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manufacturers of the world's most accurate capacitance bridges and standards

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- AH 2700A, 50 Hz - 20 kHz Ultra-precision Capacitance/Loss Bridge
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- AH 2500A, 1 kHz Automatic Capacitance Bridge,
  The World's Most Accurate Capacitance/Loss Bridge
- AH 1100 Capacitance Standard Frame, AH 11A Fused-Silica Capacitance Standard,
  The World's Most Stable Capacitance Standards in commercial production
- DCOAX Cable,
  Dual, Low Noise, Coaxial Cable Optimized For Three-Terminal Capacitance Measurements

High quality printed editions of the brochures listed above, and other Andeen-Hagerling publications listed below, may be ordered from the Reader Response Form:

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ANDEEN-HAGERLING, INC.

31200 Bainbridge Road
Cleveland, Ohio 44139-2231 U.S.A.

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AH 2700A

ANDEEN-HAGERLING

50 Hz-20 kHz
Ultra-precision

Capacitance Bridge

The World's Most Accurate 50Hz-20kHz Capacitance/Loss[1] Bridge

The AH 2700A offers unparalleled stability, resolution, linearity and accuracy in a multi-frequency capacitance/loss[1] bridge (whether manual or automatic). Its numerous state-of-the-art features make it an exceptionally user-friendly instrument. The precision of the AH 2700A is creating new applications in calibration, science, and production in a wide range of fields.

Frequencies: 50, 60, 80, 100, 120, 160, 200, 240, 320, 400, 500, 600, 800 Hz and 1.0, 1.2, 1.6, 2.0, 2.4, 3.2, 4.0, 5.0, 6.0, 8.0, 10, 12, 16 and 20 kHz

Selected Precision Specifications

Frequency	Accuracy	Stability	Temperature Coefficient	Resolution	
kHz	ppm	ppm/year	ppm/°C	aF	ppm
0.1	±9	±<1.9	±0.07	16	0.8
1	±5	±<1.0	±0.035	0.8	0.16
10	±11	±<1.9	±0.07	2.4	0.5

Complete Precision Specifications in an Excel Spreadsheet

Outstanding Features

- **Measures extremely low loss** down to a dissipation factor of $1.5\text{x}10^{-8}$ tan δ, a conductance of $3\text{x}10^{-7}$ nanosiemens or a resistance up to $1.7\text{x}10^{6}$ gigohms
- **As little as 0.4 second** required for full precision measurements and **as little as 30 ms** required for repeated measurements on the same sample
- **Fast analog output** has a frequency response of 3 kHz at 3 dB down
- **Negative capacitance and loss ranges** measure negative values to allow for unusual samples or three terminal networks
- **Commutation** (test signal reversal) to minimize external power line or other periodic signal pickup
- **Three terminal BNC connections** minimize connector costs and number of cables
- **IEEE-488 GPIB and IEEE-1174 serial** interfaces included; remote device can act as controller or logger
- **Programmability** can eliminate the need for an external controller
- **Large, variable-brightness displays** having 8 digits for capacitance and loss and 5 digits for frequency
- **Deviation measurements** of capacitance, loss or both
- **Zero correction of test fixture** capacitance and loss
- **External DC bias** up to ±100 volts
- **External trigger** capability
- **NIST or NPL traceable** calibration
- **Autoranging**
- **Automatic internal calibration**
- **Self-test diagnostics** on power-up and by command
- **Three year warranty**

Complete Product Brochure in PDF format, including Precision Specifications in algebraic form

[1] The term “loss” is used to refer to the component of the impedance which is 90° out of phase with respect to the capacitive component. The AH 2700A can report loss in units of conductance, dissipation factor, series or parallel resistance, or loss vector.

For additional information regarding the AH 2700A, possible applications, the location of your nearest sales representative, or ordering information:

Call: 440-349-0370 **Fax: 440-349-0359**
E-mail: info@andeen-hagerling.com

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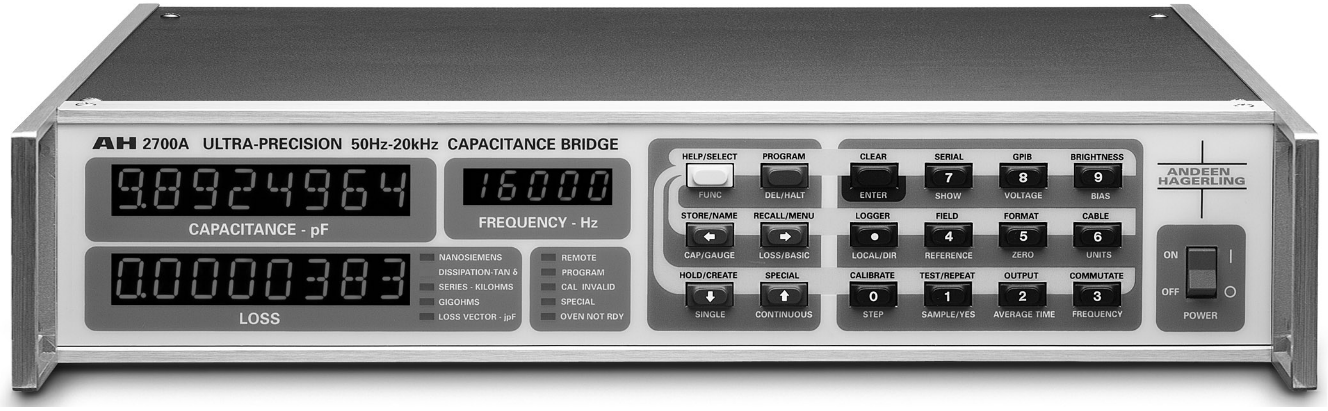
ANDEEN-HAGERLING

AH 2700A

50Hz-20kHz
Ultra-precision
Capacitance Bridge



World’s Most Accurate 50Hz-20kHz Capacitance/Loss* Bridge

The AH 2700A offers unparalleled stability, resolution, linearity and accuracy in a multi-frequency capacitance/loss* bridge (whether manual or automatic). Its numerous state-of-the-art features make it an exceptionally user-friendly instrument. The precision of the AH 2700A is creating new applications in calibration, science, and production in a wide range of fields.

Outstanding Features

- **Frequencies:** 50, 60, 80, 100, 120, 160, 200, 240, 320, 400, 500, 600, 800 Hz and 1.0, 1.2, 1.6, 2.0, 2.4, 3.2, 4.0, 5.0, 6.0, 8.0, 10, 12, 16 and 20 kHz
- **Selected Performance Specifications**

Frequency	Accuracy	Stability	Temperature Coefficient	Resolution	
kHz	ppm	ppm/year	ppm/°C	aF	ppm
0.1	±9	±<1.9	±0.07	16	0.8
1	±5	±<1.0	±0.035	0.8	0.16
10	±11	±<1.9	±0.07	2.4	0.5

- **Measures extremely low loss** down to a dissipation factor of 1.5×10^{-8} tan δ, a conductance of 3×10^{-7} nanosiemens or a resistance up to 1.7×10^{6} gigohms
- **As little as 0.4 second** required for full precision measurements and **as little as 30 ms** required for repeated measurements on the same sample
- **NIST or NPL traceable** calibration
- **Autoranging**
- **Fast analog output** has a frequency response of 3 kHz at 3 dB down
- **Negative capacitance and loss ranges** measure negative values to allow for unusual samples or three terminal networks
- **Commutation** (test signal reversal) to minimize external power line or other periodic signal pickup
- **Three terminal BNC connections** minimize connector costs and number of cables
- **IEEE-488 GPIB and IEEE-1174 serial** interfaces included; remote device can act as controller or logger
- **Programmability** can eliminate need for external controller
- **Large, variable-brightness displays** having 8 digits for capacitance and loss and 5 digits for frequency
- **Deviation measurements** of capacitance, loss, or both
- **Zero correction of test fixture** capacitance and loss
- **External DC bias** up to ±100 volts
- **External trigger** capability
- **Automatic internal calibration**
- **Self-test diagnostics** on power-up and by command
- **Three year warranty**

*The term "loss" is used to refer to the component of the impedance which is 90˚ out of phase with respect to the capacitive component. The AH 2700A can report loss in units of conductance, dissipation factor, series or parallel resistance, or loss vector.

BASIC DESIGN

The AH2700A measures capacitance and loss in medium- and high-impedance ranges, and thus allows using three-terminal rather than five-terminal connections to the unknown. Its unmatched precision is the result of a uniquely designed ratio transformer which is the culmination of over 30 years of bridge design and manufacture. Equally important is the unique temperature-controlled, fused-silica capacitance standard which allows extremely high measurement stability and immunity to mechanical shock. These elements combine to form a true bridge operating at 50 Hz - 20 kHz to give capacitance results which are independent of the exact test frequency.

MEASUREMENT FEATURES

Measurement Initiation

A single measurement is initiated by a front panel keystroke, an external trigger pulse, a single character from the IEEE-1174 serial or IEEE-488 ports, or a Group Execute Trigger from the IEEE-488 bus. Measurements can be taken continuously with a selectable delay time between the end of one reading and the start of the next. This delay time can range from zero to many hours in 0.01 second increments

Units

Capacitance units are picofarads. Loss units are selectable among nanosiemens, dissipation factor, series resistance in kilohms, parallel resistance in gigohms or magnitude of the loss vector in jpF – the choice being indicated by the front panel LED’s.

Display Results

Results are displayed on large, variable-brightness front panel LED displays to as many as eight digits. Results are sent to remote devices with as many as nine digits.

Deviation Measurements

Results may be provided in the form of a difference or offset from a reference value for capacitance or loss or both. The loss may be expressed using any of the AH2700A's loss units. The reference value can be the result of a previous measurement or a user-provided value.

DC Bias

A connector is provided to which an external DC bias voltage may be applied. The AH2700A can switch this voltage to the sample through user-selectable resistors located within the instrument.

Commutation

This selectable feature causes the test signal to be reversed periodically so as to improve rejection of external periodic signals, particularly those that are power-line related.

Speed versus Resolution

Available resolution is determined primarily by the amount of time spent averaging out noise. The trade-off between resolution and measurement speed is selectable in factors of about two from 28 milliseconds to 20 minutes.

Bridge Balancing Time

Measurement time on a previously unmeasured sample is less than 0.4 second. However, the measurements following the first can be made in less than 30 milliseconds if the averaging time is set to be short.

Zero Correction

Stray capacitance and loss (typically associated with a test fixture) may occur in parallel with the capacitance and loss that is to be measured. The stray values can be obtained from the result of a previous measurement or from a user-provided value and used to correct the reported results. The stray loss is corrected for as if it is in parallel with the loss that is intended to be measured. This occurs no matter what loss units are being used. This is more involved than a deviation measurement which would just do a simple subtraction. (The AH2700A itself has no significant zero offset.)

Analog Output

Rapidly changing capacitances or losses may be studied using the capacitance and/or loss analog outputs. The upper and lower limits of the capacitance or loss that the analog outputs are to span must be specified. Once initiated, both outputs will follow the changing sample. These outputs have a flat frequency response up to 3kHz at 3dB down.

Standards Oven

The oven (and hence the entire bridge) normally becomes stable within only 15 minutes after power-on. A blinking front panel LED indicates when the oven has not stabilized or when the ambient temperature is too extreme for stabilization.

Inductance Measurements

The AH2700A can measure negative capacitance values. One way to get a negative capacitance reading is to measure an inductor. The inductance corresponding to a negative capacitance is easily calculated using $L = -1/\omega^2C$. Any inductance above 420 µH can be measured. The AH2700A makes extremely accurate inductance measurements since its internal fused-silica reference capacitor is much more perfect than any reference inductor.

Test Voltage

The maximum test voltage applied to the sample is continuously selectable from 30 mV to 15 V r.m.s. The actual voltage applied by the AH2700A may be much smaller than the selected maximum.

Cable Length Correction

The three-terminal connection method used by the AH2700A usually makes the errors caused by the pair of cables that connect the instrument to the unknown capacitance so small that they can be ignored. However, cable capacitance and inductance can affect the accuracy of capacitance measurements made at the high end of the AH2700A's capacitance and frequency ranges. Similarly, cable resistance can affect the accuracy of loss measurements made at the high end of the AH2700A's capacitance and frequency range. In these situations, the resistance and inductance per meter of cable pair and the length of the cable pair can be entered into the instrument. The AH2700A then automatically corrects for these cable errors.

Measurement Errors

Measurement troubles are easily pinpointed by one of over a dozen English language error messages (or, optionally, error codes). Additionally, many other command and status messages are reported.

Calibration

A unique calibration technique allows internal precision components to be compared against internal temperature-controlled standards with the appropriate corrections being made by a microprocessor. The AH2700A also provides for calibration against extemal standards. To prevent unauthorized calibrations, a passcode (which only the manager of the instrument can change) must be entered before any calibration can be performed.

Self Tests

Power-on or user-initiated self-tests check the microprocessor area, transformer ratio-arm switches, D/A switches and A/D converter. Special circuitry allows numerous internal self-consistency checks.

SYSTEM INTERFACES

IEEE-1174

An IEEE-1174 standard serial interface is included with each instrument to allow simple connections to a computer, modem, printing terminal or video terminal. These devices can take control of the instrument interactively or can merely log the measured data passively.

IEEE-488

An IEEE-488 (GPIB) standard interface is included with each instrument. A full IEEE-488 implementation is provided including serial poll and extended talker/listener addressing. The AH2700A can be run with a GPIB controller or can operate in "talk only" mode to send data to a passive printer or data logger. A front panel "remote" indicator is provided.

Setup of IEEE-488 and IEEE-1174

IEEE-488 bus address and serial baud rate, parity, stop bits, and fill characters are all entered from the front panel keypad and can be permanently stored from the keypad as well.

Sample Switch Interface

Some applications need to measure more than one sample or capacitor in quick succession. A device called a “sample switch” consisting mainly of very high isolation relays can be constructed to connect one sample at a time to a capacitance bridge. The AH2700A provides an interface that allows connection to such a sample switch. This interface has a simple design that allows customized connections to one-of-a-kind sample switches.

Data Formats

Measurement results consist of any combination of five fields: error message, frequency, capacitance, loss, and voltage. The number of decimal places and the width of the capacitance and loss fields are independently selectable. Field and unit labels are optional. Numeric results can be reported in floating point, scientific or engineering notations.

Friendly Commands

Both remote-device interfaces use the same English language commands that are found on the front panel. Commands can be abbreviated by supplying only enough letters to uniquely identify the desired command.

EXAMPLES OF APPLICATIONS OF THE AH2700A

- Calibration work including use as a transfer standard in primary and secondary laboratories.
- Fuel gauge calibration.
- Measurement of cryogenic temperatures.
- Thermal expansion measurements for any type of matter, particularly metals, but also non-metals.
- Radiation measurements using crystalline structures and radiation induced changes in non-metals.
- Rapid, accurate and direct humidity measurements.
- Measurement of the thickness of metals or dielectrics.
- Liquid and vapor level measurements.
- AC resistance measurements to 1000 teraohms.
- Research, development and production testing of capacitance- or loss-based sensors.
- Displacement and strain measurements. Very small changes in dimensions are measurable, approaching the diameter of an atomic nucleus. (This is less than a millionth of the wavelength of visible light.)
- Determination of the quality and characteristics of any insulating medium (solid, liquid or gas). The presence of contaminating water is particularly easy to detect. See ASTM D150 and D924.
- Detection of contaminants in refrigerants.
- Monitoring chemical reactions.
- Applications involving the measurement of small changes in capacitance or loss. The AH2700A is very good at these due to its very high resolution and stability.
- Replacement of the electronics normally associated with currently manufactured capacitance based sensors to obtain greatly improved precision.
- Measurement of pressures ranging from high vacuum to high pressure.
- Very high pressure gauge using a solid dielectric capacitor. (Patent No. 3,787,764)

THE AH2700A HAS MANY POSSIBLE USES BEYOND CALIBRATION

The reaction of many technical persons upon first learning of the AH2700A is: "That's a very impressive instrument, but we don't see a need for such precision in our work. Furthermore, such measurements must be more difficult to make." Until the introduction of the original AH2500A, this attitude toward high precision capacitance measurements was justified. Previously, the only commercially available instruments were manually operated, required a skilled operator to spend several minutes balancing the bridge, were prone to reliability problems due to the large number of open switching contacts used, and were still far less stable than the AH2700A. It is not surprising that these bridges have not seen significant use outside of calibration or research laboratories.

Today, the incredible ease with which high precision capacitance and loss measurements can be made with the AH2700A requires a reassessment of previous attitudes. The AH2700A allows totally automated operation with no human intervention. Its ability to maintain its precision over a wide temperature range and its immunity to mechanical shock make it ideally suited for factory floor or portable field use.

To apply the AH2700A to a productive task requires obtaining a suitable sensor. This is where the possibilities become exciting, because capacitive sensors are theoretically the most precise of all electrical sensors. The reasons are:

- A perfect capacitor dissipates no power. Thus relatively high voltages can be applied to the sensor without generating any heat in it. The higher the voltage, the better the signal-to-noise ratio. In contrast, all resistive sensors dissipate heat while being measured.
- A perfect capacitor generates no noise. Resistors are always limited by thermal noise and are susceptible to other kinds of noise as well.
- A perfect capacitor is linear with applied voltage. Most resistive elements are at least slightly non-linear and inductive elements are usually extremely non-linear.
- The variation with temperature of a small capacitor can be made very small and simultaneously very linear. Other elements, such as resistors, require compensation schemes which cause them to have low temperature coefficients over a narrow temperature range but much higher and very non-linear variations over a broader range.

These characteristics allow the creation of simple yet very precise sensors based on the change in area or the change in separation of a pair of capacitor plates, cylinders, etc. Such a sensor could also be based on the introduction of a conducting material of unknown thickness, size, shape, position, or whatever into the active field of a capacitor. If the material within the active field is a reasonably good insulating dielectric, then both the dielectric constant and the loss of the material are obtainable. This can be a very simple way to observe chemical changes, detect contaminants, etc., in a wide variety of materials.

SPECIFICATIONS

Notation: The specifications are grouped according to whether the unknown is modeled as a resistor in parallel with a capacitor or in series with it.

