>$0.12V \leq V_{osc}$</td>
<td>$0.2 + 0.001 \times f_{(MHz)}$</td>
</tr>
<tr>
<td>$V_{osc} &lt; 0.02$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$8 &lt; N_{av}$</td>
<td>$0.02V \leq V_{osc} &lt; 0.12$</td>
<td>$0.1 + 0.001 \times f_{(MHz)}$</td>
</tr>
<tr>
<td></td>
<td>$0.12V \leq V_{osc}$</td>
<td>$0.1 + 0.001 \times f_{(MHz)}$</td>
</tr>
</tbody>
</table>

1. $V_{osc} = 0.12V = I_{osc} = 3 mA = P_{osc} = –10 dBm, V_{osc} = 0.02V = I_{osc} = 0.5 mA = P_{osc} = –26 dBm

### Table 1-4. $Z_s$ and $Y_o$ When Low Impedance Test Head Is Used

<table>
<thead>
<tr>
<th>Measurement Conditions</th>
<th>$Z_s$ [$\Omega$]</th>
<th>$Y_o$ [$S$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{osc} &lt; 0.02$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$1 \leq N_{av} \leq 7$</td>
<td>$0.02V \leq V_{osc} &lt; 0.12$</td>
<td>$0.1 + 0.001 \times f_{(MHz)}$</td>
</tr>
<tr>
<td></td>
<td>$0.12V \leq V_{osc}$</td>
<td>$0.05 + 0.001 \times f_{(MHz)}$</td>
</tr>
<tr>
<td>$V_{osc} &lt; 0.02$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$8 &lt; N_{av}$</td>
<td>$0.02V \leq V_{osc} &lt; 0.12$</td>
<td>$0.05 + 0.001 \times f_{(MHz)}$</td>
</tr>
<tr>
<td></td>
<td>$0.12V \leq V_{osc}$</td>
<td>$0.03 + 0.001 \times f_{(MHz)}$</td>
</tr>
</tbody>
</table>

1. $V_{osc} = 0.12V = I_{osc} = 3 mA = P_{osc} = –10 dBm, V_{osc} = 0.02V = I_{osc} = 0.5 mA = P_{osc} = –26 dBm

At the following frequency points, instrument spurious characteristics could occasionally cause measurement errors to exceed specified value because of instrument spurious characteristics.

- 10.71 MHz
- 17.24 MHz
- 21.42 MHz
- 42.84 MHz
- 514.645 MHz
- 686.19333 MHz
- 1029.29 MHz
- 1327.38666 MHz

See “EMC” under “Others” in “General Characteristics.”

The excessive vibration and shock could occasionally cause measurement errors to exceed specified values.
Options 013 and 014 High Temperature Test Heads

Figure 1-8. Impedance Measurement Accuracy Using High Temperature High Impedance Test Head (@ Low OSC Level)

Figure 1-9. Impedance Measurement Accuracy Using High Temperature High Impedance Test Head (@ High OSC Level)
Options 013 and 014 High Temperature Test Heads

Figure 1-10. Impedance Measurement Accuracy Using High Temperature Low Impedance Test Head (@ Low OSC Level)

Figure 1-11. Impedance Measurement Accuracy Using High Temperature Low Impedance Test Head (@ High OSC Level)
Options 013 and 014 High Temperature Test Heads

Typical Effects of Temperature Drift on Measurement Accuracy
When environmental temperature exceeds ±5°C of temperature at which calibration is done, add the following measurement error.

