APPENDIX A
Model 3321 Specifications

A.1 MEASUREMENT PARAMETERS

Kinds of Parameters

- Main Parameters
  AUTO: Selects the main parameters, sub-parameters and equivalent circuits automatically.
  L: Self-inductance (unit: H, henry)
  C: Capacitance (unit: F, farad)
  |Z|: Magnitude of impedance (unit: Ω)
  There are series and parallel measuring modes for each of L, C and R.
- Sub-parameters
  Q: Quality factor (quality of circuit)
  D: Dissipation factor ($= \tan\delta = 1/Q$)
  ESR: Equivalent series resistance (unit: Ω)
  G: Parallel conductance (unit: S, siemens; 1/Ω; Mho)
  θ: Phase angle of impedance (unit: degree)
- Equivalent Circuits
  AUTO: Automatic selection
  SER: Series
  PAR: Parallel
- Automatic Parameter Selection
  Parameters can be automatically selected by the phase angle of impedance.
  $\theta = +90° \pm 45° \rightarrow$ L - Q
  $\theta = -90° \pm 45° \rightarrow$ C - D
  $\theta =$ Other than the above $\rightarrow$ |Z| - θ
- Automatic Selection of Equivalent Circuits
  Equivalent circuits can be automatically selected by the value and phase angle of impedance, and the combination of parameters.

Conditions for Selection of Series Mode		Conditions for Selection of Parallel Mode	
L, C	- ESR	L, C	- G
L, C (|Z| ≤1kΩ)	- Q, D	L, C (|Z| > 1kΩ)	- Q, D
|Z|	- θ		

Displayed Resolution

4-1/2 digits (19999 max)
D and Q Resolution: 0.0001 min
θ Resolution: 0.01°

Measuring (display) Range

|Z|, ESR: 0.1mΩ to 19.999MΩ
C: 0.001pF to 199.99mF
L: 0.1nH to 19.999kH
Q, D: 0.0001 to 19999
G: 0.001μS to 199.99S
θ: –180.00° to +179.99°
These ranges are dependent on the frequency, measuring range, and phase angle of impedance.

Accuracy

Accuracy Guarantee Conditions

- Warm-up time: 30 minutes.
- Ambient temperature and humidity: 23° ±5°C, ≤90% RH.
- Zero correction: Performed under the above conditions.
- Calibration period: 12 months.

Accuracy of |Z| and θ
For 0.2Ω ≤ |Z| ≤ 20MΩ, see Table A-1.
For |Z| < 0.2Ω, see Table A-2.
For |Z| >20MΩ, see Table A-3.

Notes:
1. When a measurement is made at twice line frequency, the measured value may deviate beyond the accuracy range due to interaction with line frequency.
2. When the operating temperature is 5°-40°C, add the value shown in Table A-4 to that in Table A-1. Double the values shown in Table A-2 and A-3.
3. Tables A-1 through A-3 show the worst case value in each impedance range. Obtain the correct accuracy in the following ranges by linear interpolation:

- |Z| = 1M to 20MΩ
  In this range, as impedance increases, accuracy decreases.
  acc1: Accuracy shown in one range below the range including a Z in Table A-1.
  acc2: Accuracy (worst case value) shown in the range including a Z in Table A-1.
- |Z| = 0.2 to 2Ω
  In this range, as impedance decreases, accuracy decreases.
  acc1: Accuracy (worst case value) shown in the range including a Z in Table A-1.

Specifications subject to change without notice.

Notes Cont.:

acc2: Accuracy shown in one range above the range including a Z in Table A-1.

$$acc = [acc1\,(Z2 - Z) + acc2\,(Z - Z1)] / (Z2 - Z1)$$

Z: Magnitude of measured impedance (measured value)

Z1: Lower limit value of each impedance range in Table A-1.

Z2: Upper limit value of each impedance range in Table A-1.

acc: Measuring accuracy of impedance Z ($|Z|$ is displayed by %, and θ by degree.)

acc1: Measuring accuracy of impedance Z1

acc2: Measuring accuracy of impedance of Z2

When obtaining the accuracy in the ambient temperature ranging from 5°-40°C, add each corresponding value in Table A-4 to acc1 and acc2 in advance.

- When level = 50mV rms, accuracy is not guaranteed in the following ranges.