Parallel:	"C"	is the value of the unknown (parallel) capacitance in picofarads (pF= 10^{-12} F). Also used are attofarads (aF = 10^{-6}pF) and microfarads (µF = 10^{6}pF).
	"G"	is the value of the unknown loss expressed as a conductance in nanosiemens (nS = 10^{-9} S).
	"D"	is the value of the unknown loss expressed as a dissipation factor ($\tan\delta$). D has no units.
	"R_P"	is the value of the unknown loss expressed as a parallel resistance in gigohms (GΩ = 10^{9}Ω).
Series:	"C_S"	is the value of the unknown series capacitance in picofarads (pF = 10^{-12} F)
	"R_S"	is the value of the unknown loss expressed as a series resistance in kilohms (kΩ = 10^{3} Ω).
Misc:	"*f*"	is the frequency in kilohertz (kHz = 10^{3} Hz).
	"ω"	equals $2\pi f$.
	"t"	is the measurement time in seconds.
	"V"	is the AC test signal voltage in volts applied across the unknown. Its upper limit is selectable to have any value from 30 mV to 15 V.
	"ppm"	means Parts Per Million.

General:

The expressions which give the uncertainty for accuracy, linearity, stability, resolution, and temperature coefficient give absolute rather than statistical uncertainties. Absolute uncertainties are the most conservative of those in common use. Andeen-Hagerling guarantees repair within the warranty period of any AH2700A whose measured errors repeatedly exceed these uncertainties. The expressions may be evaluated for particular values of capacitance (C or C_S), loss (G, D, Rp, R_S or G/ω), test voltage (V), and measurement time (t). Except for absolute resolution, G/ω shares the same equations as G. Only the resolution expressions contain the measurement time. However, the other uncertainty expressions assume that the measurement time has been set to be long enough so that these other uncertainties are not limited by the resolution specification. In other words, specifications such as accuracy may be limited by the resolution rather than the accuracy expression if the measurement time is set too short.

Many of the expressions include an error contribution from cable effects. This cable is assumed to be an AH-DCOAX cable that is up to two meters in length. Where these one or two cable error contribution terms exist, they may be identified by their enclosure within a pair of braces "{}". This pair will always be the inner of two pairs of braces.

Most of the uncertainty expressions can be evaluated by direct substitution of the values of capacitance, loss and voltage as if they were read directly from the AH2700A. The instrument reports these values in the units given in the notation section above. Some expressions also require the dissipation factor, D, which, if it is not directly available, can be calculated using one of the following relations:

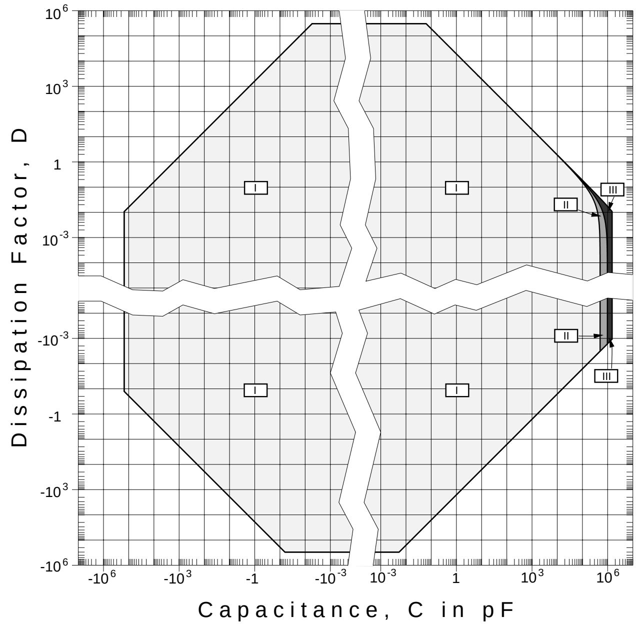


Figure 1. Measurable values of C and D are enclosed within shaded areas. II and III are examples of specific frequencies.

Region I applies to all frequencies
Regions I & II apply to frequencies below 10kHz
Regions I, II & III apply to frequencies below about 3 kHz

$D = G/\omega C$, $D = 1/\omega CRp$ or $D = \omega C_S R_S \times 10^{-6}$

For low values of capacitance and loss, the maximum allowable test voltage set by the user (usually 15 volts) can be substituted for every occurrence of V in the uncertainty expressions. For larger values of capacitance and loss, if the voltage value is not taken from a measurement result, then the value of V automatically chosen by the AH2700A must be determined from the AC Test Signal Voltage Table. The following equations may be used to convert to the units of C and G used in the table from units other than those used in the table.

Given units of: *D:* use $G = \omega CD$
R_P: $G = 1/R_P$
R_S: $G = \omega C_S D/(1+D^2)$
C_S: $C = C_S/(1+D^2)$

A comprehensive set of contour plots of all of the uncertainty expressions is available from Andeen-Hagerling upon request. Accuracy, stability, linearity and resolution specifications assume a recent internal calibration at the operating temperature. All specifications are valid only for positive values of capacitance and loss.

Range:*

Parallel: *C:* $-0.0016/D\mu F$ to $+10/(f+D/0.0019)$ µF
for $3\times10^5 \geq D \geq 0.01$
-0.15 µF to the lesser of +1.5 µF
or $+10/(f+D/0.0019)$ µF for $-0.001 \leq D < 0.01$
-0.15 µF to $+0.0016/|D|$ µF for $-0.1 \leq D < -0.001$
$-0.019/|D|$ µF to $+0.0016/|D|$ µF for $-3\times10^5 \leq D < -0.1$
The capacitance range is also graphed in Figure 1.
G: See Table 1.

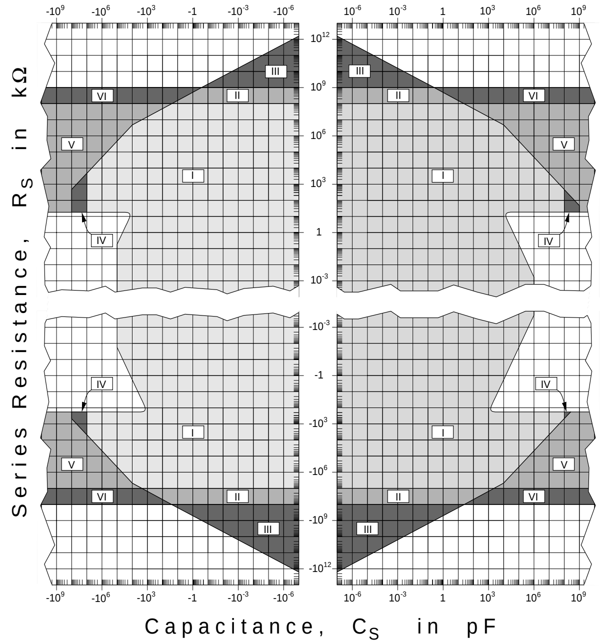


Figure 2. The values of C_S and R_S are measurable in the six shaded regions. In five of these regions, one or both of the measured values are too large to report on the AH2700A's display. In three of these five regions, one or both values are also too large to send to any remote devices. The table below shows what can be reported in each region. A "Display" entry means that the result can be shown on the instrument's display. A "Remotes" entry means that the result can be reported to an IEEE-1174 or IEEE-488 device.

	C_S	R_S
I	Display & Remotes	Display & Remotes
II	Display & Remotes	Remotes only
III	Display & Remotes	Neither
IV	Remotes only	Display & Remotes
V	Neither	Display & Remotes
VI	Neither	Remotes only

*Regions V and VI extend to infinity to the right and left because the resistance associated with an infinite C_S is measurable even though C_S itself is not reportable.

D: See Figure 1 and the equations for C above.
R_P: -8×10^{-5} GΩ to -1.7×10^6 GΩ
and $+8\times10^{-6}$ GΩ to $+1.7\times10^6$ GΩ @ 1 kHz
Series: *C_S:* See Figure 2 for the range at 1kHz.
R_S: See Figure 2 for the range at 1kHz.

*The ranges of all measurable variables except R_P cover a region defined by negative numbers for the lower limit and positive numbers for the upper limit. This is due to the AH2700A's ability to measure both positive and negative values of capacitance and loss. Other instruments typically measure only positive values and have ranges which cover a region defined by small positive numbers for the lower limits to large positive numbers for the upper limits. For the AH2700A, the small numbers corresponding to the lower limits of other instruments are given by the AH2700A's resolution specifications in absolute units.

Front Panel Display Limitations:

(The front panel display may further limit the range and resolution of the capacitance and loss.)

Capacitance: 0.1 aF is best display resolution for C and C_S.
Loss: *G:* 10^{-7} nS is best conductance display resolution.
D: 10^{-7} is best dissipation display resolution.
R_S: 10^{-7} kΩ is best series resistance display resolution.
R_P: 10^{-7} GΩ is best parallel resistance display resolution.

Remote Device Reporting Limitations:

Capacitance: 0.01 aF is best resolution for C and C_S.
Loss: *G:* 10^{-8} nS is best conductance resolution.
D: 10^{-8} is best dissipation resolution.
R_S: 10^{-7} kΩ is best series resistance resolution.
R_P: 10^{-8} GΩ is best parallel resistance resolution.

Frequencies: 50, 60, 80, 100, 120, 160, 200, 240, 320, 400, 500, 600, 800 Hz and 1.0, 1.2, 1.6, 2.0, 2.4, 3.2, 4.0, 5.0, 6.0, 8.0, 10, 12, 16 and 20 kHz ± 0.005%.

Sensitivity to changes in power line voltage:

Capacitance: ± 0.002 ppm per 1% change in line voltage.
Loss: Not measurable.

DC Bias: Up to ±100 volts may be applied to the unknown through the external DC bias input.

AC Test Signal Voltages: Any voltage from 0.030 to 15 V may be entered to a resolution of 0.1%. The available ranges for a given entered voltage are on the line in Table 1 having the next highest voltage. The AH2700A will automatically use the lesser of the user's selected voltage or the highest voltage listed in the table which provides sufficient range to be able to measure the capacitance and loss of the unknown. The voltages listed have tolerances of ±5%.

Operating temperature range: 0° to 45°C

Storage temperature range: -40° to +75°C

Humidity: 0 to 85% relative humidity, non-condensing

Power requirements: 25 watts, 48 to 440 Hz, 85 to 115, 102 to 138, 187 to 253 and 204 to 276 volts rms

Packaging: The instrument is 3.5 inches (8.9 cm) high and 15 inches (38.1 cm) deep behind the front panel. Hardware for rack mounting and a bail for bench top use are provided.

Weight: 18 pounds (8.2 kg)

Safety and EMC conformity: conforms to EN61326:1998 and EN 61010-1: 1993/A2: 1995

Patents: The AH2700A is protected by U.S. Patent No. 4,772,844 and 6,204,673

Warranty: The AH2700A is covered by a three year warranty. Forward and return shipping is covered during the first three months of the warranty.

Note: Specifications are subject to change without notice.

Table 1. Capacitance and conductance ranges for the preferred limiting voltages with $f \geq 1$ kHz. For $f < 1$ kHz, multiply Limit by f in kHz. A_T and A_C are used by the specification equations.

Limit	Capacitance range	Range of G; f is in kHz	A_T	A_C
15.00 V	-11 to +110 pF	$-0.8f$ to $+8f$ nS	0	0
7.50 V	-22 to +220 pF	$-1.6f$ to $+16f$ nS	0	0
3.00 V	-55 to +550 pF	$-4f$ to $+40f$ nS	0	0
1.50 V	-110 to +1100 pF	$-8f$ to $+80f$ nS	0	0
0.750 V	-220 to +2200 pF	$-16f$ to $+160f$ nS	0	0
0.250 V	-660 to +6600 pF	$-48f$ to $+480f$ nS	0	0
0.100 V	-1650 to +16,500 pF	$-120f$ to $+1200f$ nS	5	0.01
0.030 V	-5500 to +55,000 pF	$-400f$ to $+4000f$ nS	10	0.03
0.010 V	-16,500 to +165,000 pF	$-1200f$ to $+12{,}000f$ nS	15	0.1
0.003 V	-55,000 to +550,000 pF	$-4000f$ to $+40{,}000f$ nS	20	0.3
0.001 V	-165,000 to +1650,000 pF	$-12{,}000f$ to $+120{,}000f$ nS	30	1

Resolution in absolute units:*

Parallel:

$$C:\ \left\{\frac{C}{20}\left[2+\frac{1}{f}\right]+\frac{1.5}{V}\left[4+\frac{1}{f}+5n_c\right]+\frac{n_vC}{V}+\frac{50G}{\omega}+(1+10A_C)\frac{f^2C}{500}\left[1+\frac{1700}{200+CV}\right]\right\}\times 10^{-6}\ \text{pF}$$

$$G:\ \left\{50G+\omega\left[\frac{C}{20}\left(2+\frac{1}{f}\right)+\frac{1.5}{V}\left(4+\frac{1}{f}+5n_c\right)+\frac{n_vC}{V}+8\times10^{-6}fC^2+(3+50A_C)\frac{fC}{50}\left(1+\frac{1700}{200+CV}\right)\right]\right\}\times 10^{-6}\ \text{nS}$$

Divide result by ω to get absolute resolution for G/ω

$$D:\ \left\{(1+D^2)^{1/2}\left[50D+\frac{1}{20}\left(2+\frac{1}{f}\right)+\frac{1.5}{CV}\left(4+\frac{1}{f}+5n_c\right)+\frac{n_v}{V}+8\times10^{-6}fC+(3+50A_C)\frac{f}{50}\left(1+\frac{1700}{200+CV}\right)\right]\right\}\times 10^{-6}$$

$$R_P:\ \left\{50R_p+\omega R_p^2\left[\frac{C}{20}\left(2+\frac{1}{f}\right)+\frac{1.5}{V}\left(4+\frac{1}{f}+5n_c\right)+\frac{n_vC}{V}+8\times10^{-6}fC^2+(3+50A_C)\frac{fC}{50}\left(1+\frac{1700}{200+CV}\right)\right]\right\}\times 10^{-6}\ \text{G}\Omega$$

Series:

$$C_S:\ \left\{\frac{C_s}{20}\left[2+\frac{1}{f}\right]+\frac{1.5}{V}\left[4+\frac{1}{f}+5n_c\right](1+D^2)+\frac{n_vC_s}{V}+50DC_s+(1+10A_C)\frac{f^2C_s}{500}\left[1+\frac{1700}{200+CV}\right]\right\}\times 10^{-6}\ \text{pF}$$

$$R_S:\ \left\{50R_s+1.3+\frac{R_s}{D}\left[\frac{1}{20}\left(2+\frac{1}{f}\right)+\frac{1.5}{C_sV}\left(4+\frac{1}{f}+5n_c\right)(1+D^2)+\frac{n_v}{V}+(3+50A_C)\frac{f}{50}\left(1+\frac{1700}{200+CV}\right)\right]\right\}\times 10^{-6}\ \text{k}\Omega$$

where $n_c = 1.4t^{-1/2}$ and $n_v = 0.01(1+0.1/f)(R_S+10)^{1/2}(1+D^2)^{1/2}t^{-1/2}$. A_C is found in Table 1.
The series resistance R_S needed for n_v may be calculated using $R_S= D\times10^6/(\omega C(1+D^2))$.

Resolution in ppm:*

Parallel:

$$C:\ \frac{1}{20}\left[2+\frac{1}{f}\right]+\frac{1.5}{CV}\left[4+\frac{1}{f}+5n_c\right]+\frac{n_v}{V}+50D+(1+10A_C)\frac{f^2}{500}\left[1+\frac{1700}{200+CV}\right]$$

$$G:\ 50+\frac{\omega}{G}\left\{\frac{C}{20}\left[2+\frac{1}{f}\right]+\frac{1.5}{V}\left[4+\frac{1}{f}+5n_c\right]+\frac{n_vC}{V}+8\times10^{-6}fC^2+(3+50A_C)\frac{fC}{50}\left[1+\frac{1700}{200+CV}\right]\right\}$$

$$D:\ \frac{(1+D^2)^{1/2}}{D}\left\{50D+\frac{1}{20}\left[2+\frac{1}{f}\right]+\frac{1.5}{CV}\left[4+\frac{1}{f}+5n_c\right]+\frac{n_v}{V}+8\times10^{-6}fC+(3+50A_C)\frac{f}{50}\left[1+\frac{1700}{200+CV}\right]\right\}$$

$$R_P:\ 50+\omega R_p\left\{\frac{C}{20}\left[2+\frac{1}{f}\right]+\frac{1.5}{V}\left[4+\frac{1}{f}+5n_c\right]+\frac{n_vC}{V}+8\times10^{-6}fC^2+(3+50A_C)\frac{fC}{50}\left[1+\frac{1700}{200+CV}\right]\right\}$$

Series:

$$C_S:\ \frac{1}{20}\left[2+\frac{1}{f}\right]+\frac{1.5}{C_sV}\left[4+\frac{1}{f}+5n_c\right](1+D^2)+\frac{n_v}{V}+50D+(1+10A_C)\frac{f^2}{500}\left[1+\frac{1700}{200+CV}\right]$$

$$R_S:\ 50+\frac{1.3}{R_s}+\frac{1}{D}\left\{\frac{1}{20}\left[2+\frac{1}{f}\right]+\frac{1.5}{C_sV}\left[4+\frac{1}{f}+5n_c\right](1+D^2)+\frac{n_v}{V}+(3+50A_C)\frac{f}{50}\left[1+\frac{1700}{200+CV}\right]\right\}$$

*Resolution is the smallest *repeatable* difference in readings that is *guaranteed* to be measurable at *every* capacitance or loss value. Useful resolution is typically a factor of ten better. A_C is found in Table 1.