Conditions of typical effects of temperature drift
• Environment temperature of a test head is within –55°C to 0°C or 40°C to 200°C.
• Environment temperature of the mainframe is within ±5°C of temperature at which calibration is done, and within 0°C to 40°C.
• Other conditions are as same as the conditions of the basic measurement accuracy of Option 013/014.

|Z| Accuracy .................................................................................. ±(Ea2 + Eb2) [%]

θ Accuracy .................................................................................. ± \(\frac{(Ea2 + Eb2)}{100}\) [rad]

\[\begin{align*}
E_{a2} &= (\Delta A_1 \Delta T + \Delta A_2) \times 10^8 \\
E_{b2} &= (Z_{s2}/Z_x + Y_{o2}Z_x) \times 100
\end{align*}\]

\(\Delta A_1\) is the effect of temperature drift on the impedance measurement value as follows:
(50 + 300 \(\times f\)) [ppm/°C] (typical)
\(\Delta A_2\) is the hysteresis of the effect of temperature drift on the impedance measurement value as follows:
(\(\frac{\Delta A_1 \Delta T}{3}\) [ppm] (typical)

\(f\) : Measurement Frequency [GHz]
\(\Delta T\) : Difference of temperature between measurement condition and calibration measurement condition. [°C]
\(Y_{o2}\) = (\(\Delta Y_{o1} \Delta T + \Delta Y_{o2}\)) \(\times 10^5\) [S]
\(Z_{s2}\) = (\(\Delta Z_{s1} \Delta T + \Delta Z_{s2}\)) \(\times 10^3\) [Ω]
\(Z_x\) : Impedance measurement value [Ω]

\(Y_{o1}\) is the temperature coefficient for OPEN residual as follows:
@ High Temperature High Impedance Test Head is used ............... (0.2 + 8 \(\times f\)) [µS/°C] (typical)
@ High Temperature Low Impedance Test Head is used ............... (1 + 30 \(\times f\)) [µS/°C] (typical)

\(Y_{o2}\) is the hysteresis of the OPEN residual as follows: ............... \(\frac{\Delta Y_{o1} \Delta T}{3}\) [µS/°C] (typical)

\(\Delta Z_{s1}\) is the temperature coefficient for SHORT residual as follows:
@ High Temperature High Impedance Test Head is used ............... (4 + 50 \(\times f\)) [mΩ/°C] (typical)
@ High Temperature Low Impedance Test Head is used ............... (1 + 10 \(\times f^2\)) [mΩ/°C] (typical)

\(\Delta Z_{s2}\) is the hysteresis of the SHORT residual as follows: ............... \(\frac{\Delta Z_{s1} \Delta T}{3}\) [mΩ/°C] (typical)
Options 013 and 014 High Temperature Test Heads

Figure 1-12. Typical Frequency Characteristics of Temperature Coefficient Using High Temperature High Impedance Test Head

Figure 1-13. Typical Frequency Characteristics of Temperature Coefficient Using High Temperature Low Impedance Test Head
Options 013 and 014 High Temperature Test Heads

Operation Conditions of the Test Head
• The cable must be at the same temperature as the main frame at least 15 cm from the test station. 55°C to +200°C

Figure 1-14. Dimensions of High Temperature Test Head
Options 013 and 014 High Temperature Test Heads

Display
LCD
- Type/size: Color TFT, 8.4 inch
- Resolution: 640 x 480
- Effective Display Area: 160 mm x 115 mm (600 x 430 dots)
- Number of display channels: 2
- Format: single, dual split or overwrite, graphic, and tabular

Number of traces
- For measurement: 1 trace/channel
- For memory: 16 traces/channel (maximum)

Data math functions
- gain x data-offset
- gain x memory - offset
- gain x (data - memory) - offset
- gain x (data + memory) - offset
- gain x (data/memory) - offset
- gain x (data x/memory) - offset

Marker
- Number of markers
  - Main marker: 1 for each channel
  - Sub-marker: 7 for each channel
  - A Marker: 1 for each channel

Data Storage
- Type: floppy disk drive, Volatile memory disk
- Capacity:
  - floppy disk: 720 kB/1.44 MB
  - Volatile memory disk, can be backed up by flash memory: 448 kB (maximum)
- Disk format: LIF, DOS

GPIB
- Interface: IEEE 488.1-1987, IEC625
- Interface function: SH1, AH1, T6, TE0, L4, LE0, SR1, RL1, PPO, DC1, DT1, C1, C2, C3, C4, C11, E2
- Numeric Data Transfer formats: ASCII, 32 and 64 bit IEEE 754 Floating point format, DOS PC format (32 bit IEEE with byte order reversed)
- Protocol: IEEE 488.2-1987
Options 013 and 014 High Temperature Test Heads

