Agilent
E4991A
RF Impedance/Material Analyzer
Technical Specifications

Agilent Technologies

Definitions

All specifications apply over a 5 °C to 40 °C range (unless otherwise stated) and 30 minutes after the instrument has been turned on.

Specification (spec.)

Warranted performance. Specifications include guardbands to account for the expected statistical performance distribution, measurement uncertainties, and changes in performance due to environmental conditions.

Supplemental information is intended to provide information useful in applying the instrument, but that is not covered by the product warranty. The information is denoted as typical, or nominal.

Typical (typ.)

Expected performance of an average unit which does not include guardbands. It is not covered by the product warranty.

Nominal (nom.)

A general, descriptive term that does not imply a level of performance. It is not covered by the product warranty.

Measurement parameters and range

Measurement parameters

Impedance parameters:

$|Z|$, $|Y|$, L_s, L_p, C_s, C_p, R_s(R), R_p, X, G, B, D, Q, θ_z, θ_y,
$|\Gamma|$, Γ_x, Γ_y, θ_γ

Material parameters (option 002):

(see *"Option 002 material measurement (typical)"* on page 16)
Permittivity parameters: $|\varepsilon_r|$, ε_r', ε_r'', tanδ
Permeability parameters: $|\mu_r|$, μ_r', μ_r'', tanδ

Measurement range

Measurement range (|Z|):

130 mΩ to 20 kΩ.
(Frequency= 1 MHz,
Point averaging factor ≥8,
Oscillator level= –3 dBm; = –13 dBm; or = –23 dBm,
Measurement accuracy ≤±10%,
Calibration is performed within 23 °C ±5 °C,
Measurement is performed within ±5 °C of calibration temperature)

Source characteristics

Frequency

Range:
1 MHz to 3 GHz

Resolution:
1 mHz

Accuracy:
without Option 1D5:
±10 ppm (23˚C ±5˚C)
±20 ppm (5˚C to 40˚C)
with Option 1D5:
±1 ppm (5˚C to 40˚C)

Stability:
with Option 1D5: ±0.5 ppm/year (5˚C to 40˚C)

Oscillator level

Range:
Power (when 50Ω load is connected to test port):
–40 dBm to 1 dBm (Frequency ≤1 GHz)
–40 dBm to 0 dBm (Frequency >1 GHz[1])
Current (when short is connected to test port):
0.0894 mArms to 10 mArms (Frequency ≤1 GHz)
0.0894 mArms to 8.94 mArms (Frequency >1 GHz[1])
Voltage (when open is connected to test port):
4.47 mVrms to 502 mVrms (Frequency ≤1 GHz)
4.47 mVrms to 447 mVrms (Frequency >1 GHz[1])

Resolution:
0.1 dB[2]

Accuracy:
(power, when 50Ω load is connected to test port)
Frequency ≤1 GHz:
±2 dB (23˚C ±5˚C)
±4 dB (5˚C to 40˚C)
Frequency >1 GHz:
±3 dB (23˚C ±5˚C)
±5 dB (5˚C to 40˚C)
with option 010:
Frequency ≤ 1 GHz
±3.5 dB (23 ˚C ± 5 ˚C)
±5.5 dB (5 ˚C to 40 ˚C)
Frequency > 1 GHz
±5.6 dB (23 ˚C ± 5 ˚C)
±7.6 dB (5 ˚C to 40 ˚C)

Output impedance

Output impedance:
50Ω (nominal)

DC Bias (Option 001)

DC Voltage bias

Range:
0 to ±40 V

Resolution:
1 mV

Accuracy:
±{0.1% + 6 mV + (Idc[mA] x 20Ω)[mV]}
(23˚C ±5˚C)
±{0.2% + 12 mV + (Idc[mA] x 40Ω)[mV]}
(5˚C to 40˚C)

DC Current bias

Range:
100 µA to 50 mA, –100 µA to –50 mA

Resolution:
10 µA

Accuracy:
±{0.2%+20 µA+ (Vdc[V]/10 kΩ)[mA]}
(23˚C ±5˚C)
±{0.4%+40 µA+ (Vdc[V]/5 kΩ)[mA]}
(5˚C to 40˚C)

DC Bias monitor

Monitor parameters:
Voltage and current

Voltage monitor accuracy:
±{0.5% + 15 mV + (Idc[mA] x 2Ω)[mV]}
(23˚C ±5˚C, typical)
±{1.0% + 30 mV + (Idc[mA] x 4Ω)[mV]}
(5˚C to 40˚C, typical)

Current monitor accuracy:
±{0.5% + 30 µA + (Vdc[V] / 40 kΩ)[mA]}
(23˚C ±5˚C, typical)
±{1.0% + 60 µA + (Vdc[V] / 20 kΩ)[mA]}
(5˚C to 40˚C, typical)

1. It is possible to set more than 0 dBm (447 mV, 8.94 mA) oscillator level at frequency >1 GHz. However, the characteristics at this setting are not guaranteed.
2. When the unit is set at mV or mA, the entered value is rounded to 0.1 dB resolution.

Sweep characteristics

Sweep conditions

Sweep parameters:
Frequency, oscillator level (power, voltage, current), DC bias voltage, DC bias current

Sweep range setup:
Start/Stop or Center/Span

Sweep types:
Frequency sweep: Linear, Log, Segment
Other parameters sweep: Linear, Log

Sweep mode:
Continuous, Single

Sweep directions:
Oscillator level, DC bias (voltage and current): Up sweep, Down sweep
Other parameters sweep: Up sweep

Number of measurement points:
2 to 801

Delay time:
Types: Point delay, Sweep delay, Segment delay
Range: 0 to 30 sec
Resolution: 1 msec

Segment sweep

Available setup parameters for each segment:
Sweep frequency range, number of measurement points, Point averaging factor, oscillator level (power, voltage, or current), DC bias (voltage or current), DC bias limit (current limit for voltage bias, voltage limit for current bias)

Number of segments:
1 to 16

Sweep span types:
Frequency base or order base

Measurement accuracy

Conditions for defining accuracy

Temperature:
23˚C ±5˚C

Accuracy-specified plane:
7-mm connector of test head

Accuracy defined measurement points:
Same points at which the calibration is done.

Accuracy when open/short/load calibration is performed

(Point averaging factor ≥8, typical)

|Z|, |Y|: $\pm(E_a + E_b)$ [%] (see Figures 1 through 4 for examples of calculated accuracy)

θ: $\pm \frac{(E_a + E_b)}{100}$ [rad]

L, C, X, B: $\pm (E_a + E_b) \text{ x } \sqrt{(1 + D_x^2)}$ [%]

R, G: $\pm (E_a + E_b) \text{ x } \sqrt{(1 + Q_x^2)}$ [%]

D:

at $\left| D_x \tan \left(\frac{E_a + E_b}{100} \right) \right| < 1$: $\pm \frac{(1 + D_x^2)\tan \left(\frac{E_a + E_b}{100} \right)}{1 \mp D_x \tan \left(\frac{E_a + E_b}{100} \right)}$

at $D_x \leq 0.1$: $\pm \frac{E_a + E_b}{100}$

Q:

at $\left| Q_x \tan \left(\frac{E_a + E_b}{100} \right) \right| < 1$: $\pm \frac{(1 + Q_x^2)\tan \left(\frac{E_a + E_b}{100} \right)}{1 \mp Q_x \tan \left(\frac{E_a + E_b}{100} \right)}$

at $\frac{10}{E_a + E_b} \geq Q_x \geq 10$: $\pm Q_x^2 \frac{E_a + E_b}{100}$

Accuracy when open/short/load/low-loss capacitor calibration is performed

|Z|, |Y|: $\pm(E_a + E_b)$ [%]