Non-linearity in ppm:

Parallel:

$$C:\ \pm\left\{\frac{1}{20}\left[2+\frac{1}{f}\right]+\frac{1.5}{CV}\left[4+\frac{1}{f}\right]+50D+\frac{f^2}{200}\left[1+\frac{1700}{200+CV}\right]+\{1.5\times10^{-6}f^{2.5}C\}\right\}$$

$$G:\ \pm\left\{50+\frac{\omega}{G}\left[\frac{C}{20}\left(2+\frac{1}{f}\right)+\frac{1.5}{V}\left(4+\frac{1}{f}\right)+8\times10^{-6}fC^2+\frac{fC}{6}\left(1+\frac{1700}{200+CV}\right)\right]+\left\{\frac{1.2\times10^{-4}\omega fC^2}{G}\right\}\right\}$$

$$D:\ \pm\left\{\frac{(1+D^2)^{1/2}}{D}\left[50D+\frac{1}{20}\left(2+\frac{1}{f}\right)+\frac{1.5}{CV}\left(4+\frac{1}{f}\right)+8\times10^{-6}fC+\frac{f}{6}\left(1+\frac{1700}{200+CV}\right)\right]+\left\{\frac{(1+D^2)^{1/2}}{D}[1.2\times10^{-4}fC]\right\}\right\}$$

$$R_P:\ \pm\left\{50+\omega R_p\left[\frac{C}{20}\left(2+\frac{1}{f}\right)+\frac{1.5}{V}\left(4+\frac{1}{f}\right)+8\times10^{-6}fC^2+\frac{fC}{6}\left(1+\frac{1700}{200+CV}\right)\right]+\{1.2\times10^{-4}\omega fR_pC^2\}\right\}$$

Series:

$$C_S:\ \pm\left\{\frac{1}{20}\left[2+\frac{1}{f}\right]+\frac{1.5}{C_sV}\left[4+\frac{1}{f}\right](1+D^2)+50D+\frac{f^2}{200}\left[1+\frac{1700}{200+CV}\right]+\{1.5\times10^{-6}f^{2.5}C\}\right\}$$

$$R_S:\ \pm\left\{50+\frac{1.3}{R_s}+\frac{1}{D}\left[\frac{1}{20}\left(2+\frac{1}{f}\right)+\frac{1.5}{C_sV}\left(4+\frac{1}{f}\right)(1+D^2)+\frac{f}{6}\left(1+\frac{1700}{200+CV}\right)\right]+\left\{\frac{20}{R_s}\right\}\right\}$$

Non-linearity is the deviation from a best fit straight line through a plot of the measured quantity versus the actual quantity. The test signal voltage is assumed to be constant.

Accuracy in ppm following calibration:

Parallel:

$$C:\ \pm\left\{\frac{1}{2}\left[8+\frac{1}{f}+f\right]+\frac{1.5}{CV}\left[4+\frac{1}{f}\right]+200D+\frac{f^2}{100}\left[1+\frac{1700}{200+CV}\right]+A_T\left[f+\frac{1}{f}\right]+\left\{3\times10^{-6}f^{2.5}C+\frac{f^2}{4C}\right\}\right\}$$

A_T is found in Table 1.

$$G:\ \pm\left\{200+\frac{\omega}{G}\left[\frac{C}{2}\left(2+\frac{1}{f}+f\right)+\frac{1.5}{V}\left(4+\frac{1}{f}\right)+\frac{fC^2}{3300}+\frac{fC}{3}\left(1+\frac{1700}{200+CV}\right)+A_TC\left(f+\frac{1}{f}\right)\right]+\left\{\frac{\omega f}{G}\left[2\times10^{-4}C^2+\frac{f}{4}\right]\right\}\right\}$$

$$D:\ \pm\left\{\frac{(1+D^2)^{1/2}}{D}\left[200D+\frac{1}{2}\left(2+\frac{1}{f}+f\right)+\frac{1.5}{CV}\left(4+\frac{1}{f}\right)+\frac{fC}{3300}+\frac{f}{3}\left(1+\frac{1700}{200+CV}\right)+A_T\left(f+\frac{1}{f}\right)\right]+\left\{\frac{(1+D^2)^{1/2}f}{D}\left[2\times10^{-4}C+\frac{f}{4C}\right]\right\}\right\}$$

$$R_P:\ \pm\left\{200+\omega R_p\left[\frac{C}{2}\left(2+\frac{1}{f}+f\right)+\frac{1.5}{V}\left(4+\frac{1}{f}\right)+\frac{fC^2}{3300}+\frac{fC}{3}\left(1+\frac{1700}{200+CV}\right)+A_TC\left(f+\frac{1}{f}\right)\right]+\left\{\omega R_pf\left[2\times10^{-4}C^2+\frac{f}{4}\right]\right\}\right\}$$

Series:

$$C_S:\ \pm\left\{\frac{1}{2}\left[8+\frac{1}{f}+f\right]+\frac{1.5}{C_sV}\left[4+\frac{1}{f}\right](1+D^2)+200D+\frac{f^2}{100}\left[1+\frac{1700}{200+CV}\right]+A_T\left[f+\frac{1}{f}\right]+\left\{3\times10^{-6}f^{2.5}C+\frac{f^2(1+D^2)}{4C_s}\right\}\right\}$$

$$R_S:\ \pm\left\{200+\frac{50}{R_s}+\frac{1}{D}\left[\frac{1}{2}\left(2+\frac{1}{f}+f\right)+\frac{1.5}{C_sV}\left(4+\frac{1}{f}\right)(1+D^2)+\frac{f}{3}\left(1+\frac{1700}{200+CV}\right)+A_T\left(f+\frac{1}{f}\right)\right]+\left\{\frac{30}{R_s}+\frac{f^2(1+D^2)}{4DC_s}\right\}\right\}$$

The length of the cables connecting the 2700A to the unknown has a negligible effect on the accuracy for *small* capacitances. This assumes that the coaxial shield on these cables has 100% coverage. If uncorrected by the CABLE command, cables similar to RG-58 will increase the capacitance readings at 1kHz by about 40 ppm per meter of cable pair and per µF of capacitance being measured.

The accuracy Y years following calibration may be calculated from the expression A + YS where A is the desired accuracy expression from above and S is the corresponding stability per year below.

Stability in ppm per year:

Parallel:

$$C:\ \pm\left\{\frac{1}{10}\left[8+\frac{1}{f}+f\right]+\frac{1}{2CV}\left[4+\frac{1}{f}\right]+30D+\left\{10^{-6}f^{2.5}C+\frac{f^2}{20C}\right\}\right\}$$

$$G:\ \pm\left\{30+\frac{\omega}{G}\left[\frac{C}{10}\left(2+\frac{1}{f}+f\right)+\frac{1}{2V}\left(4+\frac{1}{f}\right)+5\times10^{-5}fC^2\right]+\left\{\frac{\omega f}{G}\left[3\times10^{-5}C^2+\frac{f}{20}\right]\right\}\right\}$$

$$D:\ \pm\left\{\frac{(1+D^2)^{1/2}}{D}\left[30D+\frac{1}{10}\left(2+\frac{1}{f}+f\right)+\frac{1}{2CV}\left(4+\frac{1}{f}\right)+5\times10^{-5}fC\right]+\left\{\frac{(1+D^2)^{1/2}f}{D}\left[3\times10^{-5}C+\frac{f}{20C}\right]\right\}\right\}$$

$$R_P:\ \pm\left\{30+\omega R_p\left[\frac{C}{10}\left(2+\frac{1}{f}+f\right)+\frac{1}{2V}\left(4+\frac{1}{f}\right)+5\times10^{-5}fC^2\right]+\left\{\omega R_pf\left[3\times10^{-5}C^2+\frac{f}{20}\right]\right\}\right\}$$

Series:

$$C_S:\ \pm\left\{\frac{1}{10}\left[8+\frac{1}{f}+f\right]+\frac{1}{2C_sV}\left[4+\frac{1}{f}\right](1+D^2)+30D+\left\{10^{-6}f^{2.5}C+\frac{f^2(1+D^2)}{20C_s}\right\}\right\}$$

$$R_S:\ \pm\left\{30+\frac{8}{R_s}+\frac{1}{D}\left[\frac{1}{10}\left(2+\frac{1}{f}+f\right)+\frac{1}{2C_sV}\left(4+\frac{1}{f}\right)(1+D^2)\right]+\left\{\frac{5}{R_s}+\frac{f^2(1+D^2)}{20DC_s}\right\}\right\}$$

Temperature coefficient relative to change in ambient temperature in ppm per °C:

Parallel:

$$C:\ \pm\left\{\frac{1}{400}\left[8+\frac{1}{f}+f\right]+20D+\frac{A_T}{33}\left[f+\frac{1}{f}\right]+\frac{200}{2+6CV(2+1/f)}+\left\{10^{-7}f^{2.5}C+\frac{f^2}{100C}\right\}\right\}$$

$$G:\ \pm\left\{20+\frac{\omega C}{G}\left[\frac{3}{400}\left(2+\frac{1}{f}+f\right)+3\times10^{-6}fC+\frac{A_T}{33}\left(f+\frac{1}{f}\right)\right]+\frac{400}{4+VG(2+1/f)/\omega}+\left\{\frac{\omega f}{G}\left[2\times10^{-6}C^2+\frac{f}{100}\right]\right\}\right\}$$

$$D:\ \pm\left\{\frac{(1+D^2)^{1/2}}{D}\left[20D+\frac{3}{400}\left(2+\frac{1}{f}+f\right)+3\times10^{-6}fC+\frac{A_T}{33}\left(f+\frac{1}{f}\right)\right]+\frac{200}{2+6CV(2+1/f)}+\frac{400}{4+CVD(2+1/f)}+\left\{\frac{(1+D^2)^{1/2}f}{D}\left[2\times10^{-6}C+\frac{f}{100C}\right]\right\}\right\}$$

$$R_P:\ \pm\left\{20+\omega CR_p\left[\frac{3}{400}\left(2+\frac{1}{f}+f\right)+3\times10^{-6}fC+\frac{A_T}{33}\left(f+\frac{1}{f}\right)\right]+\frac{400}{4+V(2+1/f)/\omega R_p}+\left\{\omega R_pf\left[2\times10^{-6}C^2+\frac{f}{100}\right]\right\}\right\}$$

Series:

$$C_S:\ \pm\left\{\frac{1}{400}\left[8+\frac{1}{f}+f\right]+20D+\frac{A_T}{33}\left[f+\frac{1}{f}\right]+\frac{200}{2+6C_sV(2+1/f)/(1+D^2)}+\left\{10^{-7}f^{2.5}C+\frac{f^2(1+D^2)}{100C_s}\right\}\right\}$$

$$R_S:\ \pm\left\{20+\frac{0.5}{R_s}+\frac{1}{D}\left[\frac{3}{400}\left(2+\frac{1}{f}+f\right)+\frac{A_T}{33}\left(f+\frac{1}{f}\right)\right]+\frac{400}{4+C_sVD(2+1/f)/(1+D^2)}+\left\{\frac{0.3}{R_s}+\frac{f^2(1+D^2)}{100DC_s}\right\}\right\}$$

where A_T is found in Table 1.

SELECTED SPECIFICATIONS IN GRAPHICAL FORM

Specifications versus frequency:

The ten graphs on this and the following two pages are plots versus frequency of the accuracy, resolution in ppm, non-linearity, stability and temperature coefficient specifications. These plots were generated by using the specification equations presented on the previous two pages. Each graph contains a set of curves for various values of capacitance. These capacitance values range from one femtofarad up to one microfarad. It is easy to see that the specifications tend to be best for capacitance values in the region of 10 pF to 1 nF and worst at either extreme of capacitance. The five graphs of capacitance specifications at the left side of each page apply for small values of dissipation factor (D<~0.001). Each curve was plotted using the maximum possible voltage.

Accuracy specifications versus C and loss:

The three graphs on the last page in the left column are contour plots of of the accuracy of capacitance(C) versus C and conductance(G). The graph at the top applies at 100 Hz, the middle one at 1 kHz and the bottom one at 10 kHz. The accuracy in the area within or below each contour is equal to or better than the labeled accuracy (in percent) for that contour. These graphs show that the accuracy of C depends not only on the value of C but also on the value of the loss. Each contour was plotted using the maximum possible voltage.

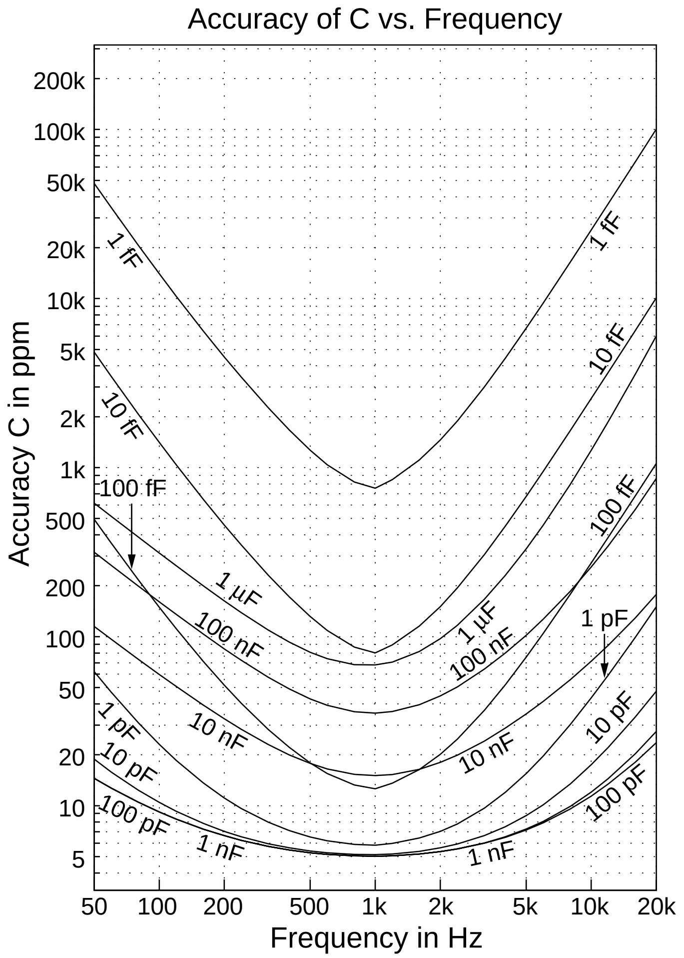
The graph at the top of the right column on the last page is a contour plot of the accuracy of the dissipation factor(D) versus C and D. The accuracy in the area within each contour is equal to or better than the labeled accuracy (in percent) for that contour. This graph shows that the accuracy of D depends not only on the value of D but also on the value of C.

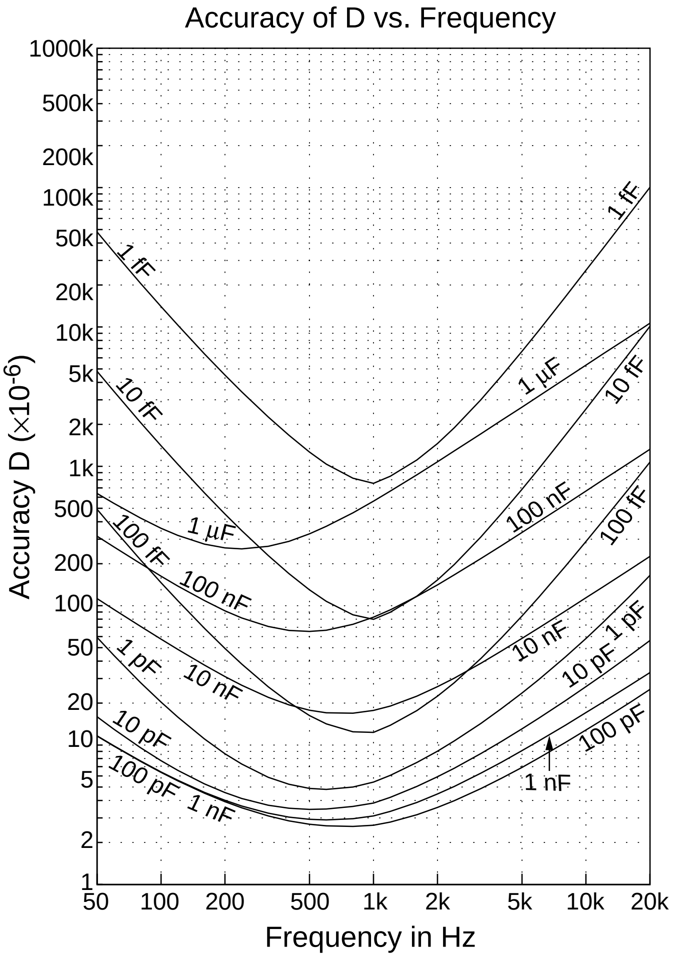
Accuracy specifications at various voltages:

The middle graph in the right column on the last page is a contour plot of the accuracy of C versus C and G. The accuracy in the area within or below each contour is equal to or better than 0.001%.

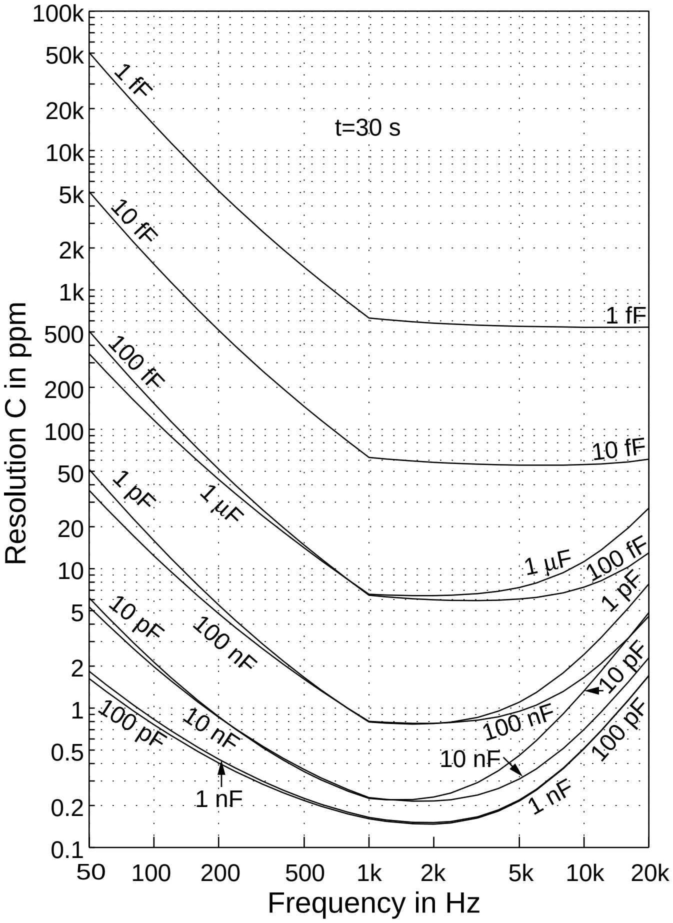
The bottom graph in the right column on the last page is a contour plot of of the accuracy of D versus C and D. The accuracy in the area within each contour is equal to or better than 0.03%.

These graphs show how the accuracy of C and D depends on the measurement voltage. Each contour represents operation at the labled voltage which is one of the voltages in Table 1 on page 6.