Printer Parallel Port
  Interface ......................................................... IEEE 1284 Centronics standard compliant
  Printer control language .............................................. HP PCL3 Printer Control Language
  Connector .......................................................... D-sub (25-pin)

General Characteristics
Input and Output Characteristics
  External reference input
    Frequency ................................................................ 10 MHz ±100 Hz (typically)
    Level ........................................................................ > -6 dBm (typically)
    Input impedance ......................................................... 50 Ω (nominal)
    Connector ................................................................. BNC female
  Internal Reference Output
    Frequency ................................................................ 10 MHz (nominal)
    Level ........................................................................ 2 dBm (typically)
    Output impedance ......................................................... 50 Ω (nominal)
    Connector ................................................................. BNC female
  External trigger input
    Level ........................................................................ TTL Level
    Pulse width (Tp) ....................................................... > 2µs (typically)
    Polarity ............................................................. positive/negative selective
    Connector ................................................................. BNC female

Figure 1-15. Trigger Signal

External monitor output
  Connector ................................................................. D-sub (15-pin HD)
  Display resolution .................................................... 640 × 480 VGA
Options 013 and 014 High Temperature Test Heads

Operation Conditions

Temperature
- Disk drive non-operating condition ........................................... 0°C to 40°C
- Disk drive operating condition ........................................... 10°C to 40°C

Humidity
- @ wet bulb temperature <29°C, without condensation ............... 15 % to 95 % RH
- Disk drive non-operating condition ........................................... 15 % to 80 % RH
- Disk drive operating condition ........................................... 15 % to 80 % RH

Altitude ................................................................. 0 to 2,000 meters

Warm-up time .......................................................... 30 minutes

Non-operation conditions

Temperature ................................................................. −20°C to 60°C

Humidity
- @ wet bulb temperature <45°C, without condensation ............... 15 % to 95 % RH

Altitude ................................................................. 0 to 4,572 meters

Others

EMC .......................................................... Complies with CISPR 11 (1990) / EN 55011 (1991) : Group 1, Class A
- Complies with IEC 1000-3-3 (1994) / EN 61000-3-3 (1995)
- Complies with IEC 1000-4-2 (1995) / EN 50082-1 (1992) : 4 kV CD, 8 kV AD
- Complies with IEC 1000-4-4 (1995) / EN 50082-1 (1992) : 1 kV / Main, 0.5k V / Signal Line

Note: When tested at 3 V/m according to IEC 1000-4-3 (1995), the measurement accuracy will be within specifications over the full immunity test frequency range of 27 to 1000 MHz except when the analyzer frequency is identical to the transmitted interference signal test frequency.

- Complies with CSA-C22.2 No. 1010.1-92.

Power requirements ........................................... 90V to 132V, or 198V to 264V (automatically switched), 47 to 63 Hz, 300VA max

Weight
- Mainframe .......................................................... 21.5 kg (SPC)
- Test Station .......................................................... 3.7 kg

Dimensions
- Mainframe .......................................................... 425 (W) × 235 (H) × 553 (D) mm
- Test Station .......................................................... 275 (W) × 95 (H) × 205 (D) mm
Options 013 and 014 High Temperature Test Heads

External Program Run/Cont Input

- Connector: BNC female
- Level: TTL
- Keyboard connector: mini-DIN
- I/O port: 4 bit in/ 8 bit out port, TTL Level

Figure 1-16. I/O Port Pin Assignment

Specifications for Option 1D5 High Stability Frequency Reference

Reference Oven Output

- Frequency: 10 MHz (nominal)
- Level: 0 dBm (typically)
- Output Impedance: 50 Ω (nominal)
- Connector: BNC female
Option 002 Material Measurement

Supplemental Characteristics for Option 002 Material Measurement

Measurement Frequency Range
- Using the Agilent 16453A ................................................................. 1 MHz to 1.0 GHz (Typical)
- Using the Agilent 16454A ................................................................. 1 MHz to 1.0 GHz (Typical)