θ: $\pm \frac{E_c}{100}$ [rad]

L, C, X, B: $\pm \sqrt{(E_a + E_b)^2 + (E_c D_x)^2}$ [%]

R, G: $\pm \sqrt{(E_a + E_b)^2 + (E_c Q_x)^2}$ [%]

D:

at $\left|D_x \tan\left(\frac{E_c}{100}\right)\right| < 1$ $\pm \frac{(1 + D_x^2)\tan\left(\frac{E_c}{100}\right)}{1 \mp D_x \tan\left(\frac{E_c}{100}\right)}$

at $D_x \le 0.1$ $\pm \frac{E_c}{100}$

Q:

at $\left|Q_x \tan\left(\frac{E_c}{100}\right)\right| < 1$ $\pm \frac{(1 + Q_x^2)\tan\left(\frac{E_c}{100}\right)}{1 \mp Q_x \tan\left(\frac{E_c}{100}\right)}$

at $\frac{10}{E_c} \ge Q_x \ge 10$ $\pm Q_x^2 \frac{E_c}{100}$

(See Figure 5)

Definition of each parameter

Dx = Measurement value of D

Qx = Measurement value of Q

Ea = (Within ±5˚C from the calibration temperature. Measurement accuracy applies when the calibration is performed at 23˚C ±5˚C. When the calibration is performed beyond 23˚C ±5˚C, the measurement accuracy decreases to half that described.)

at Oscillator level ≥–33 dBm:
±0.65 [%] (1 MHz ≤Frequency ≤100 MHz)
±0.8 [%] (100 MHz <Frequency ≤500 MHz)
±1.2 [%] (500 MHz <Frequency ≤1 GHz)
±2.5 [%] (1 GHz <Frequency ≤1.8 GHz)
±5 [%] (1.8 GHz <Frequency ≤3 GHz)

at Oscillator level <–33 dBm:
±1 [%] (1 MHz ≤Frequency ≤100 MHz)
±1.2 [%] (100 MHz <Frequency ≤500 MHz)
±1.2 [%] (500 MHz <Frequency ≤1 GHz)
±2.5 [%] (1 GHz <Frequency ≤1.8 GHz)
±5 [%] (1.8 GHz <Frequency ≤3 GHz)

Eb = $\pm \left(\frac{Z_s}{|Z_x|} + Y_o \bullet |Z_x|\right) \times 100$ [%]

(|Zx|: Measurement value of |Z|)

Ec = $\pm \left(0.06 + \frac{0.08 \times F}{1000}\right)$ [%]

(F: Frequency [MHz], typical)

Zs = (Within ±5˚C from the calibration temperature. Measurement accuracy applies when the calibration is performed at 23˚C ±5˚C. When the calibration is performed beyond 23˚C ±5˚C, the measurement accuracy decreases to half that described.
F: Frequency [MHz].)

at Oscillator level = –3 dBm, –13 dBm, or –23 dBm:
±(13 + 0.5 × F) [mΩ] (Averaging factor ≥8)
±(25 + 0.5 × F) [mΩ] (Averaging factor ≤7)
at Oscillator level ≥–33 dBm
±(25 + 0.5 × F) [mΩ] (Averaging factor ≥8)
±(50 + 0.5 × F) [mΩ] (Averaging factor ≤7)
at Oscillator level <–33 dBm
±(50 + 0.5 × F) [mΩ] (Averaging factor ≥8)
±(100 + 0.5 × F) [mΩ] (Averaging factor ≤7)

Yo = (Within ±5˚C from the calibration temperature. Measurement accuracy applies when the calibration is performed at 23˚C ±5˚C. When the calibration is performed beyond 23˚C ±5˚C, the measurement accuracy decreases to half that described.
F: Frequency [MHz].)

at Oscillator level = –3 dBm, –13 dBm, –23 dBm:
±(5 + 0.1 × F) [μS] (Averaging factor ≥8)
±(10 + 0.1 × F) [μS] (Averaging factor ≤7)
at Oscillator level ≥–33 dBm:
±(10 + 0.1 × F) [μS] (Averaging factor ≥8)
±(30 + 0.1 × F) [μS] (Averaging factor ≤7)
at Oscillator level <–33 dBm
±(20 + 0.1 × F) [μS] (Averaging factor ≥8)
±(60 + 0.1 × F) [μS] (Averaging factor ≤7)

Measurement accuracy

(continued)

Examples of calculated impedance measurement accuracy

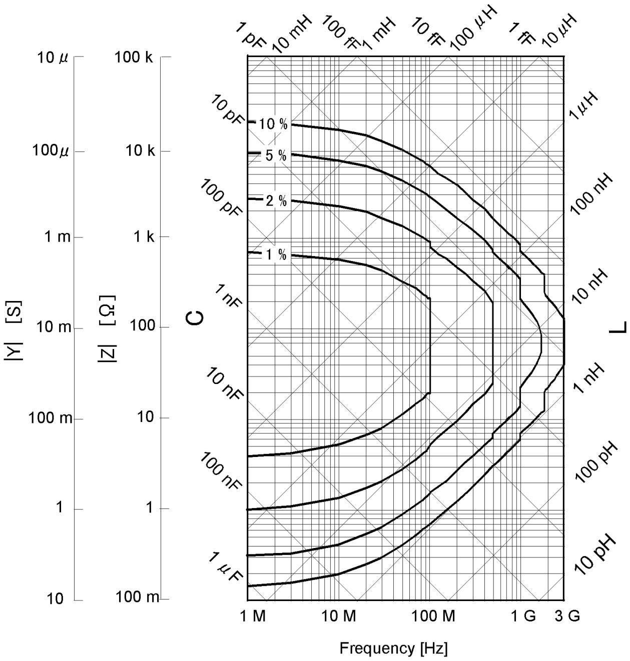

Figure 1. |Z|, |Y| Measurement accuracy when open/short/load calibration is performed. Oscillator level = –23 dBm, –13 dBm, –3 dBm. Point averaging factor ≥8 within ±5˚C from the calibration temperature.

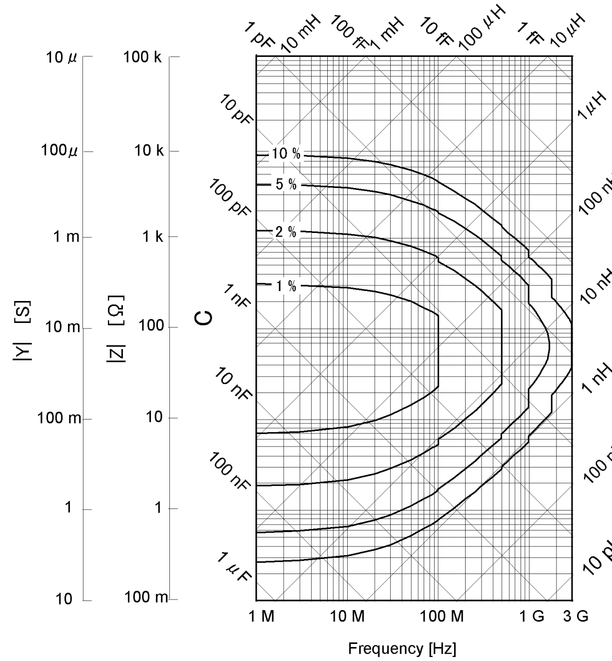

Figure 2. |Z|, |Y| Measurement accuracy when open/short/load calibration is performed. Oscillator level ≥–33 dBm. Point averaging factor ≥8 within ±5˚C from the calibration temperature.