  $|Z| \geq 20M\Omega$

  $|Z| \geq 2M\Omega$ and frequency = 100kHz

  $|Z| < 0.2\Omega$

Accuracy of ESR and G

In the case of $Q < 0.1$ ($D > 10$), use the accuracy of $|Z|$:

$|ESR| = |Z|$

$|G| = 1/|Z|$

Accuracy of L and C

In the case of $Q > 10$ ($D < 0.1$), use the accuracy of $|Z|$:

$$L = \frac{|Z|}{2\pi f}$$

$$C = \frac{1}{2\pi f\,|Z|}$$

where f is the test frequency in Hz.

Refer to Figure A-1, Conversion from LC to $|Z|$.

Accuracy of D and Q

In case D<<1 (Q>>1), use the following equations:

Accuracy of D = $\pm(0.0175 \times \theta$ accuracy (deg))

Accuracy of Q = $\pm(0.0175 \times \theta$ accuracy (deg) $\times Q^2)$

In any parameter, add the ±1/2 count, i.e., half of the resolution to the displayed value as actual accuracy.

Table A-1. Accuracy of |Z| and θ for 0.2Ω ≤ |Z| <20MΩ

|Z| (Ω)	LEVEL =1V rms Frequency, (Hz)				LEVEL = 50mVrms Frequency, (Hz)			
	120	1k	10k	100k	120	1k	10k	100k
10M≤|Z|<20M	3.0% 1.5°	1.0% 0.8°	3.5% 2.0°	20.0% 12.0°	7.0% 4.0°	3.5% 2.0°	8.5% 5.0°	– –
5M≤|Z|<10M	1.5% 0.9°	0.5% 0.4°	1.8% 1.1°	10.0% 6.0°	3.5% 2.0°	1.7% 1.0°	3.5% 2.0°	– –
2M≤|Z|<5M	0.75% 0.45°	0.3% 0.2°	0.9% 0.6°	5.0% 3.0°	2.0% 1.2°	0.9% 0.6°	1.6% 1.0°	– –
1M≤|Z|<2M	0.36% 0.22°	0.2% 0.1°	0.4% 0.2°	3.0% 2.0°	1.0% 0.6°	0.4% 0.25°	0.8% 0.5°	14.0% 8.0°
200k≤|Z|<1M	0.25% 0.15°	0.15% 0.09°	0.27% 0.16°	2.0% 1.2°	0.5% 0.3°	0.3% 0.18°	0.4% 0.25°	7.0% 4.0°
20k≤|Z|<200k	0.15% 0.10°	0.1% 0.04°	0.25% 0.15°	1.2% 0.8°	0.3% 0.18°	0.16% 0.08°	0.32% 0.18°	3.0% 1.5°
2k≤|Z|<20k	0.14% 0.09°	0.1% 0.03°	0.15% 0.08°	0.8% 0.6°	0.25% 0.15°	0.16% 0.06°	0.24% 0.14°	2.0% 1.2°
10≤|Z|<2k	0.13% 0.08°	0.1% 0.03°	0.13% 0.1°	0.7% 0.5°	0.20% 0.12°	0.15% 0.06°	0.23% 0.13°	1.6% 1.0°
2≤|Z|<10	0.25% 0.15°	0.15% 0.07°	0.32% 0.2°	1.5% 0.8°	0.5% 0.3°	0.25% 0.14°	0.5% 0.3°	4.0% 2.3°
1≤|Z|<2	0.35% 0.22°	0.2% 0.12°	0.5% 0.3°	2.0% 1.2°	1.0% 0.6°	0.5% 0.3°	0.8% 0.5°	8.0% 5.0°
0.5≤|Z|<1	0.7% 0.45°	0.4% 0.25°	0.8% 0.5°	3.3% 2.0°	1.8% 1.1°	1.0% 0.6°	1.5% 0.9°	14.0% 8.5°
0.2≤|Z|<0.5	1.4%	0.8%	1.25%	5.5%	3.7%	2.0%	2.9%	28.0%

|Z| Accuracy: ±% reading shown on upper line.
θ Accuracy: ± degrees shown on lower line.

Table A-2. Accuracy of |Z| and θ for |Z| <0.2Ω

|Z| (Ω)	LEVEL =1V rms Frequency, (Hz)			
	120	1k	10k	100k
0≤|Z|<0.2	1.7% +0.2m	1.0% +0.2m	1.4% +0.3m	6.0% +3m

|Z| Accuracy: ±(% reading + R) shown.
θ Accuracy: (θ Accuracy for 0.2≤|Z|<0.5 in Table A-1) × (0.2Ω/|Z|)

Table A-3. Accuracy of |Z| and θ for |Z|≥20MΩ

|Y| (S)	LEVEL =1V rms Frequency, (Hz)			
	120	1k	10k	100k
0≤|Y|≤50nS	1.8nS	0.6nS	2.1nS	12nS

|Z| Accuracy: Specified by the ± deviation (S) of admittance |Y| shown.
θ Accuracy: (θ Accuracy for 10M≤|Z|<20M in Table A-1 × (|Z|/20MΩ).

