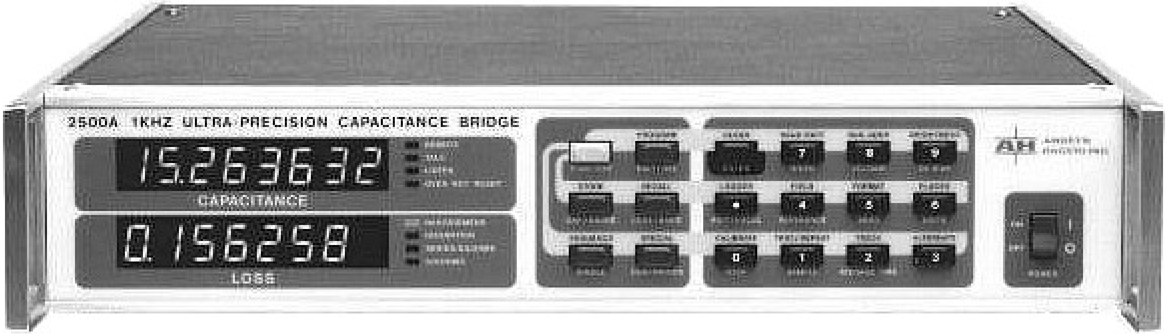
ANDEEN-HAGERLING

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
- **Please note: The non-option-E version of the AH2500A has been replaced by the AH2550A bridge. Please refer to the AH2550A page on this site.**

[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.

AH 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:

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

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 $+1.7 \times 10^{-5}$ G ohm to $+1.7 \times 10^{6}$ 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.