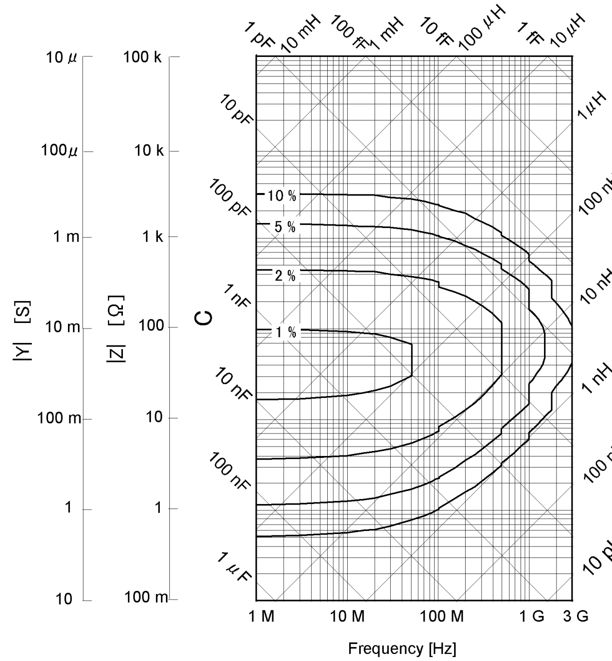

Figure 3. |Z|, |Y| Measurement accuracy when open/short/load calibration is performed. Oscillator level ≥–33 dBm. Point averaging factor ≤7 within ±5˚C from the calibration temperature.

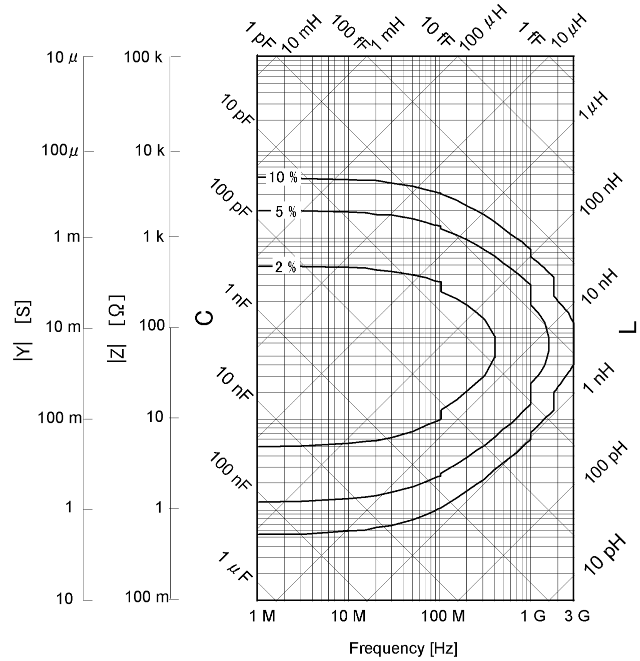

Figure 4. |Z|, |Y| Measurement accuracy when open/short/load calibration is performed. Oscillator level <–33 dBm within ±5˚C from the calibration temperature.

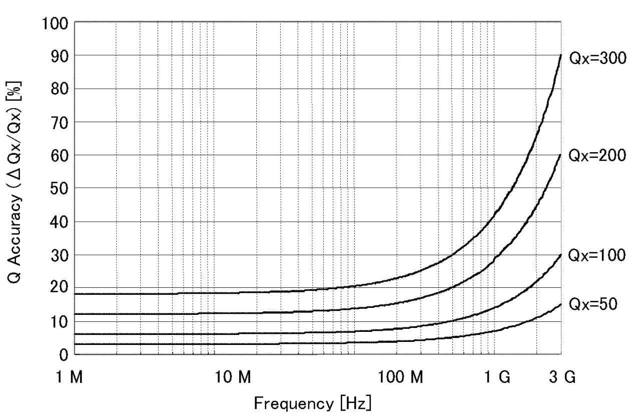

Figure 5. Q Measurement accuracy when open/short/load/low-loss capacitor calibration is performed (typical).

Measurement support functions

Error correction

Available calibration and compensation

Open/short/load calibration:

Connect open, short, and load standards to the desired reference plane and measure each kind of calibration data. The reference plane is called the calibration reference plane.

Low-loss capacitor calibration:

Connect the dedicated standard (low-loss capacitor) to the calibration reference plane and measure the calibration data.

Port extension compensation (Fixture selection):

When a device is connected to a terminal that is extended from the calibration reference plane, set the electrical length between the calibration plane and the device contact. Select the model number of the registered test fixtures in the E4991A's setup toolbar or enter the electrical length for the user's test fixture.

Open/short compensation:

When a device is connected to a terminal that is extended from the calibration reference plane, make open and/or short states at the device contact and measure each kind of compensation data.

Calibration/compensation data measurement point

User-defined point mode:

Obtain calibration/compensation data at the same frequency and power points as used in actual device measurement, which are determined by the sweep setups. Each set of calibration/compensation data is applied to each measurement at the same point. If measurement points (frequency and/or power) are changed by altering the sweep setups, calibration/compensation data become invalid and calibration or compensation data acquisition is again required.

Measurement support functions *(continued)*

Fixed frequency and fixed power point mode:
Obtain calibration/compensation data at fixed frequency and power points covering the entire frequency and power range of the E4991A. In device measurement, calibration or compensation is applied to each measurement point by using interpolation. Even if the measurement points (frequency and/or power) are changed by altering the sweep setups, you don't need to retake the calibration or compensation data.

Fixed frequency and user-defined power point mode:
Obtain calibration/compensation data at fixed frequency points covering the entire frequency range of the E4991A and at the same power points as used in actual device measurement which are determined by the sweep setups. Only if the power points are changed, calibration/compensation data become invalid and calibration or compensation data acquisition is again required.

Trigger

Trigger mode:
Internal, external (external trigger input connector), bus (GPIB), manual (front key)

Averaging

Types:
Sweep-to-sweep averaging, point averaging

Setting range:
Sweep-to-sweep averaging: 1 to 999 (integer)
Point averaging: 1 to 100 (integer)

Display

LCD display :
Type/Size: Color LCD, 8.4 inch (21.3 cm)
Resolution: 640 (horizontal) × 480 (vertical)

Number of traces:
Data trace: 3 scalar traces + 2 complex traces (maximum)
Memory trace: 3 scalar traces + 2 complex traces (maximum)

Trace data math:
Data – Memory, data/memory (for complex parameters), Delta% (for scalar parameters), offset

Format:
For scalar parameters: Linear Y-axis, Log Y-axis
For complex parameters: Z, Y: Polar, complex; Γ: Polar, complex, Smith, admittance

Other display functions:
Split/overlay display (for scalar parameters), phase expansion

Marker

Number of markers:

Main marker: One for each trace (marker 1)
Sub marker: Seven for each trace (marker 2 to marker 8)
Reference marker: One for each trace (marker R)

Marker search:

Search type: Maximum, minimum, target, peak
Search track: Performs search with each sweep

Other functions:

Marker continuous mode, marker coupled mode, marker list, marker statistics

Equivalent circuit analysis

Circuit models:

3-component model (4 models),
4-component model (1 model)

Analysis types:

