Calibration Certificate
and
OPERATING INSTRUCTIONS

COAXIAL CAPACITANCE STANDARD

Type 1405-

pF
NOMINAL CAPACITANCE

Serial No.

± % at 1 kHz
ADJUSTMENT ACCURACY

Measured Capacitance

pF

Frequency

1 kHz

Temperature

±2°C

Relative Humidity

%

MEASURED CAPACITANCE: The measured capacitance above is the capacitance at the reference plane of the GR900® connector. It was obtained by comparison with working standards whose absolute values are known to an accuracy of ±0.01%. The comparison was made to a precision better than ±0.001 pF.

The values of the working standards are determined and maintained in terms of reference standards periodically calibrated by the National Bureau of Standards.

DATE **BY**

STANDARDIZING LABORATORY

		1405-A, 20 pF	1405-B, 10 pF	1405-C, 5 pF	1405-D, 2 pF	1405-E, 1 pF
Accuracy		±0.1% (0.02 pF)	±0.2% (0.02 pF)	±0.2% (0.01 pF)	±0.25% (0.005 pF)	±0.5% (0.005 pF)
Adjustment Accuracy		±0.02%	±0.04%	±0.04%	±0.1%	±0.2%
Stability	temperature	−0.002%/°C	−0.004%/°C	+0.002%/°C	−0.004%/°C	−0.01%/°C
	humidity	—	—	+0.001%/% RH	+0.0025%/% RH	+0.005%/% RH
	aging, C change/yr	<0.1%	<0.1%	<0.1%	<0.15%	<0.3%
Frequency	0.1% C increase	30 MHz	40 MHz	60 MHz	100 MHz	120 MHz
	10% C increase	0.3 GHz	0.4 GHz	0.75 GHz	1 GHz	1.7 GHz
Residuals	D at 1 kHz	$<150 \times 10^{-6}$		$<100 \times 10^{-6}$		
	insulation R	$>10^{12}$ Ω at 23°C and <50% RH				
	equivalent L	1.4 nH at <250 MHz	1.6 nH at <250 MHz	1.4 nF at <500 MHz	1.2 nH at <500 MHz	1.8 nH at <500 MHz
Peak Volts		1 kV	1 kV	1 kV	1 kV	3 kV

GENERAL RADIO COMPANY WEST CONCORD, MASSACHUSETTS

Type 1405
COAXIAL CAPACITANCE STANDARDS

SPECIFICATIONS

Calibration: See Calibration Certificate.

Accuracy: Capacitance adjusted to within tolerance given in table.

Residual Impedances: Dissipation factor at 1 kHz, $<30 \times 10^{-6}$ for -C, -D; $<40 \times 10^{-6}$ for -E; insulation resistance is $>10^{12}\ \Omega$ at 23°C, <50% RH. Effect of series inductance and other factors is given in table below in terms of the frequency at which it causes a 10% increase in measured capacitance.

Accessories Available: Adaptors 1615-P2 for calibrating with GR 1615 bridge and 900-Q9 for connecting standard to ¼-inch x 28 threaded stud (GR 938 Binding Post) or tapped hole.

Terminal: GR900 precision coaxial connector.

Dimensions (diameter x height): 1 1/16 x 2 5/16 in. (27 x 59 mm).

Weight: Net, 4 oz (103 g); shipping, 5 oz (150 g).

Catalog Number	Type	Nominal Capacitance	Accuracy	Peak Volts	Frequency for 10% C Increase
1405-9702	**1405-C**	5 pF	±0.010 pF	1 kV	0.75 GHz
1405-9701	**1405-D**	2 pF	±0.005 pF	1 kV	1.0 GHz
1405-9700	**1405-E**	1 pF	±0.005 pF	3 kV	1.7 GHz

Figure 1-1. Type 1405-D Coaxial Capacitance Standard.

CAUTION

Keep the connector clean. Use the protective cap when the standard is not in use.