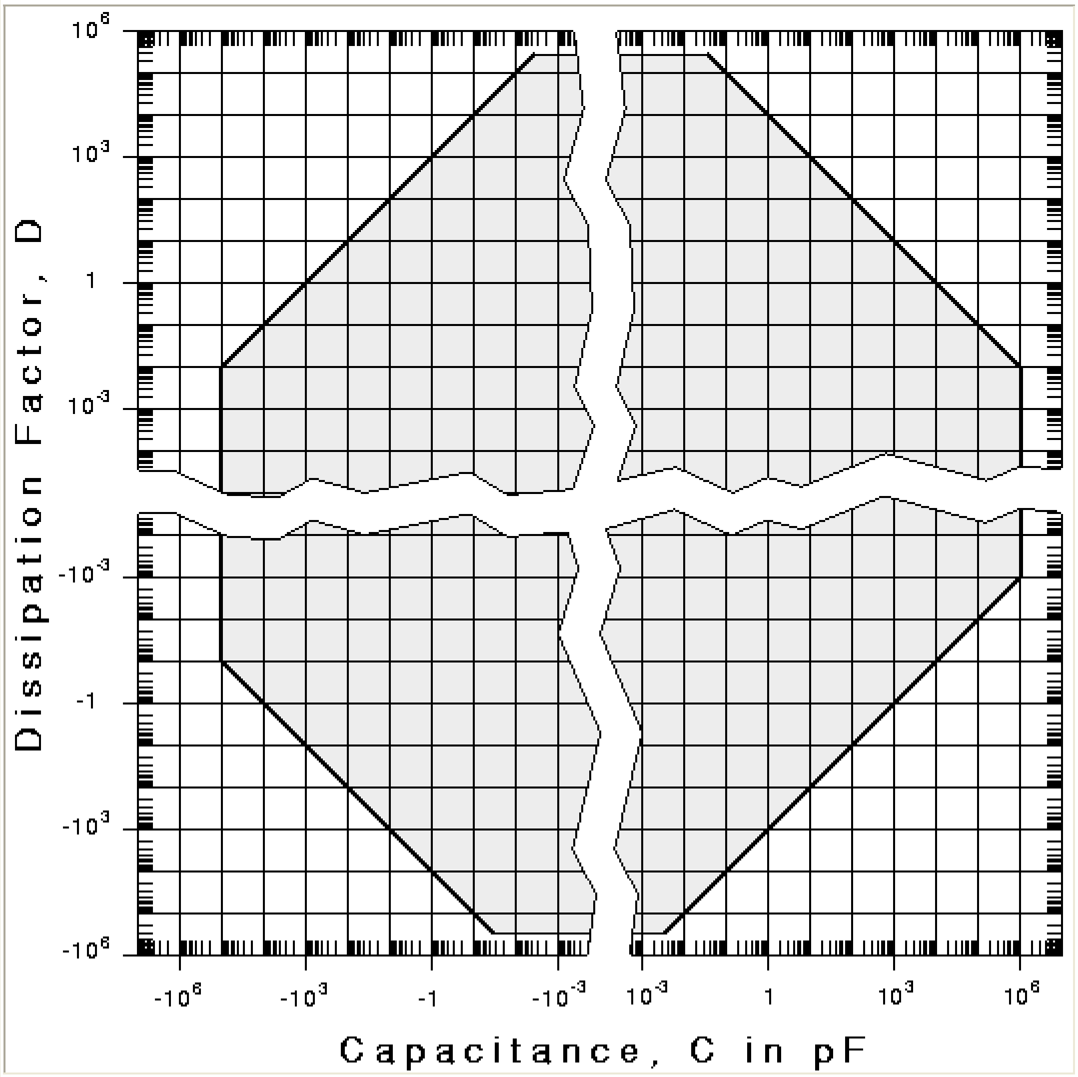


Figure 1. The measurable values of C and D are enclosed within the shaded area.