Equivalent circuit parameters calculation, frequency characteristics simulation

Limit marker test

Number of markers for limit test:

9 (marker R, marker 1 to 8)

Setup parameters for each marker:

Stimulus value, upper limit, and lower limit

Mass storage

Built-in flexible disk drive:

3.5 inch, 720 KByte or 1.44 MByte, DOS format

Hard disk drive:

2 GByte (minimum)

Stored data:

State (binary), measurement data (binary, ASCII or CITI file), display graphics (bmp, jpg), VBA program (binary)

Interface

GPIB

Standard conformity:

IEEE 488.1-1987, IEEE 488.2-1987

Available functions (function code)[3]:

SH1, AH1, T6, TE0, L4, LE0, SR1, RL0, PP0, DT1, DC1, C0, E2

Numerical data transfer format:

ASCII

Protocol:

IEEE 488.2-1987

Printer parallel port

Interface standard:

IEEE 1284 Centronics

Connector type:

25-pin D-sub connector, female

LAN interface

Standard conformity:

10 Base-T or 100 Base-TX (automatically switched), Ethertwist, RJ45 connector

Protocol:

TCP/IP

Functions:

FTP

3. Refer to the standard for the meaning of each function code.

Measurement terminal (at test head)

Connector type:
7-mm connector

Rear panel connectors

External reference signal input connector

Frequency:
10 MHz ±10 ppm (typical)

Level:
0 dBm to +6 dBm (typical)

Input impedance:
50Ω (nominal)

Connector type:
BNC, female

Internal reference signal output connector

Frequency:
10 MHz (nominal)

Accuracy of frequency:
Same as frequency accuracy described in *"Frequency"* on page 3

Level:
+2 dBm (nominal)

Output impedance:
50Ω (nominal)

Connector type:
BNC, female

High stability frequency reference output connector (option 1D5)

Frequency:
10 MHz (nominal)

Accuracy of frequency:
Same as frequency accuracy described in *"Frequency"* on page 3

Level:
+2 dBm (nominal)

Output impedance:
50Ω (nominal)

Connector type:
BNC, female

External trigger input connector

Level:
LOW threshold voltage: 0.5 V
HIGH threshold voltage: 2.1 V
Input level range: 0 V to +5 V

Pulse width (Tp):
≥2 µsec (typical). See Figure 6 for definition of Tp.

Polarity:
Positive or Negative (selective)

Connector type:
BNC, female

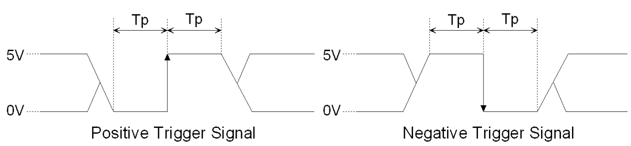

Figure 6. Definition of pulse width (Tp)

General characteristics

Environment conditions

Operating condition

Temperature:
5˚C to 40˚C

Humidity:
(at wet bulb temperature ≤29˚C, without condensation)
Flexible disk drive non-operating condition:
15% to 90% RH
Flexible disk drive operating condition:
20% to 80% RH

Altitude:
0 m to 2,000 m (0 feet to 6,561 feet)

Vibration:
0.5 G maximum, 5 Hz to 500 Hz

Warm-up time:
30 minutes

Non-operating storage condition

Temperature:
–20˚C to +60˚C

Humidity:
(at wet bulb temperature ≤45˚C, without condensation)
15% to 90% RH

Altitude:
0 m to 4,572 m (0 feet to 15,000 feet)

Vibration:
1 G maximum, 5 Hz to 500 Hz

General characteristics
(continued)

Other specifications

EMC

CE ISM 1-A

European Council Directive 89/336/EEC
IEC 61326-1:1997+A1
CISPR 11:1990 / EN 55011:1991 Group 1, Class A
IEC 61000-4-2:1995 / EN 61000-4-2:1995
4 kV CD / 4 kV AD
IEC 61000-4-3:1995 / EN 61000-4-3:1996
3 V/m, 80-1000 MHz, 80% AM
IEC 61000-4-4:1995 / EN 61000-4-4:1995
1 kV power / 0.5 kV Signal
IEC 61000-4-5:1995 / EN 61000-4-5:1995
0.5 kV Normal / 1 kV Common
IEC 61000-4-6:1996 / EN 61000-4-6:1996
3 V, 0.15-80 MHz, 80% AM
IEC 61000-4-11:1994 / EN 61000-4-11:1994
100% 1cycle

Note: When tested at 3 V/m according to EN 61000-4-3:1996, the measurement accuracy will be within specifications over the full immunity test frequency range of 80 MHz to 1000 MHz except when the analyzer frequency is identical to the transmitted interference signal test frequency.

N10149

AS/NZS 2064.1/2 Group 1, Class A

Safety

CE ISM 1-A

European Council Directive 73/23/EEC
IEC 61010-1:1990+A1+A2 / EN 61010-1:1993+A2
INSTALLATION CATEGORY II, POLLUTION DEGREE 2
INDOOR USE
IEC60825-1:1994 CLASS 1 LED PRODUCT

LR95111C

CAN/CSA C22.2 No. 1010.1-92

Power requirements

90 V to 132 V, or 198 V to 264 V (automatically switched), 47 Hz to 63 Hz, 350 VA maximum

Weight

Main unit: 17 kg (nominal)
Test head: 1 kg (nominal)

Dimensions

Main unit: See Figure 7 through Figure 9
Test head: See Figure 10

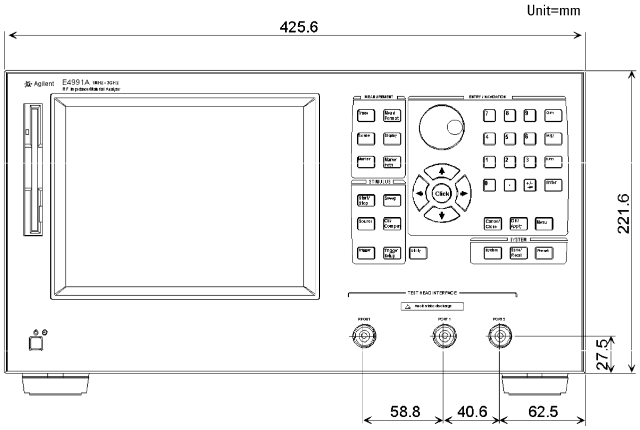

Figure 7. Main unit dimensions (front view, in millimeters, nominal)

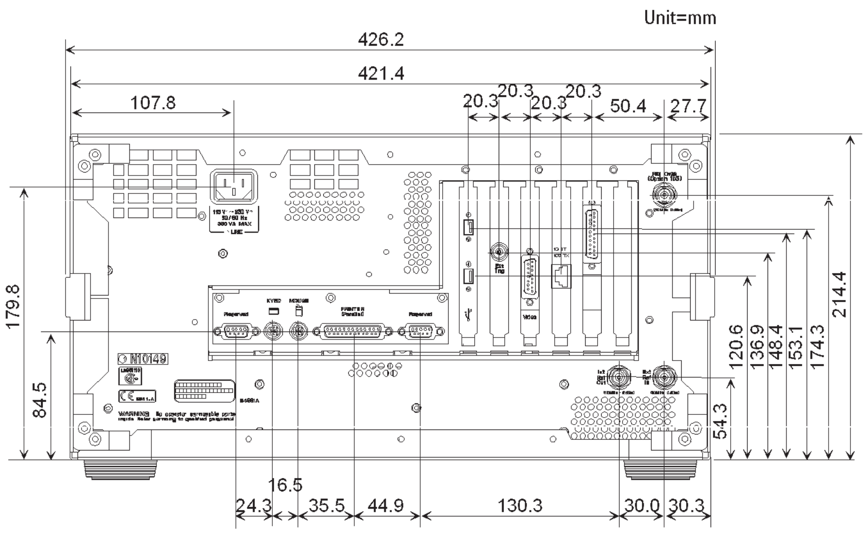

Figure 8. Main unit dimensions (rear view, in millimeters, nominal)