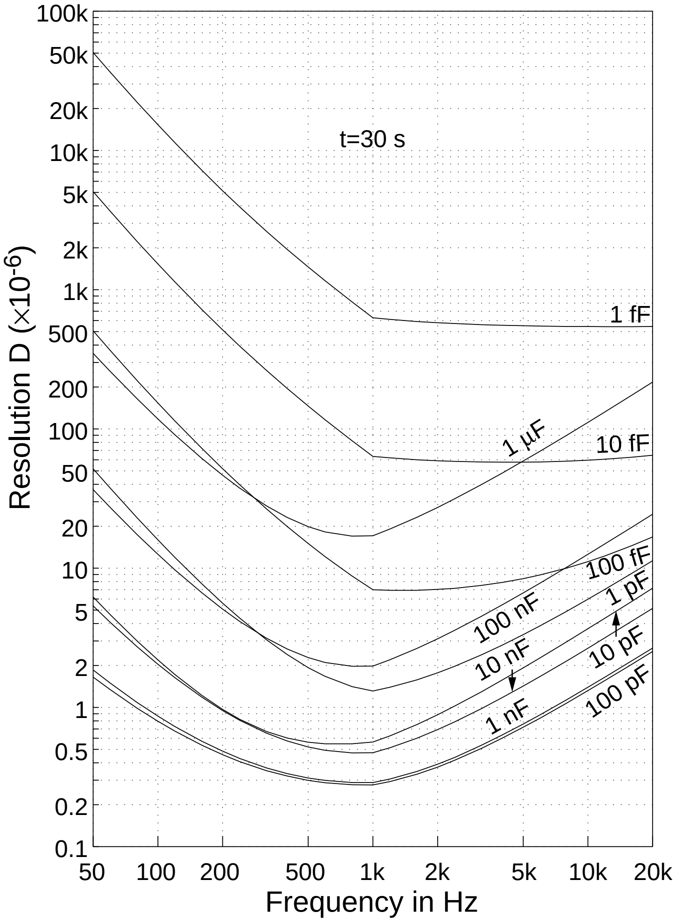




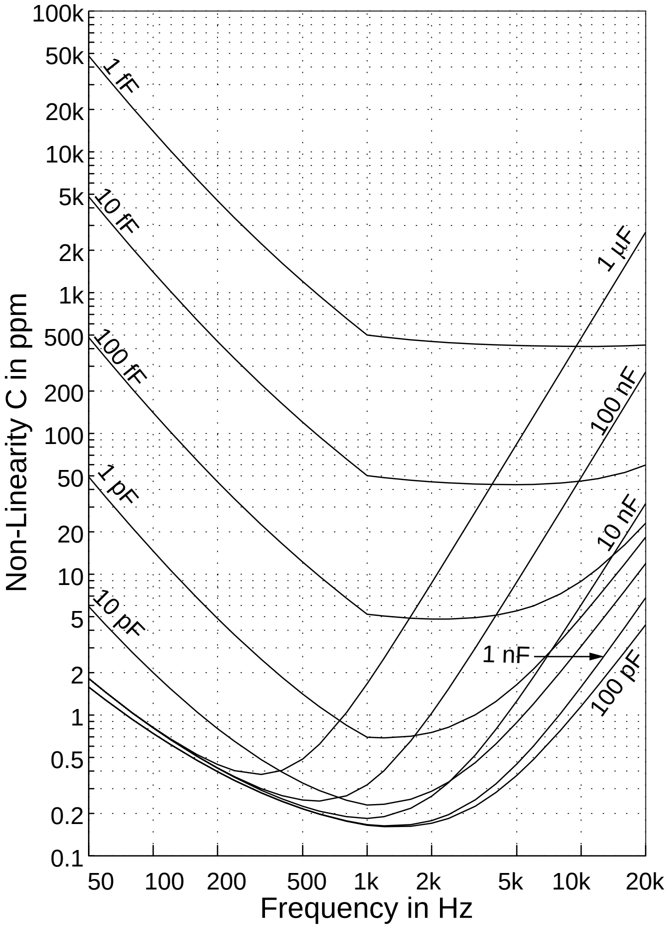
Resolution of C vs. Frequency



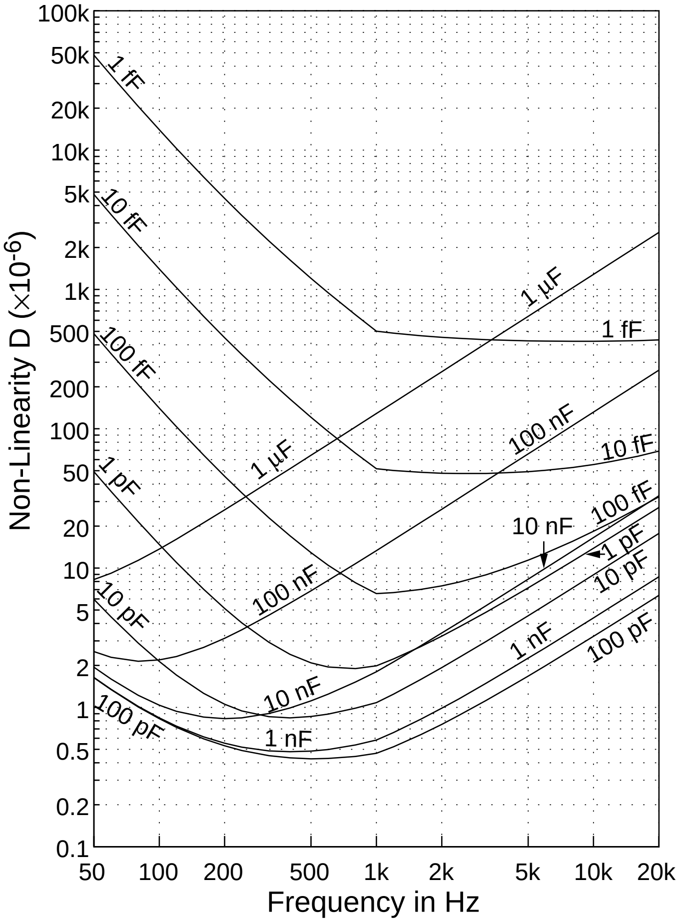
Resolution of D vs. Frequency



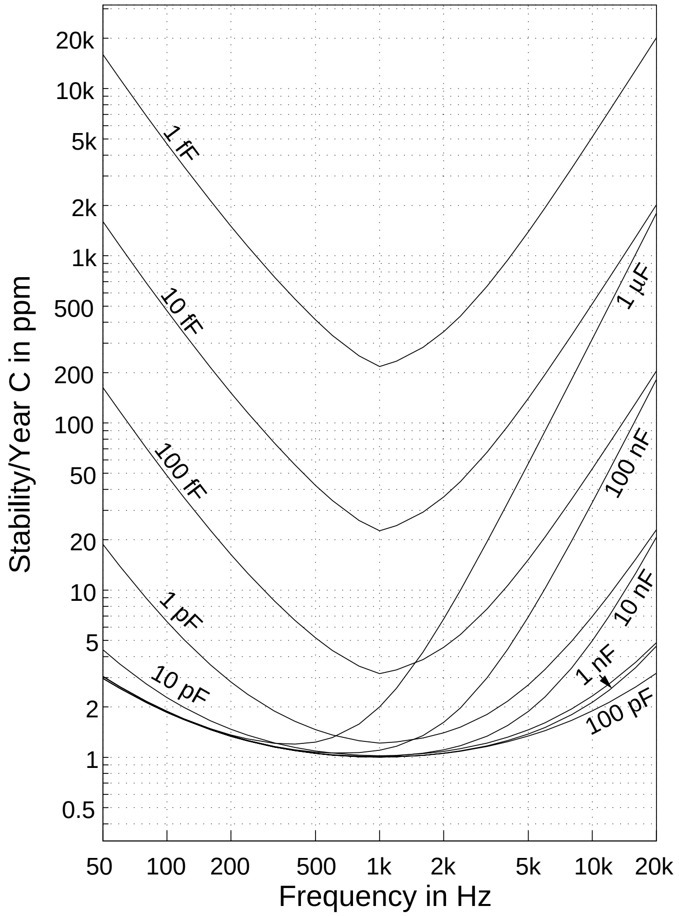
Non-Linearity of C vs. Frequency



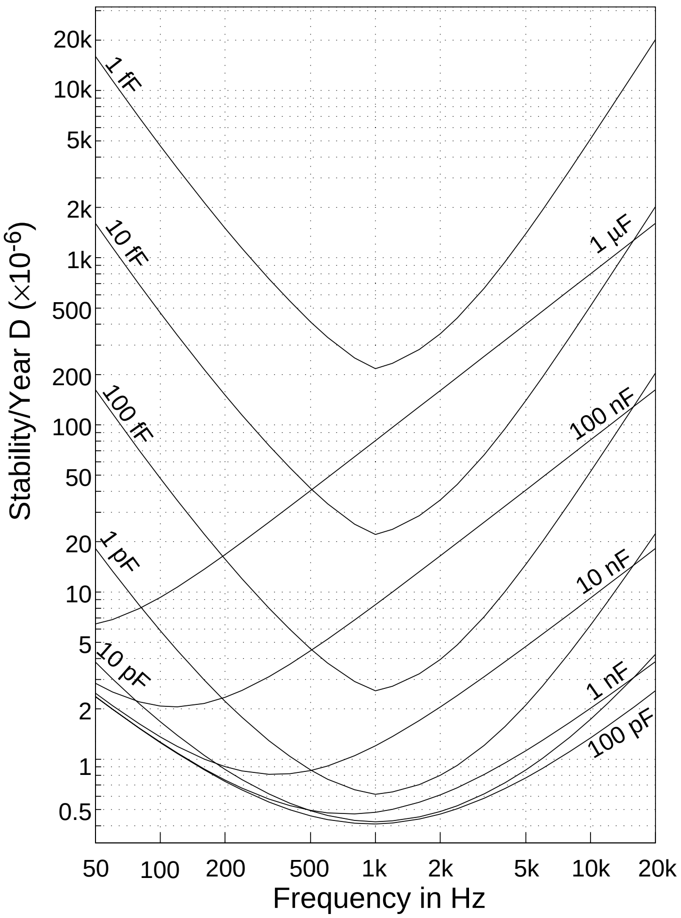
Non-Linearity of D vs. Frequency



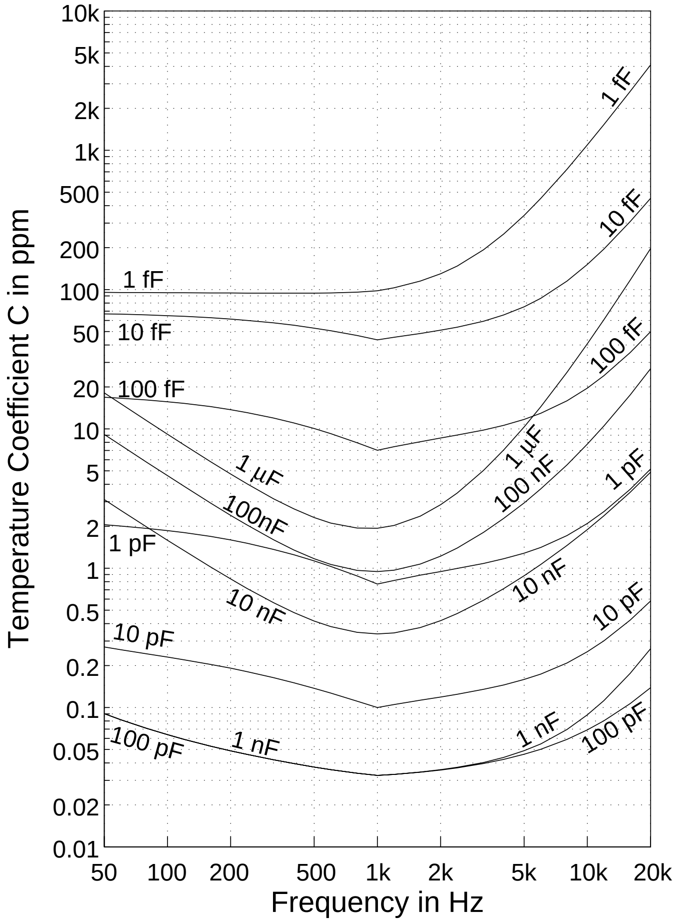
Stability/Year of C vs. Frequency



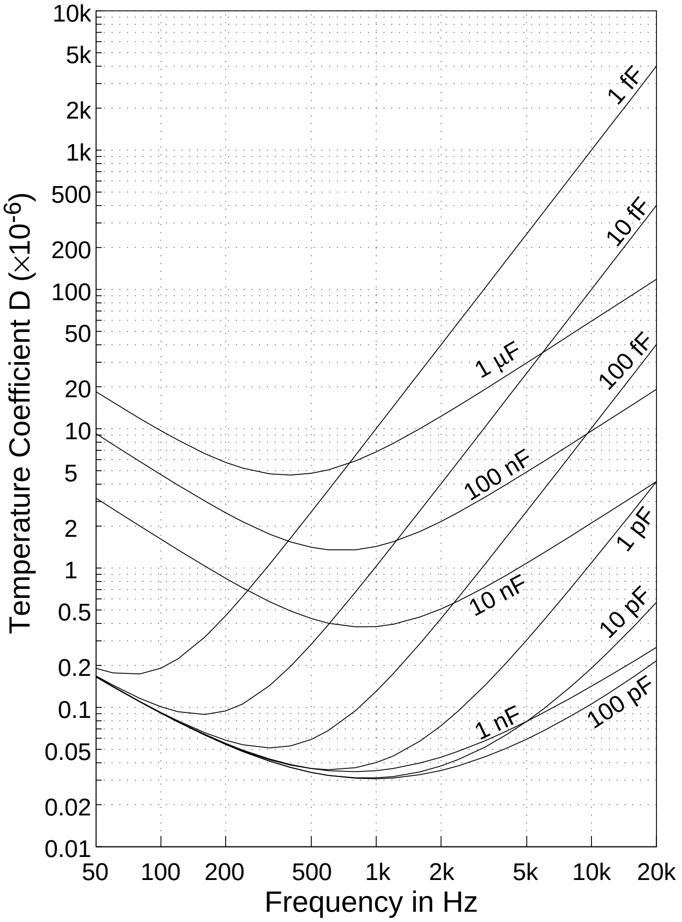
Stability/Year of D vs. Frequency

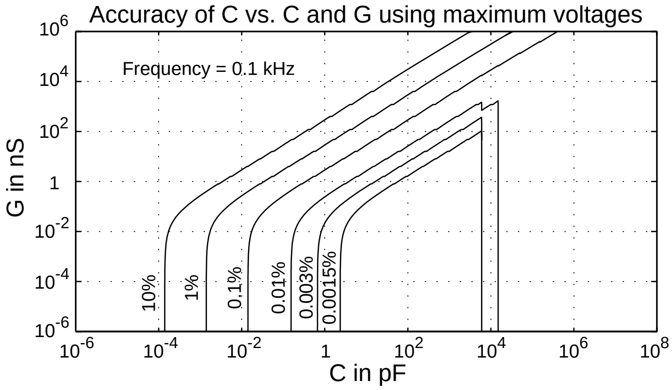


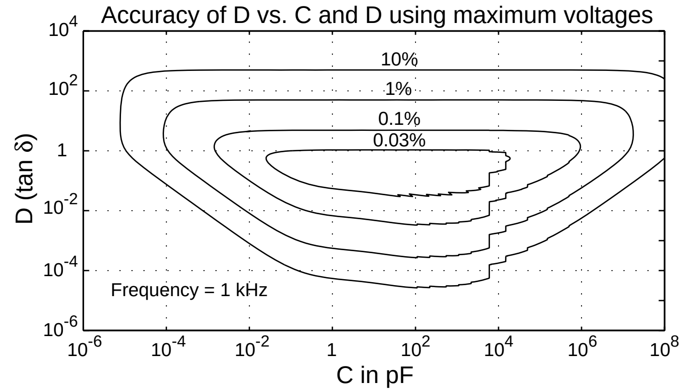
Temperature Coefficient of C vs. Frequency

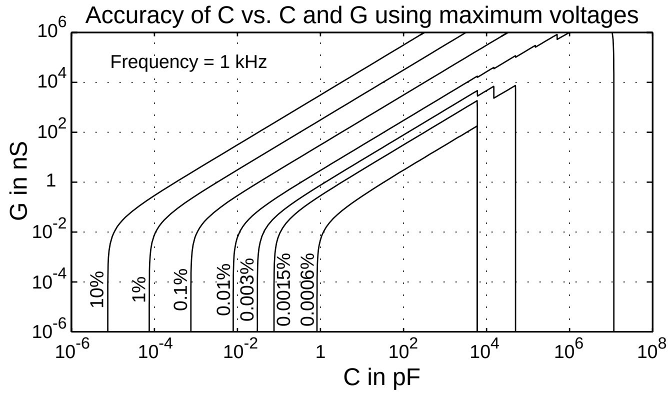


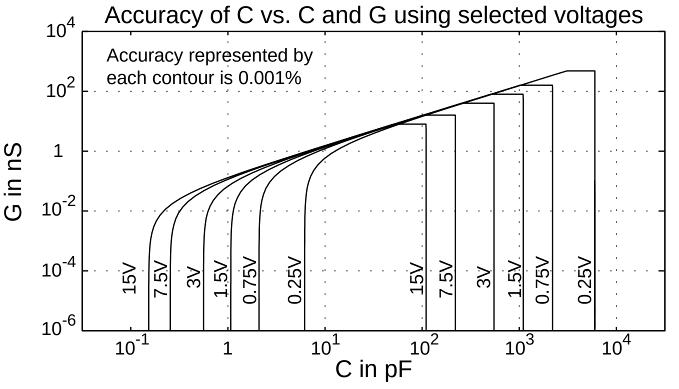
Temperature Coefficient of D vs. Frequency

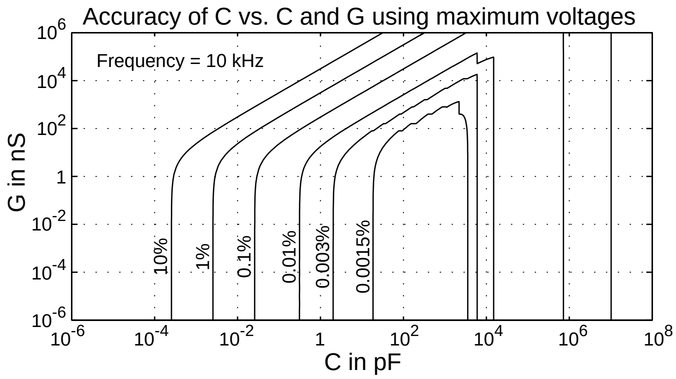


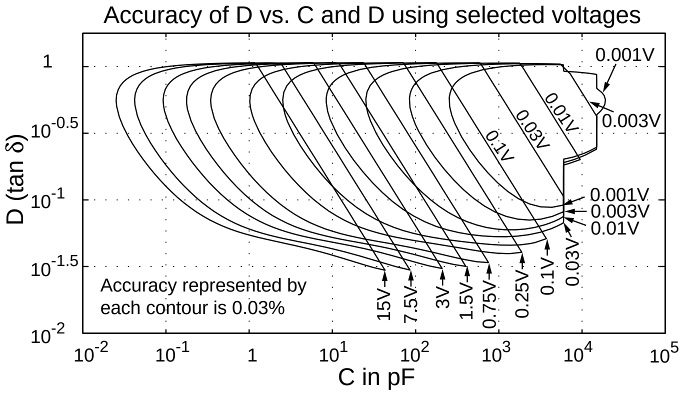

Accuracy of C vs. C and G using maximum voltages


Accuracy of D vs. C and D using maximum voltages


Accuracy of C vs. C and G using maximum voltages


Accuracy of C vs. C and G using selected voltages


Accuracy of C vs. C and G using maximum voltages


Accuracy of D vs. C and D using selected voltages

Website: www.andeen-hagerling.com

Please look for a downloadable spreadsheet to make it easy to evaluate all of the specification equations.