1 INTRODUCTION

1.1 PURPOSE.

The 1405 Coaxial Capacitance Standards are two-terminal, precision capacitors ideally suited for use as high-frequency capacitance standards. Low inductance, low rf losses, and repeatability of connections of these capacitors permit accurate, traceable calibration of high-frequency bridges and other impedance-measuring instruments.[1]

1.2 DESCRIPTION.

The 1405 capacitance standards use GR900® Precision Coaxial Connectors for terminals. These connectors have the stability, repeatability, and the well-defined reference plane required for accurate two-terminal measurements at high frequencies. Precision coaxial connectors (such as the GR900) are compatible with the National Bureau of Standards system and recommended for higher calibration accuracy.[2]

Refer to the table and specifications above for a complete listing of the 1405 models available.

Physically, the 1405 is a coaxial-line capacitor with stable PPO (Polyphenylene Oxide) support rods. These PPO supports are naturally resistant to effects from humidity at low frequencies. Their immunity to humidity is further improved by coating the rods with silicone.

The coaxial-line inner-conductor in the GR900 terminal is built up to increase the capacitance as required, and flatten the frequency response. The built-up section is set back from the reference plane so that interaction with devices connected to the 1405 is reduced.

In the 1405-C, -D, and -E capacitors, the inner conductor is cantilevered from a support rod. All 1405 capacitors have trimmers that are factory adjusted for the exact value of capacitance desired.

1.3 ACCESSORY EQUIPMENT.

The 1615 Capacitance Bridge (part of 1620-A Capacitance-Measuring Assembly) and the 1615-P2 Coaxial Adaptor are recommended for low-frequency calibration of the capacitors (refer to paragraph 4.3). Refer to the appendix for details and specifications.

2 OPERATING PROCEDURE

2.1 MATING OF GR900 CONNECTORS.

The GR900 Precision Coaxial Connector on the 1405 will mate with any other GR900 connector. Since only one locking nut is used per junction, the unused nut is stored at the rear of one of the connectors. The mating procedure is as follows (see Figure 2-1):

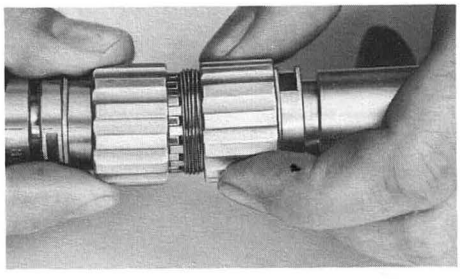

Figure 2-1. Mating of GR900 connectors.

a. To store the locking nut, slide it back until the threads engage. Then thread it back off the centering gear ring and slide it back as far as it will go.

b. Move the locking nut of the other connector back slightly. Align the connectors axially and engage the teeth of the centering gear rings in any convenient orientation.

c. Hold the connectors in the joined position, thread the active locking nut over the centering gear ring of the mating connector, and hand tighten.

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[1] Reference *General Radio Experimenter*: Vol 42, No. 5, May 1968.

[2] R. N. Jones and L. E. Huntley, "Precision Coaxial Connectors in Lumped Parameter Immittance Measurement," *Proceedings of the IEEE*, Vol 55, No. 6, June 1967.

Federal Register, Vol 32, No. 15, 24 January, 1967.

R. N. Jones and R. L. Jesch, *High Frequency Immittance Calibration Services of the National Bureau of Standards*, U.S. Department of Commerce, National Bureau of Standards, October 1, 1965.

D. E. Fossum "Progress Report of the IEEE Instrumentation and Measurement Group Technical Subcommittee on Precision Coaxial Connectors," *IEEE Transactions on Instrumentation and Measurement*, Vol IM-13, No. 4, December 1964.

2.2 CORRECTION FOR FRINGE CAPACITANCE.

The 1405 capacitor is calibrated for the capacitance value at the reference plane of its connector. This value does not include the fringe capacitance that exists outside of its reference plane. (Refer to paragraph 3.2.) Therefore, when the capacitance standard is used with an instrument that measures capacitance at the reference plane of the connector, no special correction for fringe capacitance is necessary.