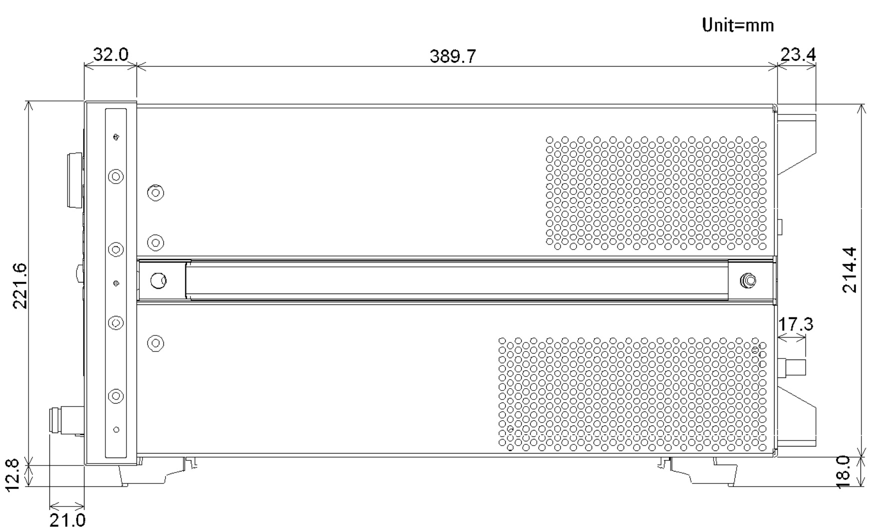

Figure 9. Main unit dimensions (side view, in millimeters, nominal)

General characteristics
(continued)

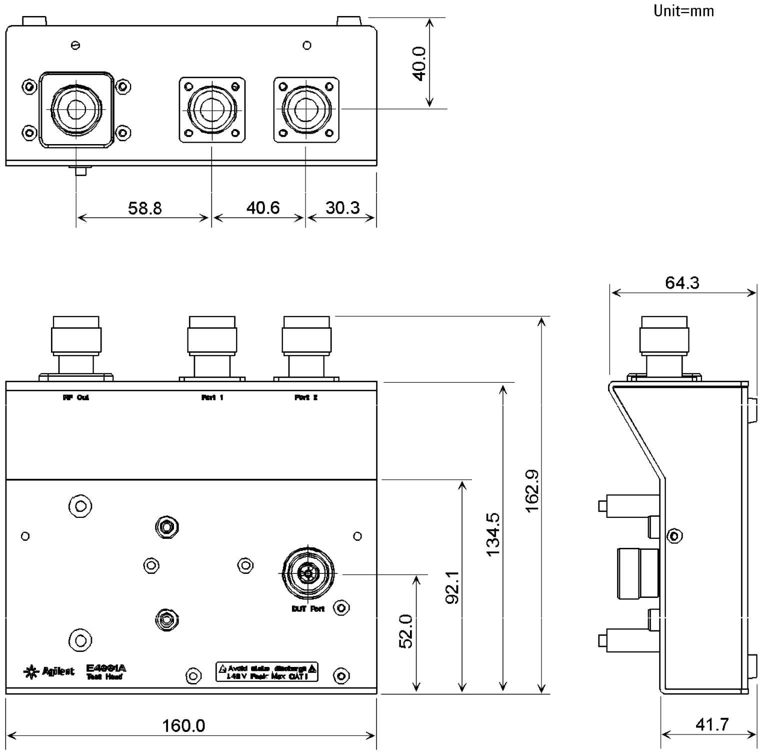

Figure 10. Test head dimensions (in millimeters, nominal)

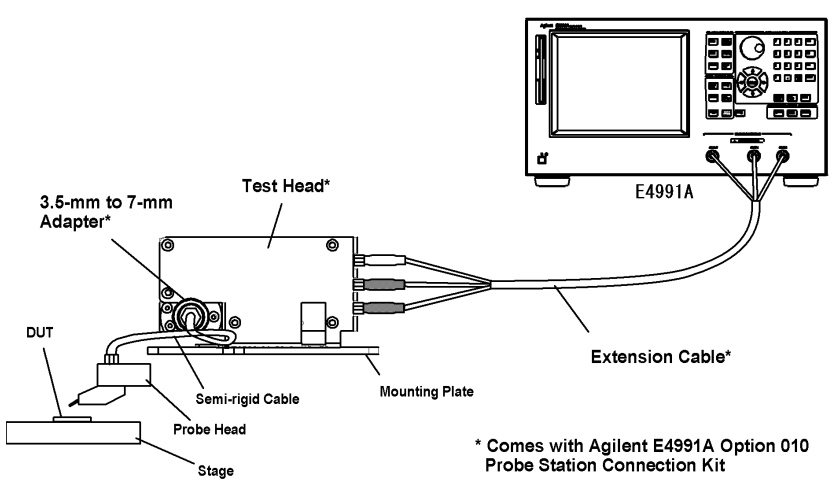

Figure 11. Option 010 test head dimensions (in millimeters,nominal)

Furnished accessories

Model/Option Number	Agilent Part Number	Description	Qty
Agilent E4991A	-	Agilent E4991A Impedance/Material Analyzer (main unit)	1
	-	Test Head	1
	-	Agilent 16195B 7-mm Calibration Kit	1
	8710-1766	Torque Wrench	1
	-	Mouse[4]	1
	-	Keyboard[5]	1
	-	Power Cable	1
Option ABA	E4991-900x0	Operation Manual[6]	1
	E4991-900x1	Installation and Quick Start Guide[6]	1
	E4991-900x2	Programming Manual[6]	1
	E4991-180x0	Sample Program Disk (3.5 inch floppy disk)[6]	1
	E4991-905x0	CD-ROM (manuals and sample programs)[6]	1
Option 1D5	8120-1838	BNC(m)-BNC(m) Cable[7]	1
Option 1CM	5063-9216	Rackmount Kit	1
Option 1CN	5063-9229	Handle Kit	1
Option 1CP	5063-9223	Rackmount & Handle Kit	1

4. Not furnished if Option 1CS (Without Mouse) is designated.
5. Not furnished if Option 1A2 (Without Keyboard) is designated.
6. The number indicated by "x" in the part number of each manual, sample program disk, or CD-ROM, is incremented by 1 each time a revision is made. The latest edition comes with the product (0 for the first edition).
7. This cable is furnished if Option 1D5 High Stability Frequency Reference is designated.

Option 002 material measurement (typical)

Measurement parameter

Permittivity parameters:
$|\varepsilon_r|$, ε_r', ε_r'', $\tan\delta$

Permeability parameters:
$|\mu_r|$, μ_r', μ_r'', $\tan\delta$

Frequency range

Using with Agilent 16453A:
1 MHz to 1 GHz (typical)

Using with Agilent 16454A:
1 MHz to 1 GHz (typical)

Measurement accuracy

Conditions for defining accuracy:

Temperature:

Temperature deviation: Within ±5˚C from the calibration temperature

Environment temperature: Measurement accuracy applies when the calibration is performed at 23˚C ±5˚C. When the calibration is performed beyond 23˚C ±5˚C, the measurement accuracy decreases to half that described.