Ordering Information: Part No.

Ultra-Precision 50 Hz-20 kHz Capacitance Bridge AH2700A

For questions regarding the AH2700A, possible applications, the location of your nearest sales representative, or ordering information:

Call: 440-349-0370 Fax: 440-349-0359 E-mail: info@andeen-hagerling.com

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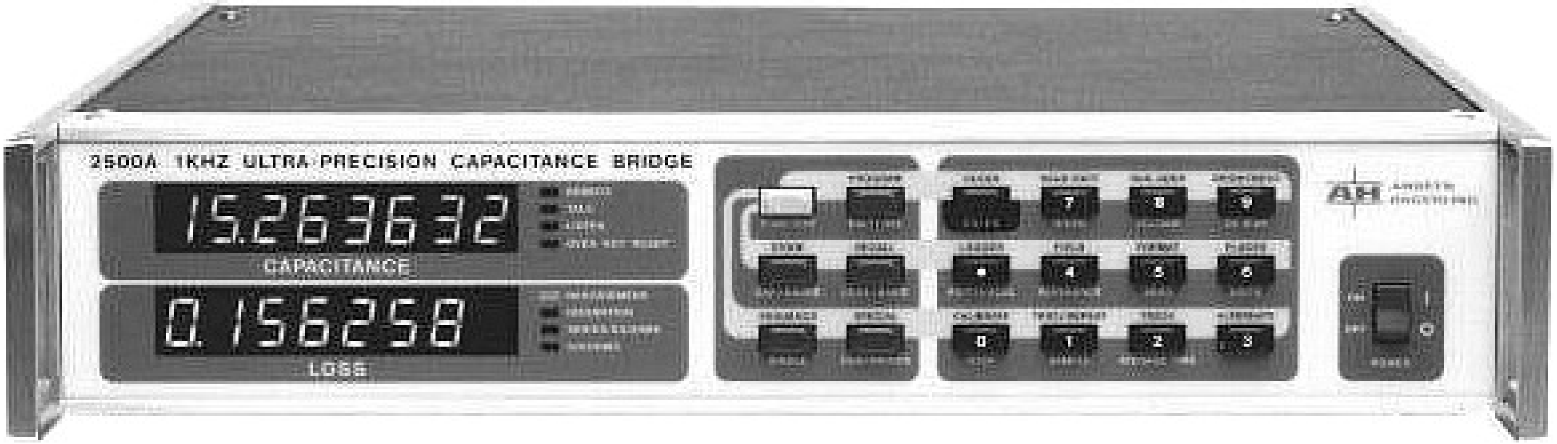
2001/9

ANDEEN-HAGERLING

AH 2500A

1 kHz Automatic

Capacitance Bridge



The World’s Most Accurate Capacitance/Loss[1] Bridge

The AH 2500A offers unparalleled stability, resolution and accuracy in a capacitance/loss[1] bridge (whether manual or automatic). Its numerous state of the art features make it an exceptionally user friendly instrument. The precision and ease of use of the 2500A are creating new applications in science, engineering and production in a range of industries.

Outstanding Features

- Accuracy of 5 ppm (or 3 ppm with Option E)
- Stability better than 1 ppm/year (or 0.5 ppm/year with Option E)
- Resolution of 0.5 attofarad (.000 0005 pF) and 0.15 ppm (or 0.5 aF and 0.07 ppm with Option E)
- Temperature Coefficient of 0.03 ppm/°C (0.01 ppm/°C with Option E)
- Measures extremely low loss down to a dissipation factor of 1.5×10^{-8} tan delta, a conductance of 3×10^{-7} nanosiemens or a resistance up to 1.7×10^{6} gigohms
- Full precision measurements in less than 0.5 second and repeated measurements on the same sample in less than 40 milliseconds
- Both capacitance and loss ranges cover negative values to allow for unusual samples or three terminal networks
- Three terminal BNC connections minimize connector costs and number of cables
- Commutation (test signal reversal) to minimize external power line or other periodic signal pickup

- Autoranging
- IEEE-488 and RS-232 interfaces included; external device can serve as controller or logger
- Programmable features can eliminate the need for an external controller
- Full or abbreviated English language commands and error messages
- Large, variable brightness, eight digit display of capacitance and loss
- Deviation measurements of capacitance, loss or both
- Zero correction of test fixture capacitance and loss
- External DC bias up to ±100 volts
- External trigger capability
- Automatic internal calibration
- NIST traceable calibration
- Self test diagnostics on power-up
- Three year warranty

[1] The term “loss” is used to refer to the component of the impedance which is 90° out of phase with respect to the capacitive component. The 2500A can report loss in units of conductance, dissipation factor, or series or parallel resistance.

BACKGROUND

Andeen-Hagerling, Inc. traces its beginning to 1966 when Carl Andeen began working on his Ph.D. research in physics at Case Western Reserve University in Cleveland. This research required measuring small changes in dielectric properties of crystals. To do this properly required the use of a precision ratio-transformer based capacitance bridge. The best bridge available at the time (and the only precision manual capacitance bridge still offered for sale) was chosen for the job.

Unfortunately, this bridge had neither the stability nor the resolution to measure the small changes required. As a result, Andeen modified this bridge to give it much better temperature stability and to increase its resolution by more than two orders of magnitude.

During this time, Andeen taught a course where he met Carl Hagerling, a student in his class. They appreciated each other’s technical abilities and quickly struck up a close friendship.

Driven by the needs of his colleagues for better capacitance bridge technology for their research, Andeen continued throughout the 1970’s to hone his expertise in this area by building numerous prototype bridges. By 1980, he was building a prototype of a fully automated, high performance, ratio-transformer based capacitance bridge. It was apparent that there would be a demand for a production version of such a bridge and that Andeen would need help meeting that demand.

Fortunately, in this same year, Hagerling graduated with his Ph.D. in physics. He and Andeen soon committed to form a company to manufacture a production version of Andeen’s high performance bridge.

Andeen-Hagerling, Inc. was incorporated in 1982. The company name is composed of the names of the founders to underscore what they knew from their past experience would be a long, stable and productive relationship.

Andeen-Hagerling is fortunate to be privately owned, and thus able to make and follow through with long-term development plans. The company's dedicated employees take pride in Andeen-Hagerling's exceptionally high standards and uncompromising view of quality, reliability, and customer satisfaction. The company is proud to be able to support its instruments which are in use in national standards laboratories and industrial, government, university and military facilities throughout the world.

Andeen-Hagerling is headquartered in the city of Solon, a suburb of Cleveland, Ohio, U.S.A.

BASIC DESIGN

The Model 2500A measures capacitance and loss in medium- and high-impedance ranges, and thus allows using three terminal rather than five terminal connections to the unknown. Its unmatched precision is the result of a uniquely designed ratio transformer which is the culmination of 15 years of custom bridge design and manufacture. Equally important is the unique temperature-controlled, fused silica capacitance standard which allows extremely high measurement stability and immunity to mechanical shock. These elements combine to form a true bridge operating at one kilohertz to give capacitance results which are independent of the exact test frequency.

MEASUREMENT FEATURES

Measurement Initiation

A single measurement is initiated by a front panel keystroke, an external trigger pulse, a single character from the RS-232 or IEEE-488 ports, or a Group Execute Trigger from the IEEE-488 bus. Measurements can be taken continuously with a selectable delay time between the end of one reading and the start of the next. This delay time can range from zero to many hours in 0.01 second increments.

Units

Capacitance units are picofarads. Loss units are selectable among nanosiemens, dissipation factor, series resistance in kilohms, parallel resistance in gigohms or magnitude of the loss vector in jpF — the choice being indicated by front panel LED's.

Display Results

Results are displayed on large, variable brightness front panel LED displays to as many as eight digits. Results are sent to remote devices with as many as nine digits.

Deviation Measurements

Results may be provided in the form of a difference or offset from a reference value for capacitance or loss or both. The loss may be expressed using any of the 2500A's loss units. The reference value can be the result of a previous measurement or a user-provided value.

Zero Correction

Stray capacitance and loss (typically associated with a test fixture) may occur in parallel with the capacitance and loss that is to be measured. The stray values can be obtained from the result of a previous measurement or from a user-provided value and used to correct the reported results. The stray loss is corrected for as if it is in parallel with the loss that is intended to be measured. This occurs no matter what loss units are being used. This is more involved than a deviation measurement which would just do a simple subtraction. (The 2500A itself has no significant zero offset.)

DC Bias

A connector is provided to which an external DC bias voltage may be applied. The 2500A can switch this voltage to the sample through user selectable resistors located within the instrument.

Test Voltage

The maximum test voltage applied to the sample is selectable from 0.5 mV to 15 V r.m.s. The actual voltage applied by the 2500A may be much smaller than the selected maximum.

Speed versus Resolution

Available resolution is determined primarily by the amount of time spent averaging out noise. The trade-off between resolution and measurement speed is selectable in factors of two from less than 40 milliseconds to 20 minutes.

Commutation

This selectable feature causes the test signal to be reversed periodically so as to improve rejection of external periodic signals, particularly those that are power-line related.

Tracking

In the case of changing or rapidly drifting samples, long averaging times have little meaning. Thus a tracking feature is provided which allows samples to be rapidly followed at a rate of about 25 measurements per second with reduced resolution. Tracking occurs automatically when this feature is enabled and the value of the sample is changing.

Bridge Balancing Time

Measurement time on a previously unmeasured sample is less than half a second. However, the measurements following the first can be made in less than 40 milliseconds if the averaging time is short.

Standards Oven

The oven (and hence the entire bridge) is normally stable within only 15 minutes after power-on. A blinking front panel LED indicates when the oven has not stabilized or when the ambient temperature is too extreme for stabilization.

Cable Length Correction

The three terminal connection method used by the 2500A usually makes the errors caused by the pair of cables that connect the instrument to the unknown capacitance so small that they can be ignored. However, cable inductance can affect the accuracy of capacitance measurements made at the high end of the 2500A's range. Similarly, cable resistance can affect the accuracy of loss measurements made at the high end of the 2500A's loss range. In these situations, the resistance and inductance per meter of cable pair and the length of the cable pair can be entered into the instrument. The 2500A will then automatically correct for these cable errors.

Measurement Errors

Measurement troubles are easily pinpointed by one of over a dozen English language error messages (or, optionally, error codes). Additionally, many other command and status messages are reported.

Calibration

A unique calibration technique allows internal precision components to be compared against internal temperature-controlled standards with the appropriate corrections being made by a microprocessor. The 2500A also provides for calibration against external standards. To prevent unauthorized calibrations, a passcode (which only the manager of the instrument can change) must be entered before any calibration can be performed.

Self Tests

Power-on or user initiated self tests check the microprocessor area, transformer ratio-arm switches, D/A switches and A/D converter. Special circuitry allows numerous internal self-consistency checks.

SYSTEM INTERFACES

RS-232

An RS-232 standard serial interface is included with each instrument to allow simple connections to a computer, modem, printing terminal or video terminal. These devices can take control of the instrument interactively or can merely log the measured data passively.

IEEE-488

An IEEE-488 (1978) standard interface is included with each instrument to allow connection to an instrument bus. A full IEEE-488 implementation is provided including serial poll and selectable extended talker/listener addressing. The 2500A can be run with a bus controller or can operate in “talk only” mode to send data to a passive printer or data logger. Front panel “remote”, “talk”, and “listen” indicators are provided.

Setup of IEEE-488 and RS-232

IEEE-488 bus address and RS-232 baud rate, parity, stop bits, and fill characters are all entered from the front panel keypad and can be permanently stored from the keypad as well.

Friendly Commands

Both remote device interfaces use the same English language commands that are found on the front panel. Commands can be abbreviated by supplying only enough letters to uniquely identify the desired command.

Data Formats

Measurement results consist of any combination of four fields: error message, capacitance, loss, and voltage. The number of decimal places and the width of the capacitance and loss fields are independently selectable. Field and unit labels are optional. Numeric results can be reported in floating point, scientific or engineering notations.

THE 2500A HAS MANY POSSIBLE USES BEYOND CALIBRATION

The reaction of many technical persons upon first learning of the Model 2500A is: “That’s a very impressive instrument, but we don’t see a need for such precision in our work. Furthermore, such measurements must be more difficult to make.” Until the introduction of the 2500A, this attitude toward high precision capacitance measurements was justified. Previously, the only commercially available instruments were manually operated, required a skilled operator to spend several minutes balancing the bridge, were prone to reliability problems due to the large number of open switching contacts used, and were still far less stable than the 2500A. It is not surprising that these bridges have not seen significant use outside of calibration or research laboratories.

Today, the incredible ease with which high precision capacitance and loss measurements can be made with the 2500A requires a reassessment of previous attitudes. The 2500A allows totally automated operation with no human intervention. Its ability to maintain its precision over a wide temperature range and its immunity to mechanical shock make it ideally suited for factory-floor or portable field use. Andeen-Hagerling is so confident of its ability to perform reliably, that it is provided with a three year warranty.

To apply the 2500A to a productive task requires obtaining a suitable sensor. This is where the possibilities become exciting, because capacitive sensors are theoretically the most precise of all electrical sensors. The reasons are:

- A perfect capacitor dissipates no power. Thus relatively high voltages can be applied to the sensor without generating any heat in it. The higher the voltage, the better the signal-to-noise ratio. In contrast, all resistive sensors dissipate heat while being measured.
- A perfect capacitor generates no noise. Resistors are always limited by thermal noise and are

susceptible to other kinds of noise as well.

- A perfect capacitor is linear with applied voltage. Most resistive elements are at least slightly non-linear and inductive elements are usually extremely non-linear. In fact, NIST will only calibrate inductors to 0.02%.
- The variation with temperature of a small capacitor can be made very small and simultaneously very linear. Other elements, such as resistors, require compensation schemes which cause them to have low temperature coefficients over a narrow temperature range but much higher and very non-linear variations over a broader range.

These characteristics allow the creation of simple yet very precise sensors based on the change in area or the change in separation of a pair of capacitor plates, cylinders, etc. Such a sensor could also be based on the introduction of a conducting material of unknown thickness, size, shape, position, or whatever into the active field of a capacitor. If the material within the active field is a reasonably good insulating dielectric, then both the dielectric constant and the loss of the material are obtainable. This can be a very simple way to observe chemical changes, detect contaminants, etc., in a wide variety of materials.

EXAMPLES OF APPLICATIONS OF THE MODEL 2500A

- Calibration work including use as a transfer standard in primary and secondary laboratories.
- Fuel gauge calibration.
- Measurement of cryogenic temperatures.
- Thermal expansion measurements for any type of matter, particularly metals, but also non-metals.
- Radiation measurements using crystalline structures and radiation induced changes in non-metals.
- Rapid, accurate and direct humidity measurements.
- Thickness of metals or dielectrics.
- Liquid and vapor level measurements.
- AC resistance measurements to 1000 teraohms.
- Displacement and strain measurements. Very small changes in dimensions are measurable, approaching the diameter of an atomic nucleus. (This is less than a millionth of the wavelength of visible light.)
- Quality and characteristics of any insulating medium (solid, liquid or gas). The presence of contaminating water is particularly easy to detect. See ASTM D150 and D924.
- Detection of contaminants in refrigerants.
- Monitoring chemical reactions.
- Applications involving the measurement of small changes in capacitance or loss. The 2500A is very good at these due to its very high resolution and stability.
- Research, development and production testing of capacitance or loss based sensors.
- Replacement of the electronics normally associated with currently manufactured capacitance based sensors to obtain greatly improved precision.
- Measurement of pressures ranging from high vacuum to high pressure.
- Very high pressure gauge using a solid dielectric capacitor. (Patent No. 3,787,764)

SPECIFICATIONS

Notation:		The specifications are grouped according to whether the unknown is modeled as a resistor in parallel with a capacitor or in series with it.
Parallel:	"C"	is the value of the unknown (parallel) capacitance in picofarads (pF = 10^{-12} F). Also used are attofarads (aF = 10^{-6} pF) and microfarads (µF = 10^{6} pF).
	"G"	is the value of the unknown loss expressed as a conductance in nanosiemens (nS = 10^{-9} S).
	"D"	is the value of the unknown loss expressed as a dissipation factor (tan delta). D has no units.
	"R_P"	is the value of the unknown loss expressed as a parallel resistance in gigohms (G ohm = 10^{9} ohm).
Series:	"C_S"	is the value of the unknown series capacitance in picofarads (pF = 10^{-12} F).
	"R_S"	is the value of the unknown loss expressed as a series resistance in kilohms (k ohm = 10^{3} ohm).
Misc:	"t_b"	is the minimum selectable time between consecutive measurements in seconds.
	"V"	is the AC test signal voltage in volts applied across the unknown. Its upper limit may be selected by the user to have any value listed in the AC Test Signal Voltages table.
	"ppm"	means Parts Per Million.