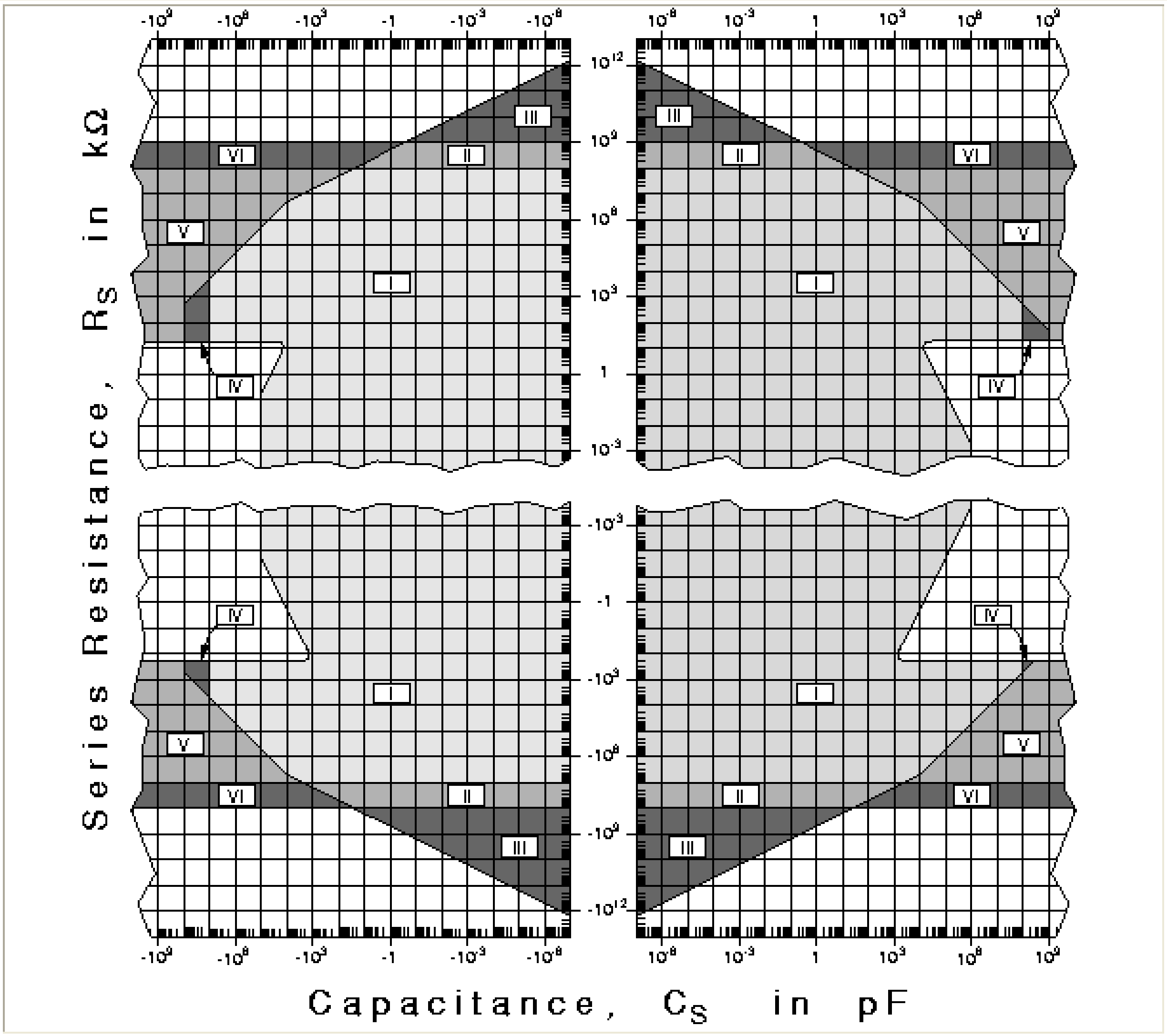


Figure 2. The values of C_S and R_S are measurable in the six shaded regions. In five of these regions, one or both of the measured values are too large to report on the 2500A's display. In three of these five regions, one or both values are also too large to send to any remote devices. The table below 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:

$t_b = 0.05 \times 2^T$ 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:* $\{0.15C + 50DC + [7.5(1+n_C) + n_V C]/V\} \times 10^{-6}$ pF

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

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

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

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

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

where $n_C = 1.4t^{-1/2}$ 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 $R_s = 1.6 \times 10^5 D/C(1+D^2)$.

Resolution in ppm:[4]

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

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

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

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

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:* $\pm\{0.15 + 50D + 7.5/CV + 15 \times 10^{-6} C\}$

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

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

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

Series: *C_S:* $\pm\{0.15 + 50D + 7.5(1+D^2)/C_S V + 15 \times 10^{-6} C_S/(1+D^2)\}$

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

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: $\pm\{2 + 3x10^{-4}C + (1+D^2)^{1/2}[200D + (0.2 + 7.5/C)/V]\}/D$

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: $\pm\{30 + [2C + 3x10^{-4}C^2 + (15 + 0.06C)/V]/G\}$

D: $\pm\{0.3 + 5x10^{-5}C + (1+D^2)^{1/2}[30D + (0.01 + 2.5/C)/V]\}/D$

R_P: $\pm\{30 + [2C + 3x10^{-4}C^2 + (15 + 0.06C)/V]R_P\}$

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: $\pm\{30 + [0.2 + 2x10^{-5}C + 0.012/V]C/G + 100/(1 + GV)\}$

D: $\pm\{[0.03 + 3x10^{-6}C + (1+D^2)^{1/2}(30D + 0.002/V)]/D + 15/(0.15 + CV) + 15/(0.15 + CDV)\}$

R_P: $\pm\{30 + [0.2 + 2x10^{-5}C + 0.012/V]CR_P + 100/(1 + V/R_P)\}$

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

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

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: $\pm\{20 + [2C + 2x10^{-4}C^2 + (15 + 0.02C)/V]/G\}$

D: $\pm\{0.3 + 3x10^{-5}C + (1+D^2)^{1/2}[20D + (0.003 + 2.5/C)/V]\}/D$

R_P: $\pm\{20 + [2C + 2x10^{-4}C^2 + (15 + 0.02C)/V]R_P\}$

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: $\pm\{10 + [0.2 + 2x10^{-5}C + 0.006/V]C/G + 15/(1 + GV)\}$

D: $\pm\{[0.03 + 3x10^{-6}C + (1+D^2)^{1/2}(10D + 0.001/V)]/D + 2/(0.15 + CV) + 2/(0.15 + CDV)\}$

R_P: $\pm\{10 + [0.2 + 2x10^{-5}C + 0.006/V]CR_P + 15/(1 + V/R_P)\}$

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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