Required calibration: Open, short, and load

Point averaging factor: ≥8

Typical accuracy of permittivity parameters:

ε_r' accuracy $\left(= \frac{\Delta\varepsilon_{rm}'}{\varepsilon_{rm}}\right)$:

$$\pm\left[5 + \left(10 + \frac{0.1}{f}\right)\frac{t}{\varepsilon'_{rm}} + 0.25\,\frac{\varepsilon'_{rm}}{t} + \frac{100}{\left|1 - \left(\frac{13}{f\sqrt{\varepsilon'_{rm}}}\right)^2\right|}\right] [\%]$$

(at $\tan\delta < 0.1$)

Loss tangent accuracy of $\dot{\varepsilon}_r$ (= $\Delta\tan\delta$):
$\pm(E_a + E_b)$ [%] (at $\tan\delta < 0.1$)

where E_a =

at Frequency ≤1 GHz:

$$0.002 + \frac{0.001}{f} \bullet \frac{t}{\varepsilon'_{rm}} + 0.004f + \frac{0.1}{\left|1 - \left(\frac{13}{f\sqrt{\varepsilon'_{rm}}}\right)^2\right|}$$

at Frequency >1 GHz:

$$0.002 + \frac{0.001}{f} \bullet \frac{t}{\varepsilon'_{rm}} + 0.004f + \frac{1.1}{\left|1 - \left(\frac{13}{f\sqrt{\varepsilon'_{rm}}}\right)^2\right|}$$

$$E_b = \left(\frac{\Delta\varepsilon'_{rm}}{\varepsilon'_{rm}} \bullet \frac{1}{100} + \varepsilon'_{rm}\,\frac{0.002}{t}\right)\tan\delta$$

f = Measurement frequency [GHz]

t = Thickness of MUT (material under test) [mm]

ε'_{rm} = Measured value of ε'_r

$\tan\delta$ = Measured value of dielectric loss tangent

Typical accuracy of permeability parameters:

μ_r' accuracy $\left(= \frac{\Delta\mu_{rm}'}{\mu_{rm}}\right)$:

$$4 + \frac{25}{F\mu'_{rm}} + F\mu'_{rm}\left(1 + \frac{15}{F\mu'_{rm}}\right)^2 f^2 [\%]$$

(at tanδ <0.1)

Loss tangent accuracy of $\dot{\mu}_r$ (= Δtanδ):

$\pm(E_a + E_b)$ [%] (at tanδ <0.1)

where,

$$E_a = 0.002 + \frac{0.001}{F\mu'_{rm}f} + 0.004f$$

$$E_b = \frac{\Delta\mu_{rm}'}{\mu'_{rm}} \bullet \frac{\tan\delta}{100}$$

f = Measurement frequency [GHz]

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

h = Height of MUT (material under test) [mm]

b = Inner diameter of MUT (material under test) [mm]

c = Outer diameter of MUT (material under test) [mm]

μ'_{rm} = Measured value of μ'_r

tanδ = Measured value of loss tangent

Option 002 material measurement (typical)

(continued)

Examples of calculated permittivity measurement accuracy

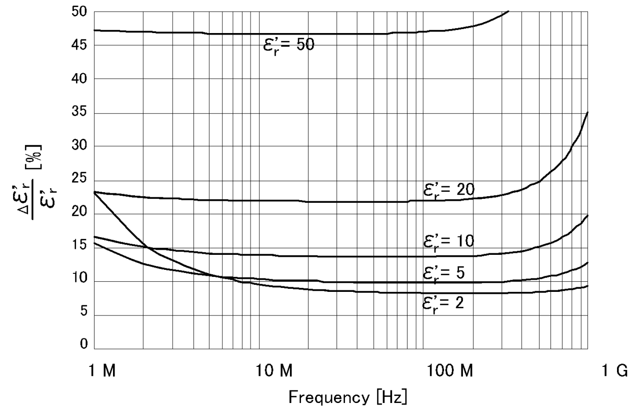

Figure 11. Permittivity accuracy $\frac{(\Delta\varepsilon'_r)}{\varepsilon'_r}$ vs. frequency (at *t* = 0.3 mm, typical)

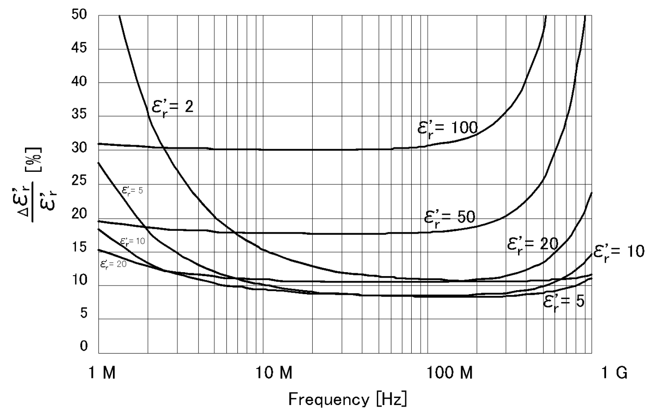

Figure 12. Permittivity accuracy $\frac{(\Delta\varepsilon'_r)}{\varepsilon'_r}$ vs. frequency (at *t* = 1 mm, typical)

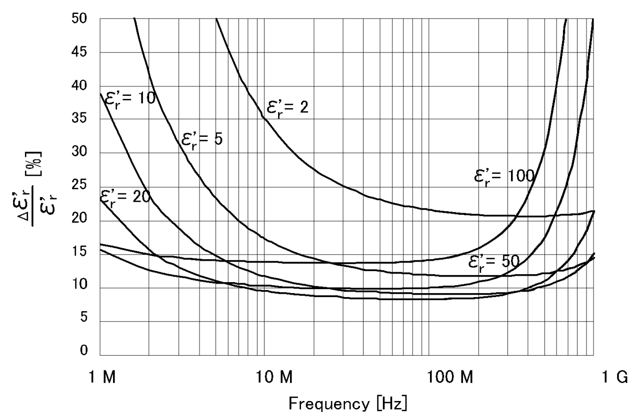

Figure 13. Permittivity accuracy $\frac{(\Delta\varepsilon'_r)}{\varepsilon'_r}$ vs. frequency (at *t* = 3 mm, typical)

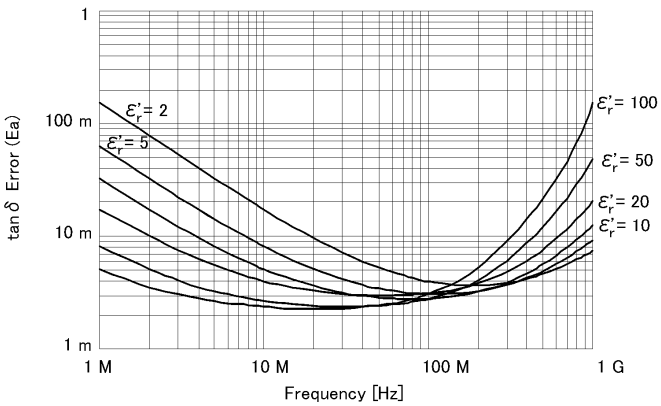

Figure 14. Dielectric loss tangent (tanδ) accuracy vs. frequency (at *t* = 0.3 mm, typical)[8]