Measurement Parameters
- Permittivity parameters ................................................................. |ε_r|, ε_r', ε_r", tanδ
- Permeability parameters ................................................................. |µ_r|, µ_r', µ_r", tanδ

Typical Measurement Accuracy

Conditions of accuracy characteristics
- Use the High Z Test Head for permittivity measurement
- Use the Low Z Test Head for permeability measurement
- OPEN/SHORT/50 Ω calibration must be done. Calibration ON.
- Averaging (on point) factor is larger than 32 at which calibration is done if Cal points is set to USER DEF.
- Measurement points are same as the calibration points if Cal point is set to USER DEF.
- Environment temperature is within ±5°C of temperature at which calibration is done, and within 13°C to 33°C. Beyond this environmental temperature condition, accuracy is twice as bad as specified.

ε_r' Accuracy \(\frac{\Delta \varepsilon_r'}{\varepsilon_r'}\)
@ tanδ < 0.1 ................................................. 5 + (10 + \(\frac{0.04}{f}\)) \(\frac{t}{\varepsilon_r'}\) + 0.25 \(\varepsilon_r'\) \(\frac{t}{\varepsilon_r'}\) + \(\frac{100}{1 - (13/\varepsilon_r')^2}\) [%] (Typical)

Loss Tangent Accuracy of \(\Delta \tan\delta\)
@ tanδ < 0.1 ...................................................................... \(E_a + E_b\) (Typical)

Where,
@ frequency ≤ 1 GHz
\(E_a = 0.002 + \frac{0.0004}{f} \frac{t}{\varepsilon_r'} + 0.004 f + \frac{0.1}{1 - (13/\varepsilon_r')^2}\) (Typical)
@ frequency > 1 GHz
\(E_a = 0.002 + \frac{0.0004}{f} \frac{t}{\varepsilon_r'} + 0.004 f + \frac{0.1}{1 - (13/\varepsilon_r')^2}\) (Typical)
\(E_b = \left(\frac{\Delta \varepsilon_r'}{\varepsilon_r'} \frac{1}{100} + \varepsilon_r' \frac{0.002}{t}\right) \tan\delta\) (Typical)

f is measurement frequency [GHz]
t is thickness of MUT [mm]
\(\varepsilon_r'\) is measured value of ε_r
\(\tan\delta\) is measured value of dielectric loss tangent
Option 002 Material Measurement

\[
\frac{\Delta \mu_r}{\mu_r} \quad \text{Accuracy} \quad \frac{\Delta \mu_r}{\mu_r}
\]

@ \tan\delta < 0.1 \quad \begin{align*}
4 + \frac{25}{F \mu_r} + \mu_r (1 + \frac{15}{F \mu_r})^2 f[\%] \quad \text{(Typical)}
\end{align*}

Loss Tangent Accuracy of \( \hat{\mu}_r (\Delta \tan\delta) \)

@ \tan\delta < 0.1 \quad \begin{align*}
E_a + E_b \quad \text{(Typical)}
\end{align*}

Where,

\[
E_a = 0.002 + \frac{0.001}{F \mu_r f} + 0.004 f \quad \text{(Typical)}
\]

\[
E_b = \frac{\Delta \mu_r}{\mu_r} \tan\delta \quad \text{(Typical)}
\]

\( f \) is measurement frequency [GHz]

\[
F = f \ln \frac{c}{b} \quad \text{[mm]}
\]

\( h \) is the height of MUT [mm]

\( b \) is the inner diameter of MUT

\( c \) is the outer diameter of MUT

\( \tan\delta \) is the measured value of loss tangent

\( \mu_r \) is the measured value of permeability

At the following frequency points, instrument spurious characteristics could occasionally cause measurement errors to exceed specified value.

\[
\begin{array}{cccc}
10.71 \text{ MHz} & 17.24 \text{ MHz} & 21.42 \text{ MHz} & 42.84 \text{ MHz} \\
514.645 \text{ MHz} & 686.1933 \text{ MHz} & 1029.29 \text{ MHz} & 1327.38666 \text{ MHz}
\end{array}
\]