General:

The expressions below for accuracy, linearity, stability, resolution, and temperature coefficient give absolute rather than statistical uncertainties. Absolute uncertainties are the most conservative of those in common use. Andeen-Hagerling guarantees repair within the warranty period of any Model 2500A whose measured errors repeatedly exceed these uncertainties. The expressions may be evaluated for particular values of capacitance (C or C_S), loss (G, D, R_P or R_S), test voltage (V), and measurement time (t). Only the resolution expressions contain the measurement time. However, the other uncertainty expressions assume that the measurement time has been set to be long enough so that these other uncertainties are not limited by the resolution specification. In other words, specifications such as accuracy may be limited by the resolution rather than the accuracy expression if the measurement time is set too short.

Most of the uncertainty expressions can be evaluated by direct substitution of the values of capacitance, loss and voltage as if they were read directly from the 2500A. The instrument reports these values in the units given in the notation section above. Some expressions also require the dissipation factor, D, which, if it is not directly available, can be calculated using one of the following relations:

$$D = G/(2 \text{ pi } C),\ D = 1/(2 \text{ pi } CR_P) \text{ or } D = 2 \text{ pi x } 10^{-6}C_SR_S.$$

For low values of capacitance and loss, the maximum allowable test voltage set by the user (usually 15 volts) can be substituted for every occurrence of V in the uncertainty expressions. For larger values of capacitance and loss, if the voltage value is not read from an instrument, then the value of V automatically chosen by the 2500A must be determined from the AC Test Signal Voltage Table. The following equations may be used to convert to the units of C and G used in the table from units other than those used in the table.

Given units of *D:* use $G = 2\pi CD$
R_P: $G = 1/R_P$
R_S: $G = 2\pi C_S D/(1+D^2)$
C_S: $C = C_S/(1+D^2)$

A comprehensive set of contour plots of all of the uncertainty expressions is available from Andeen-Hagerling upon request. Accuracy, stability, linearity and resolution specifications assume a recent internal calibration at the operating temperature.

Range:[2]

Parallel: *C:* -0.0012/|D| µF to +0.012/|D| µF for D >= 0.01
-0.12 µF to +1.2 µF for -0.001 <= D < 0.01
-0.12 µF to +0.0012/|D| µF for -0.1 <= D < -0.001
-0.012/|D| µF to +0.0012/|D| µF for D < -0.1
The capacitance range is also shown graphically in Figure 1.
G: -6000 nS to +60 000 nS
D: See Figure 1.
R_P: -1.7×10^{-4} G ohm to -1.7×10^{6} G ohm
and $+1.7\times10^{-5}$ G ohm to $+1.7\times10^{6}$ G ohm
Series: *C_S:* See Figure 2.
R_S: See Figure 2.

[2] The ranges of all measurable variables except R_P cover a region defined by negative numbers for the lower limit and positive numbers for the upper limit. This is due to the Model 2500A’s ability to measure both positive and negative values of capacitance and loss. Other instruments which only measure positive values have ranges which cover a region defined by small positive numbers for the lower limits to large positive numbers for the upper limits. For the 2500A, the small numbers which correspond to the lower limits of other instruments are given by the 2500A’s resolution specifications in absolute units.

Front Panel Display Limitations:

(The front panel display may further limit the range and resolution of the capacitance and loss.)

Capacitance: 0.1 aF is best display resolution for C and C_S.
Loss: *G:* 10^{-7} nS is best conductance display resolution.

D: 10^{-7} is best dissipation display resolution.

R_S: 10^{-7} k ohm is best series resistance display resolution.

R_P: 10^{-7} G ohm is best parallel resistance display resolution.

Remote Device Reporting Limitations:

Capacitance: 0.01 aF is best resolution for C and C_S.

Loss: *G:* 10^{-8} nS is best conductance resolution.

D: 10^{-8} is best dissipation resolution.

R_S: 10^{-7} k ohm is best series resistance resolution.

R_P: 10^{-8} G ohm is best parallel resistance resolution.

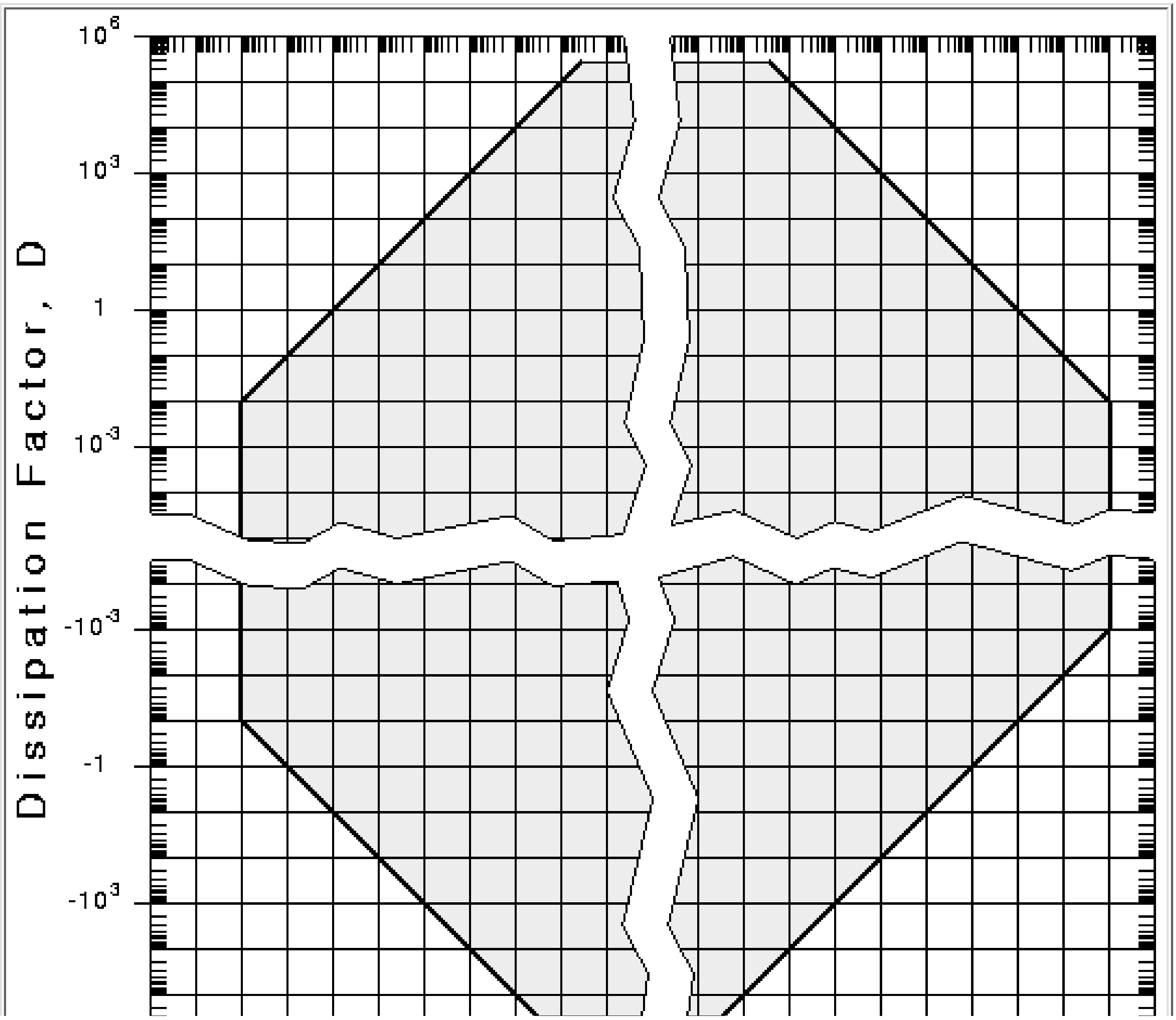


Figure 1. The measurable values of C and D are enclosed within the shaded area.

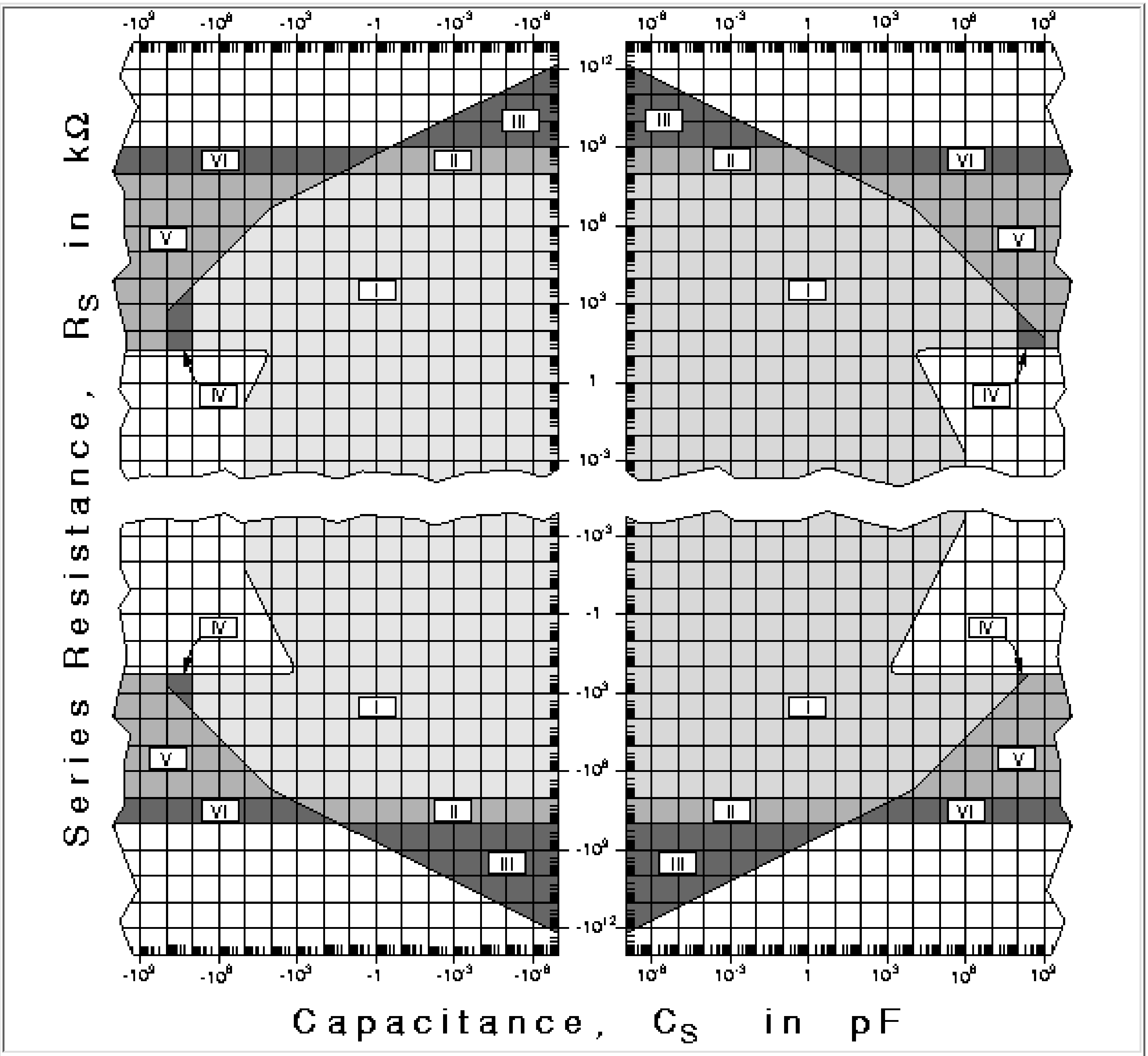


Figure 2. The values of C_S and R_S are measurable in the six shaded regions. In five of these regions, one or both of the measured values are too large to report on the 2500A's display. In three of these five regions, one or both values are also too large to send to any remote devices. The table below shows what can be reported in each region. A "Display" entry means that the result can be shown on the instrument's display. A "Remotes" entry means that the result can be reported to an RS-232 or IEEE-488 device.

	C_S	R_S
I	Display & Remotes	Display & Remotes
II	Display & Remotes	Remotes only
III	Display & Remotes	Neither
IV	Remotes only	Display & Remotes
V[3]	Neither	Display & Remotes
VI[3]	Neither	Remotes only

[3] Regions V and VI extend to infinity to the right and left because the resistance associated with an infinite C_S is measurable even though C_S itself is not reportable.

Measurement Time:

$t_b = 0.05 \text{x} 2^T$ sec. where T is a user selectable integer ranging from 0 to 15. (The first measurement on a given unknown requires a minimum of 1/2 second.)

Resolution in absolute units:[4]

Parallel: *C:* $\{0.15C + 50DC + [7.5(1+n_C) + n_V C]/V\} \text{x} 10^{-6}$ pF

G: $\{50G + C + 5 \text{x} 10^{-5} C^2 + [50(1+n_C) + 6 n_V C]/V\} \text{x} 10^{-6}$ nS

D: $\{8 \text{x} 10^{-6} C + (1+D^2)^{1/2} [0.15 + 50D + (7.5(1+n_C)/C + n_V)/V]\} \text{x} 10^{-6}$

R_P: $R_P \{50 + R_P [C + 5 \text{x} 10^{-5} C^2 + (50(1+n_C) + 6 n_V C)/V]\} \text{x} 10^{-6}$ G ohm

Series: *C_S:* $\{0.15 + 50D + [7.5(1+n_C)(1+D^2)/C_S + n_V]/V\} C_S \text{x} 10^{-6}$ pF

R_S: $\{1.3 + 50 R_S + [0.15 + [7.5(1+n_C)(1+D^2)/C_S + n_V]/V] R_S/D\} \text{x} 10^{-6}$ k ohm

where $n_C = 1.4 t^{-1/2}$ and $n_V = 0.01 (R_S + 10)^{1/2} (1+D^2)^{1/2} t^{-1/2}$.

$t = t_b$ except when $t_b = 0.05$ in which case $t = t_b/4$.

The series resistance R_S may be calculated for the parallel expressions using $R_s = 1.6 \text{x} 10^5 D/C(1+D^2)$.

Resolution in ppm:[4]

Parallel: *C:* $0.15 + 50D + [7.5(1+n_C)/C + n_V]/V$

G: $50 + \{C + 5 \text{x} 10^{-5} C^2 + [50(1+n_C) + 6 n_V C]/V\}/G$

D: $\{8\text{x}10^{-6}C + (1+D^2)^{1/2}[0.15 + 50D + (7.5(1+n_C)/C + n_V)/V]\}/D$

R_P: $50 + R_P\{C + 5\text{x}10^{-5}C^2 + [50(1+n_C) + 6n_VC]/V\}$

Series: C_S: $0.15 + 50D + [7.5(1+n_C)(1+D^2)/C_S + n_V]/V$

R_S: $1.3/R_S + 50 + \{0.15 + [7.5(1+n_C)(1+D^2)/C_S + n_V]/V\}/D$

[4] Resolution is the smallest *repeatable* difference in readings that is *guaranteed* to be measurable at *every* capacitance or loss value. Useful resolution is typically a factor of ten better.

Non-linearity in ppm:

Parallel: C: $\pm\{0.15 + 50D + 7.5/CV + 15\text{x}10^{-6}C\}$

G: $\pm\{50 + [C + 5\text{x}10^{-5}C^2 + 50/V]/G\}$

D: $\pm\{8\text{x}10^{-6}C + (1+D^2)^{1/2}[0.15 + 50D + 7.5/CV]\}/D$

R_P: $\pm\{50 + R_P[C + 5\text{x}10^{-5}C^2 + 50/V]\}$

Series: C_S: $\pm\{0.15 + 50D + 7.5(1+D^2)/C_SV + 15\text{x}10^{-6}C_S/(1+D^2)\}$

R_S: $\pm\{1.3/R_S + 50 + [0.15 + 7.5(1+D^2)/C_SV]/D\}$

Non-linearity is the deviation from a best fit straight line through a plot of the measured quantity versus the actual quantity. The test signal voltage is assumed to be constant.

Accuracy in ppm following calibration:

Parallel: C: $\pm\{5 + 200D + (0.2 + 7.5/C)/V\}$

G: $\pm\{200 + [13C + 0.002C^2 + (45 + 1.2C)/V]/G\}$

D: $\pm\{2 + 3\text{x}10^{-4}C + (1+D^2)^{1/2}[200D + (0.2 + 7.5/C)/V]\}/D$

R_P: $\pm\{200 + [13C + 0.002C^2 + (45 + 1.2C)/V]R_P\}$

Series: C_S: $\pm\{5 + 200D + [0.2 + 7.5(1+D^2)/C_S]/V\}$

R_S: $\pm\{200 + 50/R_S + [2 + (0.2 + 7.5(1+D^2)/C_S)/V]/D\}$

The length of the cables connecting the 2500A to the capacitance being measured has a negligible effect on the accuracy for *small* capacitances. This assumes that the coaxial shield on these cables has 100% coverage. If uncorrected by the CABLE command, cables similar to RG-58 will increase the capacitance readings by about 40 ppm per meter of cable pair and per µF of capacitance being measured.

The accuracy Y years following calibration may be calculated from the expression A + YS where A is the desired accuracy expression from above and S is the corresponding stability per year below.

Stability in ppm per year:

Parallel: C: $\pm\{1 + 30D + (0.01 + 2.5/C)/V\}$

G: $\pm\{30 + [2C + 3\text{x}10^{-4}C^2 + (15 + 0.06C)/V]/G\}$

D: $\pm\{0.3 + 5\text{x}10^{-5}C + (1+D^2)^{1/2}[30D + (0.01 + 2.5/C)/V]\}/D$

R_P: $\pm\{30 + [2C + 3\text{x}10^{-4}C^2 + (15 + 0.06C)/V]R_P\}$

Series: *C_S:* $\pm\{1 + 30D + (0.01 + 2.5(1+D^2)/C_S)/V\}$

R_S: $\pm\{30 + 8/R_S + [0.3 + (0.01 + 2.5(1+D^2)/C_S)/V]/D\}$

Temperature coefficient relative to change in ambient temperature in ppm per °C:

Parallel: *C:* $\pm\{0.025 + 30D + 0.002/V + 15/(0.15 + CV)\}$

G: $\pm\{30 + [0.2 + 2\text{x}10^{-5}C + 0.012/V]C/G + 100/(1 + GV)\}$

D: $\pm\{[0.03 + 3\text{x}10^{-6}C + (1+D^2)^{1/2}(30D + 0.002/V)]/D + 15/(0.15 + CV) + 15/(0.15 + CDV)\}$

R_P: $\pm\{30 + [0.2 + 2\text{x}10^{-5}C + 0.012/V]CR_P + 100/(1 + V/R_P)\}$

Series: *C_S:* $\pm\{0.025 + 30D + 0.002/V + 100/[1 + 6C_SV/(1+D^2)]\}$

R_S: $\pm\{30 + 0.5/R_S + (0.03 + 0.002/V)/D + 30/[0.15(1+D^2) + C_SV] + 100/[1 + 10^6VD^2/(1 + D^2)R_S]\}$

Sensitivity to changes in power line voltage:

Capacitance: ±0.002 ppm per 1% change in line voltage
Loss: Not measurable

DC Bias: Up to ±100 volts may be applied to the unknown through the external DC bias input.