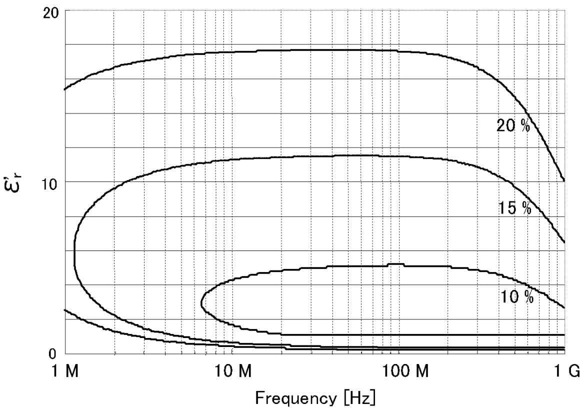

Figure 17. Permittivity (ε'_r) vs. frequency (at *t* = 0.3 mm, typical)

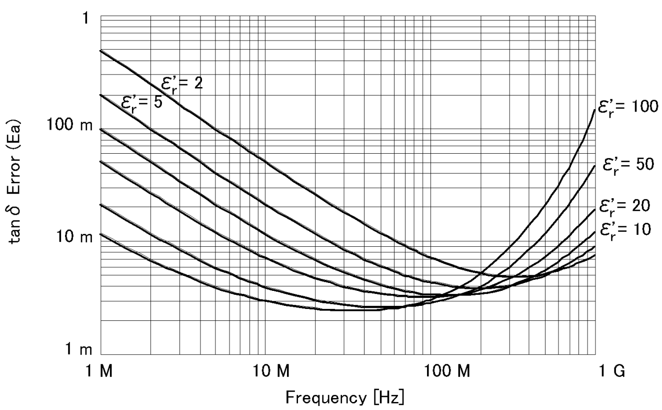

Figure 15. Dielectric loss tangent (tanδ) accuracy vs. frequency (at *t* = 1 mm, typical)[8]

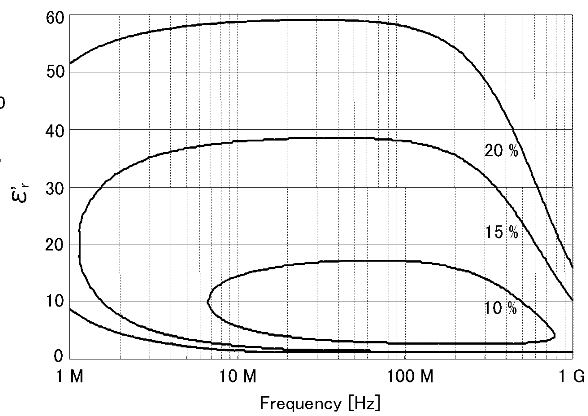

Figure 18. Permittivity (ε'_r) vs. frequency (at *t* = 1 mm, typical)

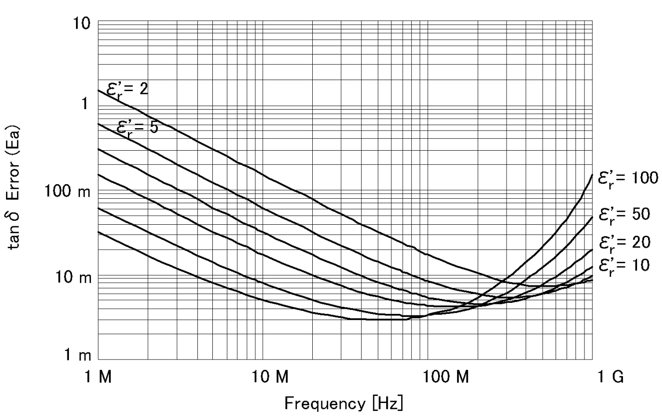

Figure 16. Dielectric loss tangent (tanδ) accuracy vs. frequency (at *t* = 3 mm, typical)[8]

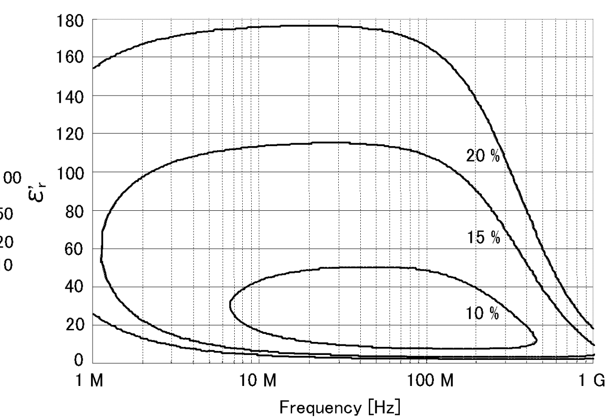

Figure 19. Permittivity (ε'_r) vs. frequency (at *t* = 3 mm, typical)

8. This graph shows only frequency dependence of E_a to simplify it. The typical accuracy of tanδ is defined as $E_a + E_b$; refer to *"Typical accuracy of permittivity parameters"* on page 16.

Option 002 material measurement (typical)

(continued)

Examples of calculated permeability measurement accuracy

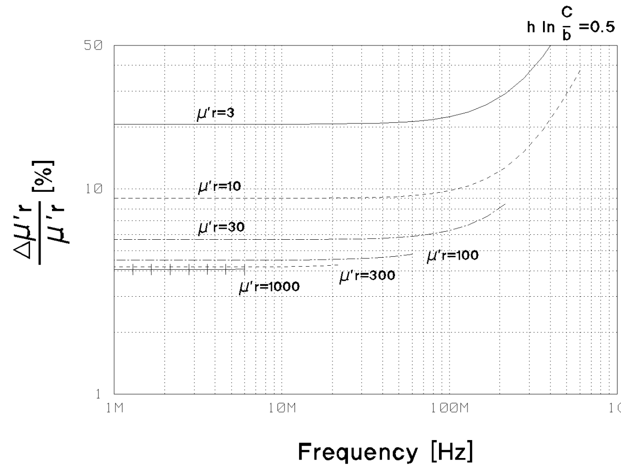

Figure 20. Permeability accuracy $\frac{(\Delta\mu'_r)}{\mu'_r}$ vs. frequency (at *F* = 0.5, typical)

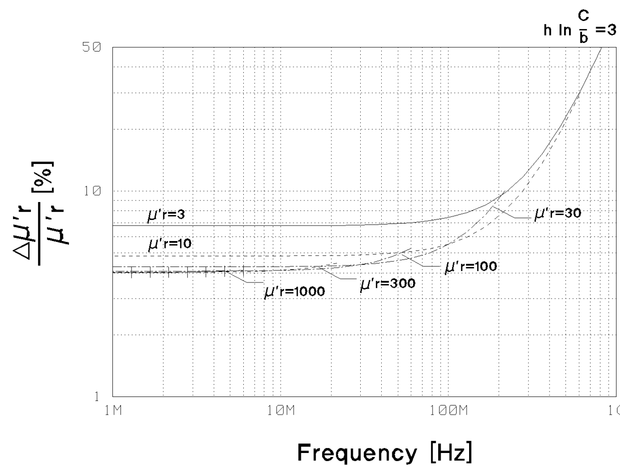

Figure 21. Permeability accuracy $\frac{(\Delta\mu'_r)}{\mu'_r}$ vs. frequency (at *F* = 3, typical)