See “EMC” under “Others” in “General Characteristics.”
Option 002 Material Measurement

Figure 1-17. Typical Permittivity Measurement Accuracy (@ thickness = 0.3 mm)

Figure 1-18. Typical Permittivity Measurement Accuracy (@ thickness = 1 mm)
Figure 1-19. Typical Permittivity Measurement Accuracy (@ thickness = 3 mm)

Figure 1-20. Typical Dielectric Loss Tangent (tanδ) Measurement Accuracy (@ thickness = 0.3 mm)
Option 002 Material Measurement

Figure 1-21. Typical Dielectric Loss Tangent (\(\tan\delta\)) Measurement Accuracy (@ thickness = 1 mm)

Figure 1-22. Typical Dielectric Loss Tangent (\(\tan\delta\)) Measurement Accuracy (@ thickness = 3 mm)
Figure 1-23. Typical Permittivity Measurement Accuracy ($\varepsilon_r$ vs. Frequency, @ thickness = 0.3 mm)

Figure 1-24. Typical Permittivity Measurement Accuracy ($\varepsilon_r$ vs. Frequency, @ thickness = 1 mm)
Option 002 Material Measurement

Figure 1-25. Typical Permittivity Measurement Accuracy ($\varepsilon_r$ vs. Frequency, @ thickness = 3 mm)
Figure 1-26. Typical Permeability Measurement Accuracy (@ $F^* = 0.5$)

Figure 1-27. Typical Permeability Measurement Accuracy (@ $F^* = 3$)  \[ F^* = \frac{h \ln \frac{C}{b}}{c_b} \]
Option 002 Material Measurement

Figure 1-28. Typical Permeability Measurement Accuracy (@ $F^* = 10$)

Figure 1-29. Typical Permeability Loss Tangent ($\tan \delta$) Measurement Accuracy (@ $F^* = 0.5$)  
$F^* = h \ln \mu_r$
Figure 1-30. Typical Permeability Loss Tangent ($\tan \delta$) Measurement Accuracy (@ $F^* = 3$)

Figure 1-31. Typical Permeability Loss Tangent ($\tan \delta$) Measurement Accuracy (@ $F^* = 10$)  

$F^* = h \ln \frac{C}{b}$
Figure 1-32. Typical Permeability Measurement Accuracy ($\mu_r$ vs. Frequency, @ $F^* = 0.5$)

Figure 1-33. Typical Permeability Measurement Accuracy ($\mu_r$ vs. Frequency, @ $F^* = 3$)  

$F^* = h \ln \frac{c}{b}$
Figure 1-34. Typical Permeability Measurement Accuracy ($\mu_r$ vs. Frequency, @ $F^* = 10$) $F^* = h \ln \frac{c}{b}$
Option 002 Material Measurement

Applicable MUT (Material Under Test) Size ........................................... See Tables 1-5 and 1-6

Maximum DC Bias Voltage / Current
  Using the Agilent 16453A .............................................................. ±40 V
  Using the Agilent 16454A .............................................................. ±500 mA

Operating Temperature
  Using the Agilent 16453A or 16454A .............................................. –55°C to +200°C

Operating Humidity
  Wet bulb temperature < 40°C
  Using the Agilent 16453A or 16454A .............................................. up to 95% RH

Table 1-5. Applicable Dielectric Material Size Using with the Agilent 16453A

<table>
<thead>
<tr>
<th>t</th>
<th>≤ 3 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
<td>≥ φ 15 mm</td>
</tr>
</tbody>
</table>

Table 1-6. Applicable Magnetic Material Size Using the Agilent 16454A

<table>
<thead>
<tr>
<th>Fixture</th>
<th>Small</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Holder</td>
<td>A</td>
</tr>
<tr>
<td>c</td>
<td>≤ φ 8 mm</td>
<td>≤ φ 6 mm</td>
</tr>
<tr>
<td>b</td>
<td>≥ φ 3.1 mm</td>
<td>≥ φ 3.1 mm</td>
</tr>
<tr>
<td>h</td>
<td>≤ 3 mm</td>
<td>≤ 3 mm</td>
</tr>
</tbody>
</table>
Material Measurement Accuracy with High Temperature Test Head