Table A-4. Additional Error for 5°-40°C

|Z| Ω	LEVEL =1Vrms Frequency, (Hz)		LEVEL = 50mVrms Frequency, (Hz)	
	120 to 10k	100k	120 to 10k	100k
10M≤|Z|<20M	0.2% 0.12°	2.0% 1.2°	0.3% 0.2°	— —
5M≤|Z|<10M	0.12% 0.07°	1.0% 0.6°	0.2% 0.12°	— —
2M≤|Z|<5M	0.07% 0.04°	0.5% 0.3°	0.14% 0.09°	— —
200k≤|Z|<2M	0.04% 0.024°	0.20% 0.12°	0.1% 0.06°	0.6% 0.4°
20k≤|Z|<200k	0.04% 0.024°	0.20% 0.12°	0.06% 0.035°	0.3% 0.2°
2k≤|Z|<20k	0.04% 0.024°	0.08% 0.05°	0.06% 0.035°	0.15% 0.1°
10≤|Z|<2k	0.04% 0.024°	0.08% 0.05°	0.06% 0.035°	0.15% 0.1°
2≤|Z|<10	0.04% 0.024°	0.10% 0.06°	0.2% 0.12°	1.0% 0.6°
1≤|Z|<2	0.07% 0.04°	0.18% 0.1°	0.4% 0.24°	2.0% 1.2°
0.5≤|Z|<1	0.12% 0.07°	0.33% 0.2°	0.8% 0.5°	4.0% 3.5°
0.2≤|Z|<0.5	0.2% 0.12°	0.6% 0.4°	2.0% 1.2°	10.0% 6.0°