However, using an instrument that measures the change in capacitance (or impedance) from open terminals is more complicated. This type of measurement involves two readings, one with open terminals (that includes the fringing capacitance), and another reading with the capacitor connected. In this case, the difference between the two readings is the value of the standard minus the value of fringe capacitance (0.155 ±0.008 pF for open GR900 connectors, or 0.172 ±0.008 pF with the GR 900-WO Precision Open Circuit installed).

$$\Delta C = C_S - C_f$$

Where C_S = value of standard added
C_f = fringe capacitance

If greater precision is required, the uncertainty (±0.008 pF) of the fringe capacitance can be reduced by simply substituting a known value of capacitance for the open-connector capacitance when taking the first measurement. This small capacitor, such as the 1405-E (1 pF), must have an accurately known value of capacitance at its reference plane. Thus, the difference between the first and second readings will be the true difference between the two known values with no uncertainty due to fringe capacitance.

The guard method (refer to paragraph 4.3), using a GR 1615 Capacitance Bridge, is an alternate means of correcting for fringe capacitance when precision measurements are required.

3 PRINCIPLES OF OPERATION

3.1 GENERAL.

Refer to the General Radio Catalog for a general discussion of the characteristics of standard capacitors. For specific information on the use of 1405 standards using GR900 connectors, refer to the following paragraphs.

3.2 FRINGE CAPACITANCE.

An open coaxial connector on a measuring instrument, as shown in Figure 3-1, has stray (fringe) capacitance (C_f) extending beyond the reference plane. A reading with the instrument using this connector in the open-circuit state, shown in Figure 3-1, would include the internal capacitance (C_o) plus the fringe capacitance (C_f).

When two coaxial connectors are properly mated, or when a guard is used, the fringe capacitance is eliminated as shown in Figure 3-2. The reference planes of the two connectors effectively become a single plane of reference with no stray capacitance existing between them. A second reading would include the internal capacitance (C_o) plus the added capacitance (C_S) of the

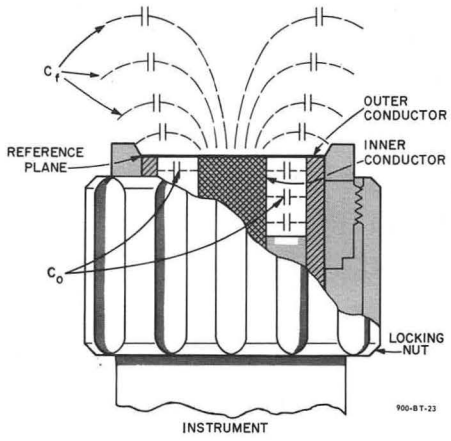


Figure 3-1. Open GR900 Precision Coaxial Connectors showing internal capacitance (C_o) and fringe capacitance (C_f).

standard and its connector. Thus, the fringe capacitance must be added to the difference between the two readings to obtain the true value of the standard capacitor.

3.3 FREQUENCY CHARACTERISTICS.

The distributed configuration of the capacitor causes its effective capacitance to increase with frequency as shown in Figure 3-3. The capacitance of 1405's changes very little with frequency. The change is so small at the lower radio frequencies that correction will be unnecessary, except for the most precise measurements.

3.4 DISSIPATION FACTOR.

At low frequencies (1 kHz, for example), and under conditions of moderate humidity and temperature, the dissipation factor of an air-capacitor standard is largely determined by losses in the insulating supports. With high humidity, losses caused by moisture on the insulators and plate surfaces become significant.

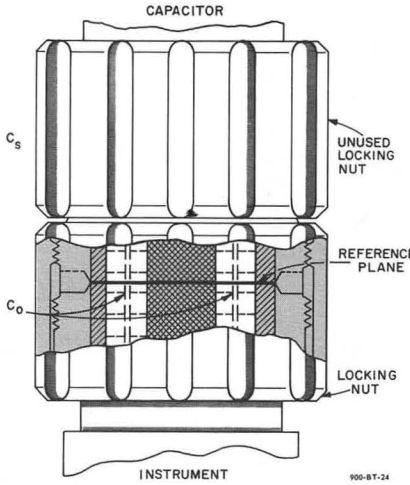


Figure 3-2. Two GR900 Precision Coaxial Connectors. A common reference plane is established and fringe capacitance is eliminated when connectors are properly mated.