Option 002 Material Measurement Accuracy with Options 013 and 014 High Temperature Test Head (Typical)

Dielectric Material Measurement Accuracy with High Temperature Test Head (Typical)

Conditions of Dielectric Material Measurement Accuracy with High Temperature Test Head
- Environment temperature is within ±5°C of temperature at which calibration is done, and within 0°C to 40°C.
- High Temperature High Impedance Test Head must be used.
- Bending cable should be smooth and the bending angle less than 30°.
- Cable position should be kept in the same position after calibration measurement.
- OPEN/SHORT/50 Ω calibration must be done. Calibration ON.
- Measurement points are same as the calibration points.
- Averaging (on point) factor must be larger than 32 at which calibration is done.
- OSC level must be same as level at which calibration is done.
- OSC level is less than or equal to 0.25 Vrms, or greater than 0.25 Vrms and frequency range is within 1 MHz to 1 GHz.
- Environment temperature of the main frame is within ±5°C of temperature at which calibration is done, and within 0°C to 40°C.

\[ \frac{\Delta \varepsilon_r}{\varepsilon_r} \] Accuracy \( \frac{\Delta \varepsilon_r}{\varepsilon_r} \) ................................................ Same as accuracy at which a normal test head is used

Loss Tangent Accuracy of \( \Delta \tan \delta \) .............................. Same as accuracy at which a normal test head is used

At the following frequency points, instrument spurious characteristics could occasionally cause measurement errors to exceed specified value.

| Frequency  
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10.71 MHz</td>
</tr>
<tr>
<td>17.24 MHz</td>
</tr>
<tr>
<td>21.42 MHz</td>
</tr>
<tr>
<td>42.84 MHz</td>
</tr>
<tr>
<td>514.645 MHz</td>
</tr>
<tr>
<td>686.19333 MHz</td>
</tr>
<tr>
<td>1029.29 MHz</td>
</tr>
<tr>
<td>1327.38666 MHz</td>
</tr>
</tbody>
</table>

See “EMC” under “Others” in “General Characteristics.”
The excessive vibration and shock could occasionally cause measurement errors to exceed specified value.
Material Measurement Accuracy with High Temperature Test Head

Typical Effects of Temperature Drift on Dielectric Material Measurement Accuracy
When environment temperature is without ±5°C of temperature at which calibration is done, add the following measurement error.

\[
\varepsilon_r' \text{ Accuracy} (\frac{\Delta \varepsilon_{rm}}{\varepsilon_{rm}}) \quad \varepsilon_c + \varepsilon_{a3} + \varepsilon_{b3} \quad \% \\
\text{Loss Tangent Accuracy of } \delta (\Delta \tan \delta) \quad \varepsilon_{\tan \delta} \varepsilon_{a3} + \varepsilon_{b3} \quad \% \quad \frac{100}{\varepsilon_{\tan \delta}} 
\]

Where,
- \( \varepsilon_c \) is \( \varepsilon_r' \) accuracy when a normal test head is used.
- \( \varepsilon_{\tan \delta} \) is loss tangent accuracy when a normal test head is used.
- \( \varepsilon_{a3} \) is the effect of temperature drift on the accuracy as follows:

\[
\varepsilon_{a3} = T_c \Delta T 
\]

\( \varepsilon_{b3} \) is the hysteresis of the effect of temperature drift on the accuracy as follows:

\[
\varepsilon_{b3} = \frac{T_c \Delta T}{3} 
\]

Where,
- \( T_c \) is temperature coefficient as follows:

\[
T_c = K_1 + K_2 + K_3 \\
K_1 = 1 \times 10^{-6} \times (50 + 300f) \\
K_2 = 3 \times 10^{-6} \times (4 + 50f) \left( \frac{\varepsilon_{\text{rm}}}{\varepsilon_c} \right) \left( \frac{1}{1 - (f/f_0)^2} + 10 \right) f \\
K_3 = 5 \times 10^{-3} \times (0.2 + 8f^2) \left( \frac{\varepsilon_{\text{rm}}}{\varepsilon_c} \right) \left( \frac{1}{1 - (f/f_0)^2} + 10 \right) f 
\]