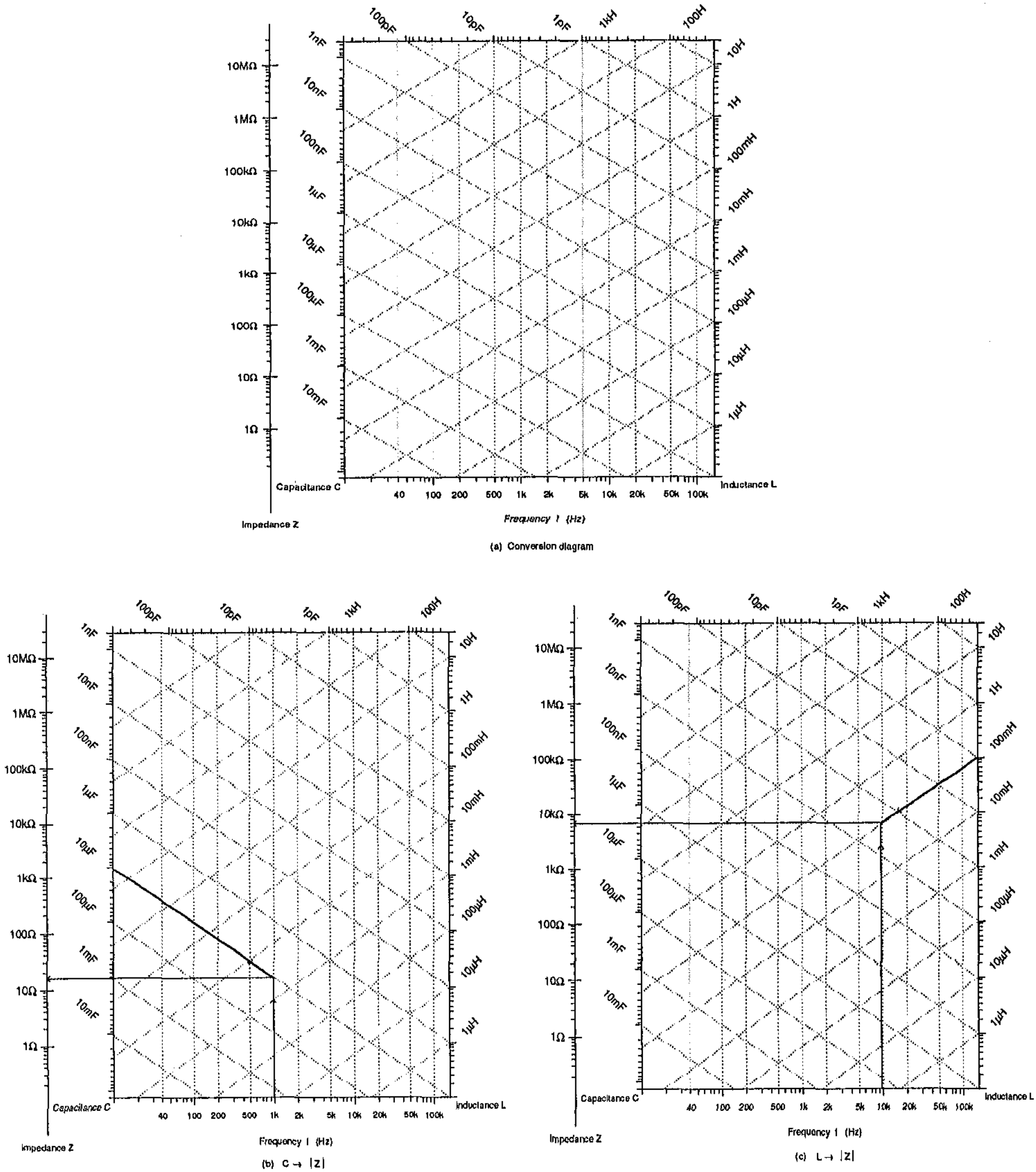

Figure A-1. Conversion Diagram from L or C to |Z|

Examples of Determining Accuracy

Ex. 1: Find the accuracy when R=33kΩ, f=10kHz, 1V, while Q<0.1.

1. Find the accuracy from Table A-1, using the following parameters: 1V, 10kHz and 20k to 200kΩ.
2. When operating within a temperature range from 5 to 40°C, add the value in Table A-4.
3. When accuracy is needed for ≥1MΩ or ≤2Ω, interpolate the value according to Note 3.
4. Add ±1/2 count of display value. When the display shows a measured value of 33.14kΩ, the 1/2 count becomes 0.005kΩ.

Ex. 2: Find the accuracy when C = 10μF, f=1kHz, 50mV, while D < 0.1.

1. Find |Z| from Figure A-1 Conversion Diagram.
   - Find the line descending from C = 10μF. Find the vertical line from frequency = 1kHz. Mark their intersection.
   - Extend a horizontal line from the intersection, to the left side. Read the value of |Z| (≈16Ω). Also, you can calculate the accuracy using the following equation.

$$|Z| = |1/2\pi fC|$$

2. Find the accuracy from Table A-1, using the following parameters: 50mV, 1kHz and 10 to 2kΩ.
3. When operating within a temperature range from 5 to 40°C, add the value in Table A-4.
4. When accuracy is needed for ≥1MΩ or ≤ 2Ω, interpolate the value according to Note 3.
5. Add ±1/2 count of display value.

Ex. 3: Find the accuracy when L = 680μH, f=100kHz, while Q > 10.

1. Find |Z| from Figure A-1 Conversion Diagram.
   - Draw a straight line from L = 680μH, in parallel with the ascending lines. Find the intersection with the vertical line at frequency = 100kHz.
   - Read |Z| as shown in Ex. 2. Also, you can calculate the accuracy using the following equation:

$$|Z| = |2\pi fL|$$

2. Find the accuracy from Table A-1, using the following parameters: f=100kHz and 10 to 2kΩ. Repeat procedures 3 to 5 in Ex. 2.

Ex. 4: Find the accuracy of |Z| at any θ and for parameters other than θ.

1. Measure |Z| and θ, or calculate the accuracy, using the other parameters.

$Q = 1/D$	$\|\theta\| = \|\arctan Q\|$
$= 2\pi f Ls/ESR$	$\|Z\| = \|2\pi f Ls/\sin\theta\|$
$= 1/(2\pi f Cs\ ESR)$	$= \|1/(2\pi f Cs \sin\theta)\|$
$= 2\pi f Cp/G$	$= \|1/(2\pi f Cp \sin\theta)\|$
$= 1/(2\pi f Lp\ G)$	$= \|2\pi f Lp/\sin\theta\|$

   f: Frequency (Hz)

   Suffix s: Series equivalent circuit

   p: Parallel equivalent circuit
2. Find the accuracies of |Z| and θ. Refer to Ex. 1.
3. Find the maximums and minimums of |Z| and θ from the measured values and accuracies of |Z| and θ.