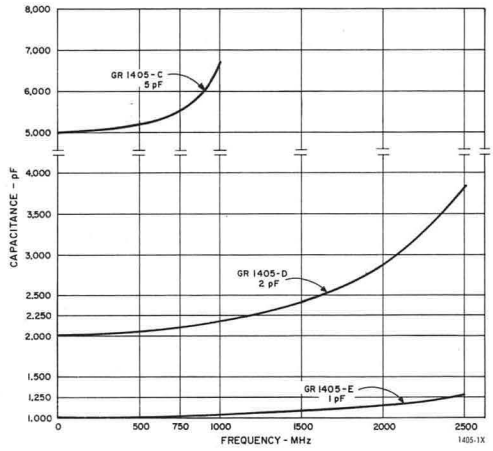


Figure 3-3. Typical increase (%) in value of 1405 Coaxial Capacitance Standards, with frequency.

At higher frequencies, losses result from the resistance of the coaxial line and the insulating supports. In the 1405 standards, PPO (Polyphenylene Oxide) insulators with a special coating are used to minimize losses under all conditions of humidity and temperature.

3.5 EFFECTS OF HUMIDITY.

Changes in humidity affect the value of capacitance in two ways: by changing the dielectric constant of the air (about 2.5 ppm for each percent change in relative humidity), and because of moisture that collects on the insulators and plate surfaces. The change due to moisture becomes particularly important with the smaller values of capacitance, and at lower frequencies. For example, at a frequency of 1 kHz, the change due to moisture will be considerably greater than the change due to an increase in the dielectric constant of the air. This effect is negligible at high frequencies and should be considered only when preparing to calibrate the capacitor at low frequencies.

4 SERVICE AND MAINTENANCE

4.1 WARRANTY.

We warrant that each new instrument manufactured and sold by us is free from defects in material and workmanship and that, properly used, it will perform in full accordance with applicable specifications for a period of two years after original shipment. Any instrument or component that is found within the two-year period not to meet these standards after examination by our factory, District Office, or authorized repair agency personnel will be repaired or, at our option, replaced without charge, except for tubes or batteries that have given normal service.

4.2 SERVICE.

The two-year warranty stated above attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible. If the difficulty cannot be eliminated by use of the following service instructions, please write or phone our Service Department (see rear cover), giving full information of the trouble and of steps taken to remedy it. Be sure to mention the serial and type numbers of the instrument.

Before returning an instrument to General Radio for service, please write to our Service Department or nearest District Office, requesting a "Returned Material Tag". Use of this tag will ensure proper handling and identification. For instruments not covered by the warranty, a purchase order should be forwarded to avoid unnecessary delay.

4.3 CALIBRATION.

It is recommended that calibration of the 1405 be made at a frequency of 1 kHz, using a GR 1615 Capacitance Bridge (or GR 1620 Capacitance-Measuring Assembly, refer to appendix) fitted with a GR 1615-P2 Adaptor. Two methods of calibration are described in the following paragraphs; for details on the general use of this equipment for calibrating capacitance standards of all types, refer to the individual instructions furnished with the equipment.

Correction Method. This procedure (refer to paragraph 2.2) involves the subtraction of the fringing capacitance from the final reading. The results obtained are adequate for all but the most precise requirements.

The GR 900-WO Precision Open Circuit is recommended because it establishes a well-shielded open circuit, thus shielding the measurement system and eliminating undesirable field effects from objects in the immediate proximity.

Guard Method. This is the more accurate of the two calibrating procedures. Instead of correcting for the fringe capacitance, it is guarded out with a system comprised of a GR 900-Q874 (or GR 874-Q900L) Adaptor, a GR 874-R22A (or GR 874-R22LA) Patch Cord, installed on a GR 1615 Capacitance Bridge fitted with a 1615-P2 Adaptor. The procedure is as follows:

a. Connect the patch cord to the UNKNOWN (H) GR874® connector on the bridge.

b. Connect the 900-Q874 (or 874-Q900L) adaptor to the other end of the patch cord.

c. Remove the inner-conductor contacts from the 900-Q874 and the 1615-P2 (installed on the bridge), using a 1/16-inch Allen wrench. (Store the contacts in a safe place to prevent damage.)

d. Connect the 900-Q874 to the 1615-P2 on the bridge.

e. On the bridge: set the C MAX switch to the desired capacitance range, the CAPACITANCE and DISSIPATION FACTOR switches to zero, and the D MAX switch to 0.01 (white). Set the Mx switch to produce a null, while adjusting the zero-adjust control on the 1615-P2.