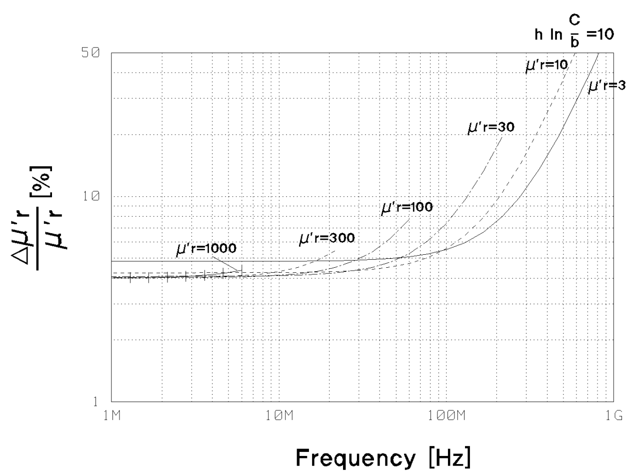

Figure 22. Permeability accuracy $\frac{(\Delta\mu'_r)}{\mu'_r}$ vs. frequency (at *F* = 10, typical)

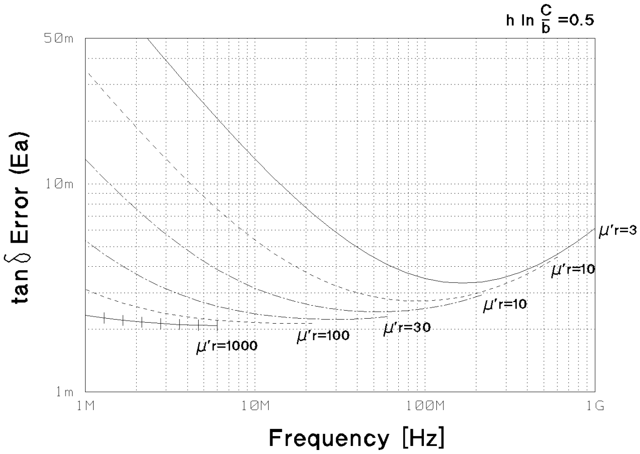

Figure 23. Permeability loss tangent (tanδ) accuracy vs. Frequency (at *F* = 0.5, typical)[9]

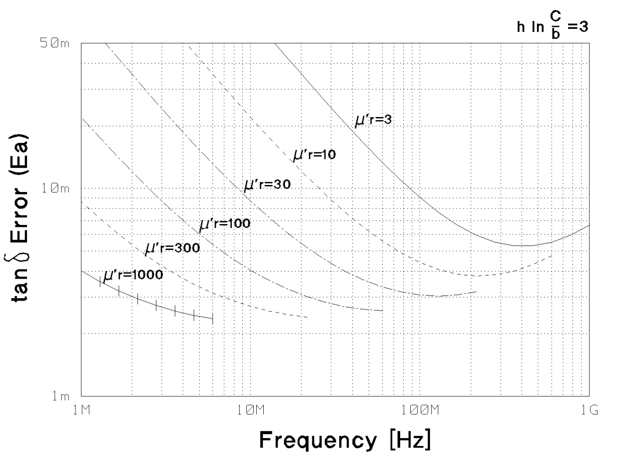

Figure 24. Permeability loss tangent (tanδ) accuracy vs. frequency (at *F* = 3, typical)[9]

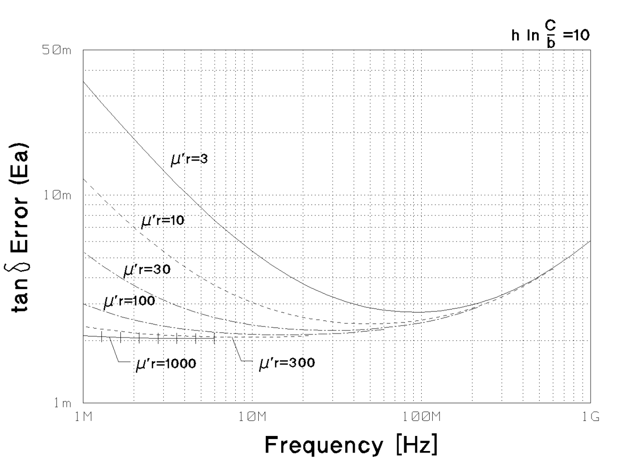

Figure 25. Permeability loss tangent (tanδ) accuracy vs. frequency (at *F* = 10, typical)[9]

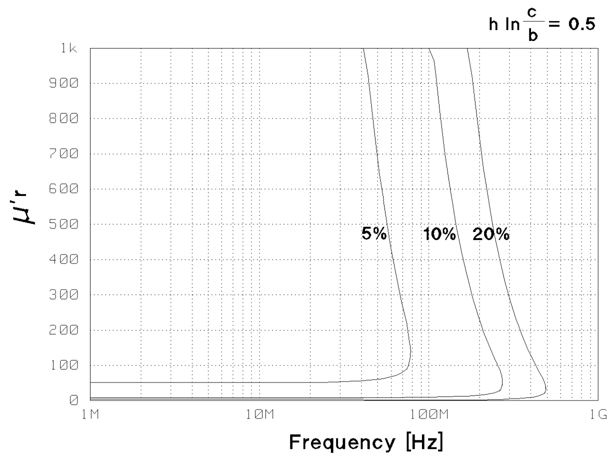

Figure 26. Permeability (μ'_r) vs. frequency (at *F* = 0.5, typical)

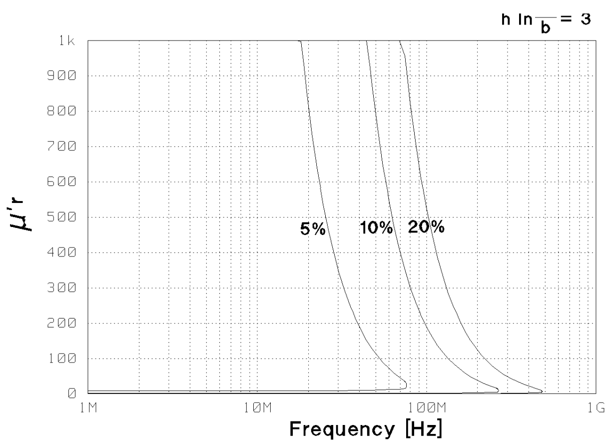

Figure 27. Permeability (μ'_r) vs. frequency (at *F* = 3, typical)

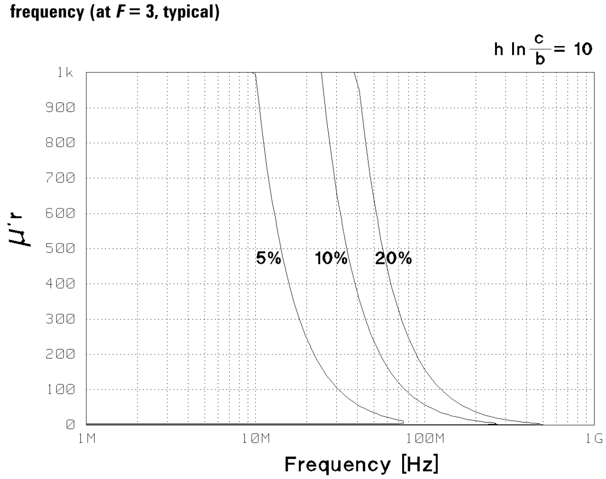

Figure 28. Permeability (μ'_r) vs. frequency (at *F* = 10, typical)

9. This graph shows only frequency dependence of E_a to simplify it. The typical accuracy of tanδ is defined as $E_a + E_b$; refer to *"Typical accuracy of permeability parameters"* on page 17.

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