\( f \): Measurement Frequency [GHz]

\( f_0 = \sqrt{\varepsilon_{\text{rm}}} \) [GHz]

\( t \): Thickness of MUT [mm]

\( \varepsilon_{\text{rm}} \): measured value of \( \varepsilon_r' \)

The illustrations of temperature coefficient \( T_c \) are shown in Figures 1-35 to 1-37.

\( \Delta T \) is difference of temperature between measurement condition and calibration measurement condition as follows:

\[
\Delta T = |T_{\text{meas}} - T_{\text{cal}}| 
\]

\( T_{\text{meas}} \): Temperature of Test Head at measurement condition
\( T_{\text{cal}} \): Temperature of Test Head at calibration measurement condition
Figure 1-35. Typical Frequency Characteristics of Temperature Coefficient of $\varepsilon_{r}'$ and Loss Tangent Accuracy (Thickness = 0.3 mm)
Material Measurement Accuracy with High Temperature Test Head

Figure 1-36. Typical Frequency Characteristics of Temperature Coefficient of $\varepsilon_r'$ and Loss Tangent Accuracy (Thickness = 1 mm)
Figure 1-37. Typical Frequency Characteristics of Temperature Coefficient of $\varepsilon'_r$ and Loss Tangent Accuracy (Thickness = 3 mm)
Material Measurement Accuracy with High Temperature Test Head (Typical)

**Conditions of Dielectric Material Measurement Accuracy with High Temperature Test Head**

- Environment temperature is within ±5°C of temperature at which calibration is done, and within 0°C to 40°C.
- High Temperature Low Impedance Test Head must be used.
- Bending cable should be smooth and the bending angle less than 30°.
- Cable position should be kept in the same position after calibration measurement.
- OPEN/SHORT/50 Ω calibration must be done. Calibration ON.
- Measurement points are same as the calibration points.
- Averaging (on point) factor must be larger than 32 at which calibration is done.
- OSC level must be same as level at which calibration is done.
- OSC level is less than or equal to 0.25 Vrms, or greater than 0.25 Vrms and frequency range is within 1 MHz to 1 GHz.
- Environment temperature of the main frame is within ±5°C of temperature at which calibration is done, and within 0°C to 40°C.

\[
\mu'_{rm} \quad \text{Accuracy} \quad \left( \frac{\Delta \mu_{rm}}{\mu_{rm}} \right) \quad \text{Same as accuracy at which a normal test head is used}
\]

**Loss Tangent Accuracy of \( \mu' (\Delta \tan \delta) \) **

Same as accuracy at which a normal test head is used

At the following frequency points, instrument spurious characteristics could occasionally cause measurement errors to exceed specified value.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>10.71 MHz</th>
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</tr>
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<tbody>
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<td>514.645 MHz</td>
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<td>1327.38666 MHz</td>
<td></td>
</tr>
</tbody>
</table>

See “EMC” under “Others” in “General Characteristics.”

The excessive vibration and shock could occasionally cause measurement errors to exceed specified value.
Material Measurement Accuracy with High Temperature Test Head

Typical Effects of Temperature Drift on Magnetic Material Measurement Accuracy
When environment temperature exceeds ±5°C of temperature at which calibration is done, add the following measurement error.

$$\mu'_r \text{ Accuracy } \left( \frac{\Delta \mu_{rm}}{\mu_{rm}} \right) \quad \text{E}_{\mu} + E_{a3} + E_{b3}$$

Loss Tangent Accuracy of $$\mu'_r (\Delta \tan \delta) \quad \text{E}_{\tan \delta} + \frac{(E_{a3} + E_{b3})}{100}$$