NOTE

To obtain a satisfactory null, and the most accurate D reading, it may be necessary to adjust the 2 TERM ZERO ADJ (R) screwdriver adjustment located under the removable panel (just above the DISSIPATION FACTOR switches) on the bridge panel.

f. Remove the guard system, replace the inner-conductor contact in the 1615-P2, and proceed with a normal calibration.

The 1405 is an extremely stable capacitance standard. It is always possible, however, to subject it accidently to excessive shock which could result in a change in capacitance. In the case of a capacitance change such as this, the inductance will not change significantly, and 1-kHz measurements can be used to detect capacitance changes that will affect high-frequency calibration. When the capacitance change is small, such as that which might occur with normal aging and handling, the change in capacitance at high frequencies will always be proportional to the change at 1 kHz.

4.4 MAINTENANCE.

4.4.1 General.

Maintenance and parts replacement should be limited to the external parts of the capacitor.

CAUTION

Do not remove the case unless it is necessary. If the case must be removed, avoid handling internal parts and do not attempt to disassemble or make adjustments.

4.4.2 Parts Replacement.

The parts that may need replacement at some time are listed as follows:

Catalog No.	Description
0900-7190	Protective Cap, white plastic
0900-2000	Inner-Contact Assembly, on GR900 connector.

To replace the Inner-Contact Assembly on the connector, remove the old contact assembly, using a 1/16 Allen wrench, and thread the replacement assembly in its place. Tighten firmly, but avoid using excessive torque.

4.4.3 Contact Cleaning.

The butt surfaces of the connector must be kept clean, both at the outer-and inner-contact junctions. When there is evidence of dirt on these surfaces, or poor make-break repeatability, cleaning is necessary. Only certain solvents may be used in cleaning; Freon TF, denatured alcohol, synthetic methanol, grain alcohol, and petroleum ether are recommended. Liquid cleaning is generally more effective than dry cleaning; abrasive cleaning can remove the protective plating and is not recommended. The GR 900-TOC is recommended as a suitable cleaning kit, complete with detailed instructions on cleaning GR900 connectors.

Poor repeatability results also if the inner conductor of the mating connector (with contact removed) protrudes beyond the outer conductor. The end of the inner conductor must be flush with, or below (0 to 0.002 inch), the front face of the outer conductor.

APPENDIX

TYPE 1615-P2 COAXIAL ADAPTOR

specifications

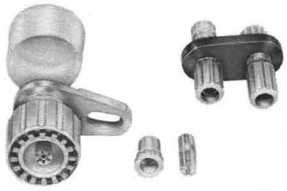
Capacitance Range When Mounted on Type 1615 Terminals:
Maximum: ≥5.6 pF
Minimum: ≤5.2 pF

Fringing Capacitance
With Open GR900 Connector: 0.155 pF ±0.008 pF
With GR900-WO: 0.172 pF ±0.008 pF

Inductance: 25 nH (typical)

Catalog Number	Description
1615-9602	**1615-P2 Coaxial Adaptor,** GR900 to 1615 Bridge

TYPE 900-Q9 ADAPTOR



specifications

CONVERSION OF BINDING POSTS TO GR900 CONNECTOR

Capacitance: Added by adaptor to Type 938 Binding Posts (3/4-inch spacing) on 2-terminal bridge, typically 3.55 pF, not including the 0.155 pF fringing capacitance of the GR900 connector.

Inductance: Typically 4.8 nH.

CONVERSION OF GR900 CONNECTOR TO BINDING POSTS (Adaptor plus binding-post assembly)

Capacitance: Typically 5.2 pF.

Inductance: Typically 10.9 nH.