Frequency: 1.0000 ±0.005% kilohertz

Operating temperature range: 0° to 45°C

Storage temperature range: -40° to +75°C

Humidity: 0 to 85% relative humidity, non-condensing

AC Test Signal Voltages: Any voltage listed below may be selected. The capacitance and loss ranges measurable at the selected voltage are shown. The 2500A will automatically use the lesser of the user’s selected voltage or the highest voltage listed in the table which provides sufficient range to be able to measure the capacitance and loss of the unknown. The voltages listed have tolerances of ±5%.

Voltage:		Range of C:		Range of G:	
15.0	V	-8 to	+80 pF	-0.4 to	+4 nS
7.50	V	-16 to	+160 pF	-0.8 to	+8 nS
3.75	V	-16 to	+160 pF	-0.8 to	+8 nS
3.00	V	-40 to	+400 pF	-2 to	+20 nS

1.50	V	-80 to	+800 pF	-4 to	+40 nS
0.750	V	-160 to	+1600 pF	-8 to	+80 nS
0.375	V	-160 to	+1600 pF	-8 to	+80 nS
0.250	V	-480 to	+4800 pF	-24 to	+240 nS
0.125	V	-480 to	+4800 pF	-24 to	+240 nS
0.100	V	-1200 to	+12 000 pF	-60 to	+600 nS
0.050	V	-1200 to	+12 000 pF	-60 to	+600 nS
0.030	V	-4000 to	+40 000 pF	-200 to	+2000 nS
0.015	V	-4000 to	+40 000 pF	-200 to	+2000 nS
0.010	V	-12 000 to	+120 000 pF	-600 to	+6000 nS
0.0050	V	-12 000 to	+120 000 pF	-600 to	+6000 nS
0.0030	V	-40 000 to	+400 000 pF	-2000 to	+20 000 nS
0.0015	V	-40 000 to	+400 000 pF	-2000 to	+20 000 nS
0.0010	V	-120 000 to	+1200 000 pF	-6000 to	+60 000 nS
0.0005	V	-120 000 to	+1200 000 pF	-6000 to	+60 000 nS

Power requirements: 25 watts

Power frequency: 48 to 440 Hz

Power voltage ranges: 85 to 115, 102 to 138, 187 to 253 and 204 to 276 volts rms

Packaging: The instrument is 3.5 inches (8.9 cm) high and 15 inches (38.1 cm) deep behind the front panel. Hardware for rack mounting and a bail for bench top use are provided.

Weight: 18 pounds (8.2 kg)

Safety: Designed in accordance with UL1244, IEC348 and BS4743.

Radiated emissions: Designed and tested to meet FCC and VDE class A requirements.

Patents: The Model 2500A is protected by U.S. Patent No. 4 772 844. Foreign patents are pending.

Warranty: The Model 2500A is covered by a three year warranty. Forward and return shipping is covered during the first three months of the warranty.

Note: Specifications are subject to change without notice.

OPTIONS

The 2500A may be ordered with **Option E** which enhances the precision of the bridge. These enhanced specifications are listed below. All other specifications remain unchanged. Notes related to the specifications below may be found in the specifications above for the standard version of the bridge.

Resolution in absolute units:

Parallel: C: $\{0.07C + 20DC + (7.5(1+n_C) + n_V C)/V\}x10^{-6}$ pF

G: $\{20G + 0.4C + 5x10^{-5}C^2 + (50(1+n_C) + 6n_V C)/V\}x10^{-6}$ nS

D: $\{8x10^{-6}C + (1+D^2)^{1/2}[0.07 + 20D + (7.5(1+n_C)/C + n_V)/V]\}x10^{-6}$

R_P: $R_P\{20 + R_P[0.4C + 5x10^{-5}C^2 + (50(1+n_C) + 6n_V C)/V]\}x10^{-6}$ G ohm

Series: C_S: $\{0.07 + 20D + [7.5(1+n_C)(1+D^2)/C_S + n_V]/V\}C_S x10^{-6}$ pF

R_S: $\{1.3 + 20R_S + \{0.07 + [7.5(1+n_C)(1+D^2)/C_S + n_V]/V\}R_S/D\}x10^{-6}$ k ohm

Resolution in ppm:

Parallel: C: $0.07 + 20D + [7.5(1+n_C) /C + n_V]/V$

G: $20 + \{0.4C + 5x10^{-5}C^2 + [50(1+n_C) + 6n_V C]/V\}/G$

D: $\{8x10^{-6}C + (1+D^2)^{1/2}[0.07 + 20D + (7.5(1+n_C)/C + n_V)/V]\}/D$

R_P: $20 + R_P\{0.4C + 5x10^{-5}C^2 + [50(1+n_C) + 6n_V C]/V\}$

Series: C_S: $0.07 + 20D + [7.5(1+n_C)(1+D^2)/C_S + n_V]/V$

R_S: $1.3/R_S + 20 + \{0.07 + [7.5(1+n_C)(1+D^2)/C_S + n_V]/V\}/D$

Non-linearity in ppm:

Parallel: C: $\pm\{0.07 + 20D + 7.5/CV + 5x10^{-6}C\}$

G: $\pm\{20 + [0.4C + 5x10^{-5}C^2 + 50/V]/G\}$

D: $\pm\{8x10^{-6}C + (1+D^2)^{1/2}[0.07 + 20D + 7.5/CV]\}/D$

R_P: $\pm\{20 + R_P[0.4C + 5x10^{-5}C^2 + 50/V]\}$

Series: C_S: $\pm\{0.07 + 20D + 7.5(1+D^2)/C_S V + 5x10^{-6}C_S/(1+D^2)\}$

R_S: $\pm\{1.3/R_S + 20 + [0.07 + 7.5(1+D^2)/C_S V]/D\}$

Accuracy in ppm following calibration:

Parallel: C: $\pm\{3 + 100D + (0.01 + 7.5/C)/V\}$

G: $\pm\{100 + [13C + 0.002C^2 + (45 + 0.06C)/V]/G\}$

D: $\pm\{2 + 3x10^{-4}C + (1+D^2)^{1/2}[100D + (0.01 + 7.5/C)/V]\}/D$

R_P: $\pm\{100 + [13C + 0.002C^2 + (45 + 0.06C)/V]R_P\}$

Series: C_S: $\pm\{3 + 100D + [0.01 + 7.5(1+D^2)/C_S]/V\}$

R_S: $\pm\{100 + 50/R_S + [2 + (0.01 + 7.5(1+D^2)/C_S)/V]/D\}$

Stability in ppm per year:

Parallel: C: $\pm\{0.5 + 20D + (0.003 + 2.5/C)/V\}$

G: $\pm\{20 + [2C + 2\text{x}10^{-4}C^2 + (15 + 0.02C)/V]/G\}$

D: $\pm\{0.3 + 3\text{x}10^{-5}C + (1+D^2)^{1/2}[20D + (0.003 + 2.5/C)/V]\}/D$

R_P: $\pm\{20 + [2C + 2\text{x}10^{-4}C^2 + (15 + 0.02C)/V]R_P\}$

Series: C_S: $\pm\{0.5 + 20D + [0.003 + 2.5(1+D^2)/C_S]/V\}$

R_S: $\pm\{20 + 5/R_S + [0.3 + [0.003 + 2.5(1+D^2)/C_S]/V]/D\}$

Temperature coefficient relative to change in ambient temperature in ppm per °C:

Parallel: C: $\pm\{0.008 + 10D + 0.001/V + 2/(0.15 + CV)\}$

G: $\pm\{10 + [0.2 + 2\text{x}10^{-5}C + 0.006/V]C/G + 15/(1 + GV)\}$

D: $\pm\{[0.03 + 3\text{x}10^{-6}C + (1+D^2)^{1/2}(10D + 0.001/V)]/D + 2/(0.15 + CV) + 2/(0.15 + CDV)\}$

R_P: $\pm\{10 + [0.2 + 2\text{x}10^{-5}C + 0.006/V]CR_P + 15/(1 + V/R_P)\}$

Series: C_S: $\pm\{0.008 + 10D + 0.001/V + 15/[1 + 6C_SV/(1+D^2)]\}$

R_S: $\pm\{10 + 0.5/R_S + (0.03 + 0.001/V)/D + 4/[0.15(1+D^2) + C_SV] + 15/[1 + 10^6VD^2/(1 + D^2)R_S]\}$

Ordering Information:	**Part No.**
Model 2500A Capacitance Bridge	2500A
Enhanced performance option for Model 2500A	Option E

Consult factory or your sales representative for price and availability of Option E for bridges that were not originally purchased with this option.

For questions regarding the AH 2500A, possible applications, the location of your nearest sales representative, or ordering information:

Call: 440-349-0370 **Fax: 440-349-0359**

E-mail: info@andeen-hagerling.com

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AH 1100 Capacitance Standard Frame

AH 11A Fused-Silica Capacitance Standard

The World’s Most Stable Capacitance Standards[1]

The AH 1100 capacitance standard frame containing from one to four AH 11A fused-silica capacitance standards provides reference capacitors of unexcelled stability. The inherent stability of this system when subjected to mechanical or thermal shock makes it the ideal transfer standard for capacitance. The built-in precision temperature controllers make it a simple, reliable system to use. These are the only standards currently sold that are sufficiently accurate to calibrate the AH 2500A capacitance bridge to the limits of its specifications.

Outstanding Features

- ***Any*** capacitance value in the range from below 1 pF up to 115 pF may be ordered.
- Stability of larger capacitors is better than 0.3 ppm/year.
- Temperature coefficient of the capacitance with respect to changes in ambient temperature is less than 0.01 ppm/°C.
- Hysteresis resulting from temperature cycling is less than 0.05 ppm.
- Hysteresis resulting from mechanical shock is less than 0.05 ppm.
- AC voltage coefficient is less than 0.003 ppm/volt.
- DC voltage coefficient is less than 0.0001 ppm/volt.
- Power line sensitivity is less than 0.0003 ppm per 1% change in power line voltage.

- Dissipation factor is less than 0.000 003 tan delta.
- Three year warranty
- The user-selected capacitance value is set at the factory to a NIST traceable accuracy of 2 ppm at 1 kHz.
- The built-in precision oven in each AH 11A uses a dual temperature sensor system which provides increased reliability and confidence.
- The AH 1100 frame provides monitoring of critical temperature control parameters such as the differences within the dual temperature sensors in each standard.
- Each AH 11A standard can be easily removed from the AH 1100 frame. Their small size and light weight make them easy to ship for calibration.
- Shipping is simple since continuous temperature control of the ovens is not needed to maintain the stability specification.
- The fused-silica element is hermetically sealed in dry nitrogen.
- Three-terminal BNC connections minimize connector costs and number of cables.

[1] in commercial production.

BRIEF HISTORY

Capacitance standards using fused silica as a dielectric have been investigated at NBS (now NIST) for many years. Some particularly thorough research was done in the early 1960’s by Cutkosky and Lee[2]. They constructed two versions of fused-silica based capacitors and characterized most of the important features of these standards. The set of twelve that they created contained several standards which were exceptionally stable. These and several later ones have been used ever since as the primary capacitance standards of the United States. These primary standards are calibrated on a regular basis against the calculable capacitor at NIST. The latter is now the ultimate reference.

[2] R. D. Cutkosky and L. H. Lee, Improved Ten-Picofarad Fused Silica Dielectric Capacitor, J. of Res. of the National Bureau of Standards - C., Vol. 69C, No. 3, July-Sept. 1965.

BASIC DESIGN

AH 1100 Frame

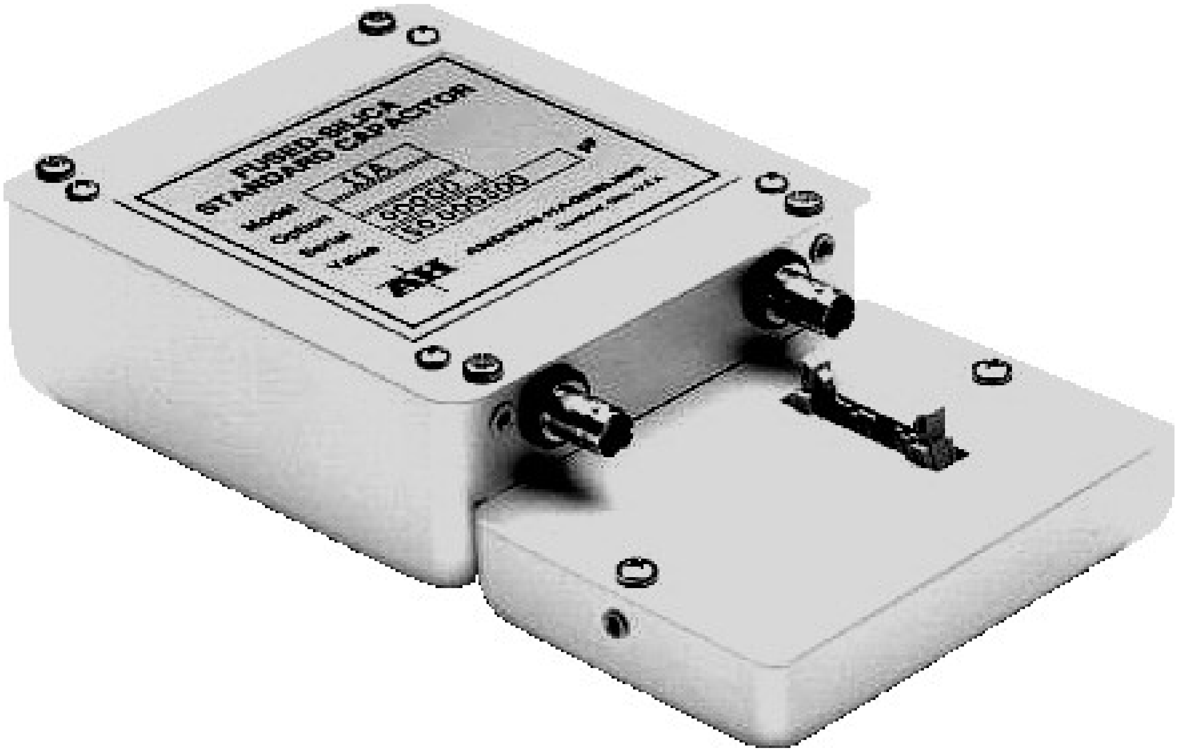
The AH 1100 frame consists of a 3.5 inch (8.9 cm) high, standard width, bench-top or rack-mountable frame. This frame can hold up to four AH 11A fused-silica capacitance standards. The frame provides the electrical power to operate the precision temperature-controlled oven that is part of each AH 11A. The frame also provides the metering circuits that monitor internal power voltages and temperatures. A three-terminal connection to each standard is made independently from pairs of BNC connectors on the front of the AH 1100. The AH 1100 also contains extra space to accommodate several optional features that will be available in the future.

AH 11A Standard

Each AH 11A standard has, as its basic element, a fused-silica disk which is used to form a set of capacitors having values that are binary weighted. Factory selection of the appropriate capacitors from this set allows the AH 11A to be offered in a wide range of very accurately set values. Final trimming of the value is achieved by a small adjustment to the temperature of the oven. This method avoids the introduction of a separate trimming capacitor with its associated instabilities. Thus the dielectric of the AH 11A is very nearly 100% solid fused silica.

The fused-silica disk is hermetically sealed in a copper chamber that is thermally well insulated from the outside case of the AH 11A. The temperature of this chamber is measured by two precision temperature sensors, connected to two totally independent monitoring circuits. The *average* of the output voltages produced by these two circuits is used to control the temperature of the copper chamber. The *difference* in these output voltages may be selected for display on the front panel of the AH 1100 frame. As the standard ages, this difference should remain near zero. The smaller the difference, the greater the confidence in the stability of the oven temperature.

Each AH 11A incorporates the temperature measurement and control circuitry needed for its oven. Connection from the AH 11A to the AH 1100 frame is made with three connectors: two BNC and one 16 pin.



The AH 11A standard

FEATURES

User-Selected Values

AH 11A capacitance standards can be ordered with any value from below 1 pF up to 115 pF. Furthermore, if the application for which the original value was purchased becomes obsolete, the AH 11A can be returned to the factory and set to a totally new value for a nominal cost.

Traditionally, capacitance values for transfer of higher echelon calibration values have been chosen to be several parts per million above 10, 100 and 1000 pF. The AH 11A can be ordered with values such as these for 10 and 100 pF. For applications requiring calibration of an AH 2500A capacitance bridge, values near 100 pF are preferred to those near 10 pF. In fact, for calibration of an AH 2500A at a single value, Andeen-Hagerling recommends using an AH 11A standard having a value of 99.99950 pF. This is 5 ppm below 100 pF. Values slightly below 10, 100, or 1000 are preferred to those above since this allows the capacitance bridge to most conveniently display an additional digit. Otherwise, the exact choice of values should be based on convention, personal preference, and standardization among groups that are exchanging calibration values.

Applications of User-Selected Values

- **Calibration of a Range**

For end applications requiring the measurement of a narrow range of values, one may desire one or more standards that fall within that range of values. Such application-specific standards can substantially increase confidence in the accuracy of measurements made within that range of values. An example might be fuel gauging where the capacitance values representing “full” and “empty” are useful calibration points since they represent the limits of the range being measured.

- **Calibration of a Set**

For end applications requiring the measurement of a well defined set of values, the possession of a set of standards whose values equal the nominal values within the application set can substantially increase confidence in the accuracy of measurements made near values in that application set. Especially, for volume applications, this may allow using lower cost capacitance meters to achieve a given accuracy. The ability of the AH 11A to be set to any value makes such strategies possible to a degree of accuracy never before attainable.

- **Deviation Measurements**

The ability to precisely set the value of the AH 11A allows it to serve as a reference capacitor against which an unknown capacitance is compared. This configuration allows differential capacitance measurements to be made that can be simultaneously very fast and very accurate.