   Z max, min = Measured value |Z| × [1 ± Accuracy of |Z| (%)/100]

   θ max, min = Measured value θ ± Accuracy θ (degree)
4. Find the maximums and minimums of the parameters for the four sets of combinations of maximums and minimums of |Z| and θ, using the calculating equation of each parameter. B is a susceptance, i.e., an imaginary component of admittance.

$ESR = \|Z\| \cos\theta$	$G = (1/\|Z\|)\cos\theta$
$X = \|Z\| \sin\theta$	$B = -(1/\|Z\|)\sin\theta$
$Ls = X/2\pi f$	$Lp = -1/2\pi fB$
$Cs = -1/2\pi fX$	$Cp = B/2\pi f$
$Q = \|\sin\theta\|/\cos\theta$	$D = \cos\theta/\|\sin\theta\|$
5. The accuracy is the value that the error of 1/2 count of display is added to |maximum value - measured value| or |minimum value - measured value|, whichever is greater.

A.2 MEASURING SIGNAL

Frequency

Range: 120, 1k, 10k, 100k (Hz)

Accuracy: ±0.005% (±50ppm)

Signal level (HCUR open voltage with terminal)

1Vrms: ±3% at 1kHz
±4% at 120Hz to 10kHz
±5% at 100kHz

50mVrms: ±5% at 1kHz
±6% at 120Hz to 10kHz
±7% at 100kHz

DC bias

Internal: 2V, ±5%

External: 0 to ±35V

A.3 MEASURING RANGE

Number of ranges: 6 (Reference resistance: 100Ω, 1kΩ, 10kΩ, 50kΩ, upper and lower extension ranges 2)

Selection: Automatic

A.4 MEASURING SPEED (reference value)

Measuring time (fixed range and auto trigger mode)

When the range is not switched, the following values become effective:

150ms (typ) 1kHz, 1kΩ

600ms (max) all ranges, all frequencies

Automatic range switching time (per range)

The automatic range switching time is nearly equal to the measuring time. When the frequency is ≤120Hz and the impedance is ≥1MΩ, it will take time for the measured value to stabilize. When measuring a device whose impedance changes according to the magnitude of the measuring signal, time will extend until the value of the device becomes stable.

Level switching stabilization time: 200ms to 4s

The level switching stabilization time will change according to the kinds of devices under test. Time increases when measuring non-linear elements, such as diodes, or when switching from 1V to 50mV. This is the time required for the stabilization of measured values. The time needed to change the device under test is excluded.

Bias stabilization time: (4 + 0.015C)s

Where C=capacitance of device under test (μF).

Frequency switching stabilization time: 150ms to 4s

The frequency switching stabilization time increases when a high frequency is changed to a low frequency (e.g.: 100kHz to 120Hz)

Also, time changes according to the device under test. This is the time required for the stabilization of the measured value. The time taken to change the device under test is excluded.

A.5 TRIGGER

Trigger mode: Automatic only.
Trigger delay time: 0 to 199.99s

A.6 MEASUREMENT TERMINALS

4 terminals (BNC) + guard terminal

A.7 SETUP MEMORY

Memory Content: All settable data (except bias on-off).
Battery Life: 3 years minimum when stored at 40°C max.

A.8 GPIB

Interface Functions: SH1, AH1, T6, L4, SR1, RL2, PP0, DC1, DT1, C0.

Setting: Of the items settable via the front panel, all the parameters except address and delimiter of GPIB can be set. Also, trigger, OPEN/SHORT compensation and memory operation can be performed.
Readout: All the settable parameters, measurement data and status.
Standards: Based on IEEE-488-1978 and IEEE-488A-1980.
Code: ISO 7 bit code (ASCII code).

A.9 GENERAL

Power requirements: AC line voltage: selectable to 100V, 120V, 220V, 240V ±10% (250V max.). 48 to 62Hz, approx. 21VA.
Operating Environment: 0° to 40°C, 10 to 90% RH (non-condensing).
Storage Environment: -10 to +50°C, 10 to 80% RH (non-condensing).
Dimensions, Weight: 216mm wide × 132.5mm high × 350mm deep (8-1/2 in. × 5-1/4 in. × 13-3/4 in.), excluding protrusions. Net weight 3.6kg (7.9lb.).