Catalog Number	Description
0900-9874	**900-Q9 Adaptor,** GR900 to binding posts

ACCESSORIES

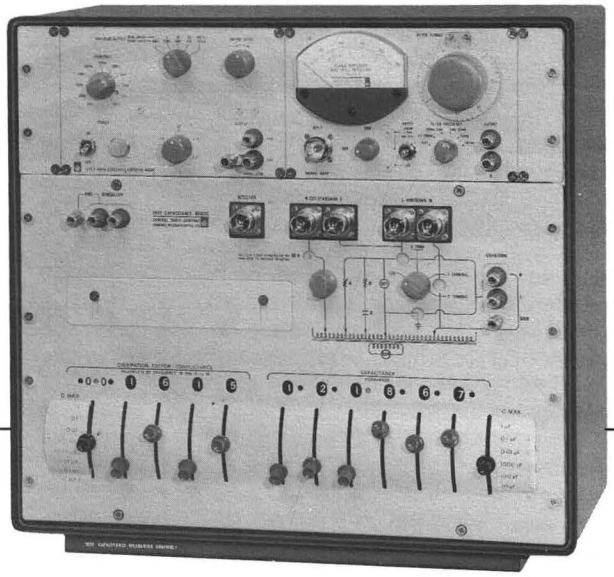
Catalog Number	Type		Description
0900-9883	900-Q874		ADAPTOR: contains GR900 and GR874 connectors.
0874-9709	874-Q900L		ADAPTOR: contains GR874 and GR900 connectors.

Catalog Number	Type		Description
0900-9981	900-WO		PRECISION OPEN-CIRCUIT TERMINATION: contains GR900 connector.
0874-9682	874-R22A		PATCH CORDS: three-foot patch cords with GR874 connectors (R22LA is locking).
0874-9683	874-R22LA		

CAPACITANCE-MEASURING ASSEMBLY

Type 1620-A

- 10^{-5} pF to 11.1 μF, 2- or 3-terminal
- 0.01% accuracy, 1 ppm resolution
- lever balance, in-line readout
- reads dissipation factor or conductance



1620-A Capacitance-Measuring Assembly including:
1615-A Capacitance Bridge, 1311-A Oscillator,
1232-A Tuned Amplifier and Null Detector

The 1620-A is a self-contained assembly of the GR 1615-A Capacitance Bridge with appropriate oscillator and null detector for measurements at 11 frequencies between 20 Hz and 20 kHz. For applications requiring other or higher frequencies, to 100 kHz, the 1615-A bridge can be supplied separately and the oscillator and detector selected as needed.

The 1620-A is intended for

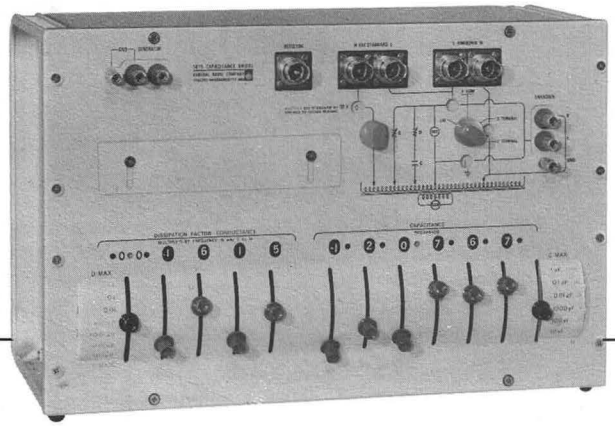
- accurate and precise measurements of capacitance and dissipation factor
- measurement of circuit capacitances
- dielectric measurements
- intercomparison of capacitance standards differing in magnitude by as much as 1000:1

The 1615-A Capacitance Bridge brings to the measurement of capacitance, to the intercomparison of standards, and to the measurement of dielectric properties an unusual degree of accuracy, precision, range, and convenience.

High accuracy is achieved through the use of precisely wound transformer ratio arms and highly stable standards fabricated from Invar and hermetically sealed in nitrogen. For calibration these standards can be intercompared.

Accurate three-terminal measurements can be made even in the presence of capacitances to ground as large as 1 μF as might be encountered with the unknown connected by means of long cables. The bridge has the necessary internal shielding to permit one terminal of the unknown to be directly grounded, so that both true two-terminal and three-terminal measurements can be made over the whole capacitance range.

Catalog Number	Description
1620-9701	**Capacitance-Measuring Assembly 1620-A**
1620-9829	**1620-AP, with 1232-P2 detector preamplifier**



CAPACITANCE BRIDGE

Type 1615-A

Catalog Number	Description
	1615-A Capacitance Bridge
1615-9801	Bench Model
1615-9811	Rack Model

GENERAL RADIO
West Concord, Massachusetts 01781

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