- **Linearity Measurements**

Possession of a set of only four standards in a 1, 2, 4, 5 or similar sequence allows high precision linearity calibrations to be made over one decade of values. In this example, a set having 10, 20, 40, and 50 pF standards can be used to form parallel combinations that create every decade capacitance value from 10 to 120 pF. The addition of one more value to the set such as 1, 1, 2, 4, 5 allows the set to be self-checked for internal consistency.

Monitoring

The AH 1100 frame incorporates a panel meter with a three-and-one-half digit LED display to monitor internal parameters whose stability is critical to the stability of the capacitance values. This meter can read the most important power supply voltages at the press of a button. The meter also reads the difference in the readings taken by the pair of temperature sensors in each AH 11A. For convenience, these differences are reported in units of ppm of the capacitance value. Although the temperature of the AH 1100 chassis is not critical, its temperature may also be read by the panel meter. In addition, each AH 11A standard has an associated LED on the AH 1100 front panel that will flash if control of the oven temperature is lost, even briefly.

Ease of Shipping

AH 11A standards may be sent for calibration by shipping the entire AH 1100 frame containing up to four standards. Alternatively, if the calibrating lab has an AH 1100 frame, then only the AH 11A standards that are to be calibrated need be sent. These are easily removed by removing the top cover of the AH 1100, disconnecting three cables from each AH 11A, and loosening four mounting screws. The calibrating lab installs the AH 11A in that lab’s AH 1100 frame to perform the calibration.

The AH 1100/11A system is much more impervious to its environment than other capacitance standards. The AH 1100 and AH 11A’s can be shipped in a well cushioned box comparable to that used to ship other precision instruments. With such packaging, no other special handling requirements are necessary.

The small thermal hysteresis of the AH 11A means that it does not need to be shipped at its operating temperature. This eliminates the need to include heavy batteries in its shipping container.

Stability during Shipping

As a result of the AH 11A’s resistance to thermal and mechanical shock, the expected changes in the capacitance value due to shipping are more than two orders of magnitude smaller than with Invar plate, gas dielectric capacitors. This can eliminate the all too common problem where the Invar plate standard that just returned from the national primary calibration laboratory has changed by 20 or more ppm during shipping even though its calibration papers say it should be good to 5 ppm.

Storage

While accurate measurements can only be made with the AH 1100/11A under power and with stable oven temperatures, this is only necessary while measurements are actually being made. When not in use, these standards can be left on the shelf with the power off and may have better long term stability under such conditions.

Temperature Range

The operating temperature range for the AH 1100/11A system is wider than for other capacitance standards and does not require a carefully controlled laboratory environment.

AH 1100/11A SPECIFICATIONS

Range of capacitance values that can be ordered: Any value from below 1 pF up to 115 pF.

Accuracy of initial setting: 2 + 1/C ppm at 1 kHz where “C” is the value of the 11A in pF.

Stability in ppm per year: 0.3 + 1/C ppm/year

Temperature coefficient relative to a change in ambient temperature: 0.01 ppm/°C

Hysteresis from temperature cycling: 0.05 ppm

Hysteresis from mechanical shock: 0.05 ppm

AC voltage coefficient: 0.003 ppm/volt rms at 1 kHz

DC voltage coefficient: 0.0001 ppm/volt

Sensitivity to power line voltage changes: 0.0003 ppm per 1% change in power line voltage

Dissipation factor: less than 0.000 003 tan delta

Maximum allowable applied voltage: 250 volts peak

Warm up time from power-on: 30 minutes

Operating temperature range: 10° to 40° C

Storage temperature range: -40° to +75° C

Humidity: 0 to 85% relative humidity, non-condensing

Power requirements: 40 watts max. during power-on, 20 watts after power-on

Power frequency: 48 to 440 Hz

Power voltage ranges: 85 to 115, 102 to 138, 187 to 253 and 204 to 276 volts rms

AH 1100 packaging: The AH 1100 frame is 3.5 inches (8.9 cm) high and 15 inches (38.1 cm) deep behind the front panel. Hardware for rack mounting and a bail for bench top use are provided.

Weight of AH 1100 only: 15 pounds (7 kg)

AH 11A packaging: 4.45 wide by 8.0 long by 2.0 inches high (11.3 wide by 20.3 long by 5.1 cm high).

AH 11A weight: 1.5 pounds (0.7 kg)

Safety: Designed in accordance with UL1244, IEC348, and BS4743

Radiated emissions: Designed to meet FCC and VDE class A requirements

Warranty: The AH 1100 and AH 11A are covered by a three year warranty. Forward and return shipping is covered during the first three months of the warranty period.

Note: Specifications are subject to change without notice.

Ordering Information	Order Number
AH 1100 Capacitance Standard Frame	AH 1100
AH 11A Fused-Silica Capacitance Standard	AH 11A-(*value in pF*)

For questions regarding these products, possible applications, the location of your nearest sales representative, or ordering information:

Call: 440-349-0370 **Fax: 440-349-0359**

E-mail: info@andeen-hagerling.com

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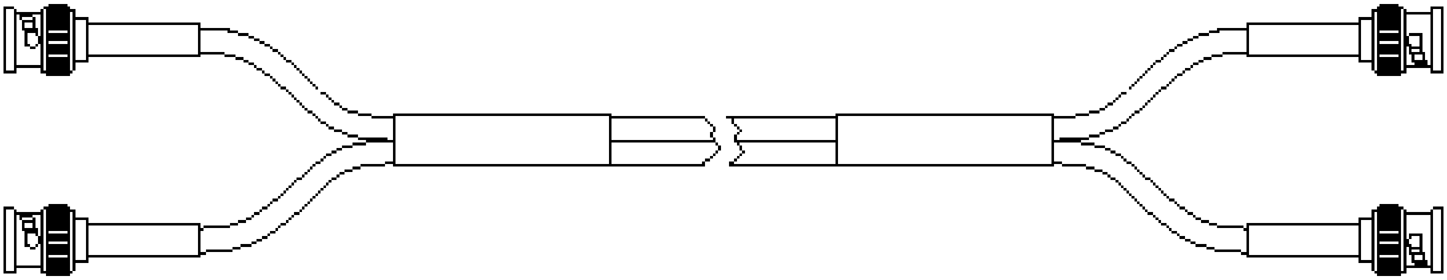
ANDEEN-HAGERLING

DCOAX

Cable



Dual, Low Noise, Coaxial Cable Optimized For Three-Terminal Capacitance Measurements

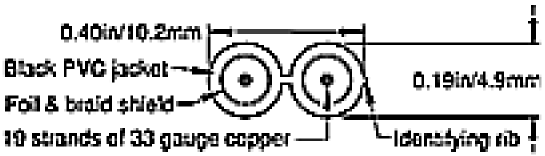
Very high precision, three-terminal capacitance measurements can be affected by the self-inductance of the test cables, mainly at higher capacitance values. Magnetically induced noise can also reduce the quality of measurements. The cable now offered by Andeen-Hagerling both minimizes these problems and provides a way to standardize the residual self-inductance. High precision calibration measurements can now use a standard one meter length of test cable to minimize and standardize cable induced errors.

Outstanding Features

- Low triboelectric noise
- Minimizes self-inductance at frequencies below 1 MHz
- Minimizes the enclosed area to reduce pickup from magnetic fields
- Rib on one half cable allows easy identification
- Shielding is 100% using foil and copper braid construction
- Center conductor is equivalent to 20 gauge to minimize resistance
- Good flexibility makes it suitable for test leads
- Easily zippable

Specifications and Cross-Section View

Capacitance of one cable half: 106 picofarads/meter
Center resistance of one cable half: 36 milliohms/meter
Shield resistance of one cable half: 14 milliohms/meter
Loop inductance at 1 kHz: 1.1 microhenries/meter



Ordering Information	**Order Number**
Standard one meter calibration cable	DCOAX-1-BNC
Made-to-length BNC cable	DCOAX-(length in meters)-BNC
Cable without connectors	DCOAX-(length in meters)

For technical questions regarding this cable, or ordering information:

Call: 440-349-0370 **Fax: 440-349-0359**

E-mail: info@andeen-hagerling.com

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Last name:

Title:

Department:

Organization:

Mailing address:

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If you can, please mention something about your application(s) for our products:

Please check all printed Andeen-Hagerling publications you wish to receive at your mailing address:

☐ MODEL 2500A, 1 kHz Automatic Capacitance Bridge, Product Brochure
☐ AH 1100 Capacitance Standard Frame, AH 11A Fused-Silica Capacitance Standard, Product Brochure
☐ DCOAX Cable, Product Brochure
☐ Substantive Differences between the AH 2500A without and with the Option-E: “What the Option-E buys you”
☐ AH 2700A Multi-frequency Ultra-precision Capacitance/Loss Bridge, Specifications

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DOWNLOAD - LabVIEW DRIVERS

The Andeen-Hagerling Model 2500A bridge includes an IEEE-488 (1978) standard interface to allow connection to an instrument bus. Often users integrate the bridge into computer systems via GPIB controller boards and configure the system with LabVIEW, a product of National Instruments. (This is also possible with the RS-232 interface.) The LabVIEW program defines but does not include a “virtual instrument” driver, the software LabVIEW needs to communicate with the Andeen-Hagerling Model 2500A. Such “virtual instrument” drivers, or “vi's,” have been written and kindly contributed by our customers. No technical support for these drivers is provided.

- Download AH_READ.ZIP (41,886 bytes) by Dr. Fang Zhong - a ZIP file containing two compressed files
  - AH_READ.VI (37,657 bytes) low level driver for AH2500A commands: “single” and “continuous” measurements
  - AH_READ2.VI (102,688 bytes) (requires AH_READ.VI) additional functionality for AH2500A commands: “voltage,” “DC bias,” and “average time”

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If you wish to contribute LabVIEW drivers or improvements, please e-mail to webmaster@andeen-hagerling.com.

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TECHNICAL SUPPORT ARTICLES

Complete documentation is contained in the “Operation and Maintenance Manual” provided with the 2500A and 2700A Capacitance Bridges. The articles posted here supplement the manuals:

- AH2500A to IBM PC Type Serial Port
- AH2700A to IBM PC Type Serial Port

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AH2500A to IBM PC Type Serial Port

Back to Andeen-Hagerling technical support index

To attach an Andeen-Hagerling 2500A bridge to an IBM PC Type Serial Port and command the bridge from the PC:

The official documentation is in the "Operation and Maintenance Manual." Here are some shortcuts. You need a cable to physically connect, an unused serial port on the PC and a terminal emulation program running on the PC.

Physical Connection

- The connectors are of type DB-25 (25 pins) on the bridge and some ports of the PC. Other serial ports on PCs have DB-9 (9 pins). Bridge and PC serial ports are all male. PC parallel ports are all female. Do not cross connect serial and parallel ports: the result is usually permanent destruction of the parallel port.
- If you have a DB-25 male on the PC, the connection is usually simple. A cable is needed with female DB-25 on both ends, and only pins 2, 3 and 7 are required. But pins 2 and 3 must cross (that is, 2 on one connector attached to 3 on the other connector of the cable and vice versa). This is usually called a null modem cable.
- If a "straight" (not null modem) cable is available, with pins 2, 3 and 7 run through the cable without 2 and 3 reversing, enter the command "BAUD .1" on the bridge front panel and also "STORE BAUD 1" if you like, so the change is permanent. Henceforth, the bridge will do the needed reversing internally. Contrapositively, enter "BAUD .0" and "STORE BAUD 1" to undo this.
- If you have a DB-9 (male of course) on the PC, you need pin 5 on the DB-9 connected to pin 7 on the DB-25 (for ground), and pins 2 and 3 on the DB-9 connected to pins 2 and 3 of the DB-25 without reversing.
- Usually, there are several serial ports on a PC, and you need to know which you are using. If you can't tell, try finding out which ports are already attached to other things, so narrowing down the number of possibilities. In any case, you can always try them all. Usually, the PC serial ports are named COM1:, COM2:, COM3: and COM4:.
- Attach the cable. If your computer goes berserk, you've connected to a port with some driver running on it, and so disconnect the cable, reboot and see what you have done wrong.

Running the Terminal Emulation

- The standard terminal emulation program is called "HyperTerminal" and is on Windows 95 and Windows 98, though probably in different places in the Start Menu. A reference to the program is probably under Programs|Accessories in Windows 95, and in Programs|Accessories|Communications in Windows 98.

- This selection may ask you immediately if you want a new connection (that is, the program is running) or merely drop you in a folder. In this latter case, find "Hypertrm.exe" (or maybe just "Hypertrm") and select to run it.
- Now you are asked to name the connection, which is anything you please and can easily remember, or perhaps you must select from the menu File|New Connection first.
- You will then configure the connection through a dialog box, an entry of which will identify the device, usually, patronizingly, your modem. You aren't interested in a modem, but the list should include entries of the form "Direct to COM<number>:" and select that, where <number> is the port on the PC to which the cable is attached.
- Press the button labelled "Configure" in this first dialog box to make another dialog box pop up that has the RS-232 configuration: including baud rate, data bits, parity, stop bits and flow control.
- Select these configuration parameters to match the bridge defaults (you can tweak them later): 9600 baud, 8 data bits, no parity, 1 stop bit and Xon/Xoff flow control.
- Press OK until the dialog boxes clear and you return to the main window of HyperTerminal.
- Press Enter several times as an experiment. You should see a prompt from the bridge ">" (a greater than sign). Then type "single" and press Enter to see that the bridge takes and reports a measurement to confirm that it is working.
- In case of trouble: try selecting from the HyperTerminal menu: Call|Disconnect and then press Enter again as an experiment. (Sometimes configuration option changes don't get a clean restart without this command). Also try toggling power on the bridge for the same reason. If you are relying on a "BAUD .1" command (see above) and did not do "STORE BAUD 1" then "BAUD .1" must be entered again on the bridge front panel after power is reapplied. Also try quitting HyperTerminal entirely and restarting that program.
- If the configuration seems bad, you can get back to the appropriate window in HyperTerminal by selecting from its menu File|Properties.
- If all goes well with HyperTerminal, select from the menu "File|Save" and the connection configuration will be available next time by the name you entered for the connection this time.
- There are many interesting problems that could occur that aren't described here. Most of the problems are common to all RS-232 connections with PCs, so any generic documentation on the topic is useful. And, although it takes a while to learn to use it, an RS-232 diagnostic tool with LEDs and jumper wires is very handy. A useful hardware remedy is always to have a selection of RS-232 cables, adapters and doodads (variously called gender menders, sex changers and null modems) and attach these at random until something good happens.
- Eventually, while connected via RS-232 to the bridge, you will want to enter the command "define terminal video".

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AH2700A to IBM PC Type Serial Port

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To attach an Andeen-Hagerling 2700A bridge to an IBM PC Type Serial Port and command the bridge from the PC:

The official documentation will be in the "Operation and Maintenance Manual." Here are some shortcuts. You need a cable to physically connect, an unused serial port on the PC and a terminal emulation program running on the PC.

Physical Connection

- The connectors are of type DB-9 (9 pins) on the bridge and some ports of the PC. Other serial ports on PCs have DB-25 (25 pins). Bridge and PC serial ports are all male. PC parallel ports are all female. Do not cross connect serial and parallel ports: the result is usually permanent destruction of the parallel port.
- If you have a DB-9 male on the PC, the connection is usually simple. A cable is needed with female DB-9 on both ends, and only pins 2, 3 and 5 are required. But pins 2 and 3 must cross (that is, 2 on one connector attached to 3 on the other connector of the cable and vice versa). This is usually called a null modem cable.
- If you have a DB-25 (male of course) on the PC, you need pin 7 on the DB-25 connected to pin 5 on the DB-9 (for ground), and pins 2 and 3 on the DB-25 connected to pins 2 and 3 of the DB-9 without reversing.
- Usually, there are several serial ports on a PC, and you need to know which you are using. If you can't tell, try finding out which ports are already attached to other things, so narrowing down the number of possibilities. In any case, you can always try them all. Usually, the PC serial ports are named COM1:, COM2:, COM3: and COM4:.
- Attach the cable. If your computer goes berserk, you've connected to a port with some driver running on it, and so disconnect the cable, reboot and see what you have done wrong.

Running the Terminal Emulation

- The standard terminal emulation program is called "HyperTerminal" and is on Windows 95, Windows 98, etc., though probably in different places in the Start Menu. A reference to the program is probably under Programs|Accessories in Windows 95, and in Programs|Accessories|Communications in Windows 98.
- This selection may ask you immediately if you want a new connection (that is, the program is running) or merely drop you in a folder. In this latter case, find "Hypertrm.exe" (or maybe just "Hypertrm") and select to run it.
- Now you are asked to name the connection, which is anything you please and can easily remember, or perhaps you must select from the menu File|New Connection first.

- You will then configure the connection through a dialog box, an entry of which will identify the device, usually, patronizingly, your modem. You aren't interested in a modem, but the list should include entries of the form "Direct to COM<number>:" and select that, where <number> is the port on the PC to which the cable is attached.
- Press the button labelled "Configure" in this first dialog box to make another dialog box pop up that has the RS-232 configuration: including baud rate, data bits, parity, stop bits and flow control.
- Select these configuration parameters to match the bridge defaults (you can tweak them later): 9600 baud, 8 data bits, no parity, 1 stop bit and Xon/Xoff flow control.
- Press OK until the dialog boxes clear and you return to the main window of HyperTerminal.
- Press Enter several times as an experiment. You should see a prompt from the bridge ">" (a greater than sign). Then type "single" and press Enter to see that the bridge takes and reports a measurement to confirm that it is working.
- In case of trouble: try selecting from the HyperTerminal menu: Call|Disconnect and then press Enter again as an experiment. (Sometimes configuration option changes don't get a clean restart without this command). Also try toggling power on the bridge for the same reason. Also try quitting HyperTerminal entirely and restarting that program.
- If the configuration seems bad, you can get back to the appropriate window in HyperTerminal by selecting from its menu File|Properties.
- If all goes well with HyperTerminal, select from the menu "File|Save" and the connection configuration will be available next time by the name you entered for the connection this time.
- There are many interesting problems that could occur that aren't described here. Most of the problems are common to all RS-232 connections with PCs, so any generic documentation on the topic is useful. And, although it takes a while to learn to use it, an RS-232 diagnostic tool with LEDs and jumper wires is very handy. A useful hardware remedy is always to have a selection of RS-232 cables, adapters and doodads (variously called gender menders, sex changers and null modems) and attach these at random until something good happens.
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