Where,
- $$E_{\mu}$$ is $$\mu'_r$$ accuracy when a normal test head is used.
- $$E_{\tan \delta}$$ is loss tangent accuracy when a normal test head is used.
- $$E_{a3}$$ is the effect of temperature drift on the accuracy as follows:
  $$E_{a3} = T_c \Delta T$$

*$$E_{b3}$$ is the hysteresis of the effect of temperature drift on the accuracy as follows:
  $$E_{b3} = \frac{T_c \Delta T}{3}$$

Where,
- $$T_c$$ is temperature coefficient as follows:
  $$T_c = K_1 + K_2 + K_3$$

$$K_1 = 1 \times 10^{-4} \times (50 + 300f)$$

$$K_2 = 1 \times 10^{-2} \times (1 + 10f^2) \quad \frac{[1 - 0.01 \{ F (\mu'_{rm} - 1) + 10 \}] f^2}{[ F (\mu'_{rm} - 1) + 20]f + 10}f$$

$$K_3 = 2 \times 10^{-4} \times (1 + 30f) \quad \frac{[ F (\mu'_{rm} - 1) + 20]f}{[1 - 0.01 \{ F (\mu'_{rm} - 1) + 10 \}] f^2}$$

$$f$$: Measurement Frequency [GHz]

$$F = \frac{h \ln c}{b} \quad \text{[mm]}$$

- $$h$$ is the height of MUT [mm]
- $$b$$ is the inner diameter of MUT
- $$c$$ is the outer diameter of MUT
- $$\mu'_{rm}$$ is the measured value of permeability

The illustrations of temperature coefficient $$T_c$$ are shown in Figures 1-38 to 1-40.

$$\Delta T$$ is difference of temperature between measurement condition and calibration measurement condition as follows:

$$\Delta T = |T_{\text{meas}} - T_{\text{cal}}|$$

$$T_{\text{meas}}$$: Temperature of Test Head at measurement condition
$$T_{\text{cal}}$$: Temperature of Test Head at calibration measurement condition
Material Measurement Accuracy with High Temperature Test Head

Figure 1-38. Typical Frequency Characteristics of Temperature Coefficient of $\mu_r'$ and Loss Tangent Accuracy ($F^* = 0.5$)

$$F^* = \frac{1}{\ln \frac{c}{b}}$$
Material Measurement Accuracy with High Temperature Test Head

Figure 1-39. Typical Frequency Characteristics of Temperature Coefficient of $\mu_r'$ and Loss Tangent Accuracy ($F^* = 3$)

$h \ln \frac{c}{b} = 3$
Material Measurement Accuracy with High Temperature Test Head

Figure 1-40. Typical Frequency Characteristics of Temperature Coefficient of $\mu', \tan\delta$ and Loss Tangent Accuracy ($F^* = 10$)

$F^* = h \ln \frac{c}{b}$
## Furnished Accessories

<table>
<thead>
<tr>
<th>Accessory</th>
<th>Agilent part number</th>
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<tbody>
<tr>
<td>Operating Manual</td>
<td>04291-90020</td>
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<tr>
<td>Programming Manual</td>
<td>04291-90027</td>
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<td>Service Manual¹</td>
<td>04291-90111</td>
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<td>Program Disk Set</td>
<td>04291-18000</td>
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<td>50 Ω Termination</td>
<td>04291-65006</td>
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<tr>
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<td>04191-85300</td>
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<td>0 S Termination</td>
<td>04191-85302</td>
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<tr>
<td>Low-Loss Capacitor</td>
<td>04291-60042</td>
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<td>Calibration Kit Carrying Case</td>
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<td>16190-25011</td>
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<td>Fixture Stand³</td>
<td>04291-60121</td>
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<td>Pad</td>
<td>04291-09001</td>
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<td>E2083-90000</td>
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<td>5062-3991</td>
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<tr>
<td>Rack Mount and Handle Kit⁷</td>
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</table>

1. Option OBW only
2. The power cable depends on where the instrument is used; see User’s Guide.
3. Option 013 and 014 only
4. Option 1DS only
5. Option 1CN only
6. Option 1CM only
7. Option 1CP only
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5966-1543E