◆ PRECISION INSTRUMENTS FOR TEST AND MEASUREMENT ◆

MODEL 1422

Precision Variable Capacitor

User and Service Manual

1422 im/May, 2002

IET LABS, INC.
Standards • Decades • Strobes • Sound Level Meters • Bridges
Formerly manufactured by
GenRad
534 Main Street, Westbury, NY 11590
TEL: (516) 334-5959 • (800) 899-8438 • FAX: (516) 334-5988
www.ietlabs.com

INSTRUCTIONS

Type 1422 PRECISION CAPACITOR

The 1422 is a stable and precise variable air capacitor intended for use as a continuously adjustable standard of capacitance.

One of the most important applications is in ac bridge measurements, either as a built-in standard or as an external standard for substitution measurements. It is available in a variety of ranges, terminal configurations, and scale arrangements to permit selection of precisely the required characteristics.

Two-Terminal The 1422-D is a dual-range, two-terminal capacitor, direct reading in total capacitance at the terminals.

Three-terminal The 1422-CB, -CL, and -CD are three-terminal capacitors with shielded coaxial terminals for use in three-terminal measurements. The calibrated direct capacitance is independent of terminal capacitances to ground, and losses are very low. The 1422-CL has particularly low, constant terminal capacitances, making it suitable for measurement circuits in which high capacitance to guard cannot be tolerated.

Construction The capacitor assembly is mounted in a cast frame for rigidity. This frame and other critical parts are made of aluminum alloys selected to give the strength of brass with the lightness of aluminum. The plates of most models are also aluminum, so that all parts have the same temperature coefficient of linear expansion.

A worm drive is used to obtain high precision of setting. To avoid eccentricity, the shaft and the worm are accurately machined as one piece. The worm and worm wheel are also lapped into each other to improve smoothness. The dial end of the worm shaft runs in a self-aligning ball bearing, while the other end is supported by an adjustable spring mounting, which gives positive longitudinal anchoring to the worm shaft through the use of a pair of sealed, self-lubricating, preloaded ball bearings. Similar pairs of preloaded ball bearings provide positive and invariant axial location for the main or rotor shaft. Electrical connection to the rotor is made by means of a silver-alloy brush bearing on a silver-overlay drum to assure a low-noise electrical contact.

Stator insulation in all models is a cross-linked thermosetting modified polystyrene having low dielectric losses and very high insulation resistance. Rotor insulation, where used (Types 1422-CB and -CL), is grade L-4 steatite, silicone treated.

Accuracy The errors tabulated in the specifications are possible errors, i.e., the sum of error contributions from setting, adjustment, calibration, interpolation, and standards. When the capacitor is in its normal position with the panel horizontal, the actual errors are almost always smaller. The accuracy of the CL and CD units is improved when the readings are corrected using the 12 calibrated values of capacitance given on the correction chart on the capacitor panel and interpolating linearly between calibrated points. Even better accuracy can be obtained from a precision calibration of approximately 100 points on the capacitor dial, which permits correction for slight residual eccentricities of the worm drive and requires interpolation over only short intervals. This precision calibration is available for the CL and CD models at an extra charge. Models so calibrated are listed with the additional suffix letter, P, in the type number. A plastic-enclosed certificate of calibration is supplied, giving corrections to one more figure than the tabulated accuracy.

SPECIFICATIONS

Accuracy: See table.

Stability: .02% of full scale per year for the CL and CD, 0.5% of full scale per year for the D and CB models. Long-term accuracy can be estimated from the stability and the initial accuracy.

Calibration: Measured values (supplied with CL and CD) are obtained by comparison at 1 kHz, with working standards whose absolute values are known to an accuracy of ±(0.01% + 0.0001 pF). Each comparison is made to a precision better than ±0.01%.

		Two-Terminal		Three-Terminal			
Type 1422		-D		-CB	-CL	-CD	
CAPACITANCE RANGE, pF	Min	100	35	50	10	0.5	0.05
	Max	1150	115	1100	110	11	1.1
SCALE, pF/Division:		0.2	0.02	0.2	0.02	0.002	0.0002
INITIAL ACCURACY: ± Picofarads Direct-Reading (Adjustment): Total Capacitance		1.5*	0.3*	1.5*	0.1	0.04	0.008
With Corrections from Calibration Chart (supplied): Total Capacitance		N.A.	N.A.	N.A.	0.04	0.01	0.002
With Corrections from Precision Calibration (extra charge): Total Capacitance		N.A.	N.A.	N.A.	0.01	0.001	0.0002
RESIDUALS (typical values): Series Inductance, μH		0.06	0.10	0.14	0.13	0.17	0.17
Series Resistance, ohms at 1 MHz		0.04	0.05	0.1	0.1		
Terminal Capacitance, pF, typical:	high terminal to case	min scale		36	34	98	25
		max scale		35	33	74	23
	low terminal to case	min scale		58	58	117	115
		max scale		53	55	92	93

* Total capacitance is the capacitance added when the capacitor is plugged into a 777-Q3 Adaptor.

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

The indicated value of total capacitance of a two-terminal capacitor is the capacitance added when the 1422 Capacitor is plugged into a 777-Q3 Adaptor. The uncertainty of this method of connection is approx ±0.03 pF.

Resolution: Dial can be read and set to 1/5 of a small division, i.e., to 0.004% of full scale. BACKLASH: Negligible for any setting reached consistently from lower scale readings; <0.004% of f s, for settings reached from alternate directions.

Temperature Coefficient: Approx +20 ppm/°C, for small temperature changes.

Residual Parameters: See table. Series resistance varies as $\sqrt{f}$, for $f > 100$ kHz; negligible, for $f < 100$ kHz.

Frequency Characteristic: 2-terminal model, see curve. 3-terminal models: 20, 40, and 60 MHz (approx) resonant frequency for 1422-CB, -CL, and -CD (each section), respectively.

Dissipation Factor: 2-terminal, loss primarily in stator supports of low-loss polystyrene (the product $DC \approx 10^{-14}$). 3-terminal, estimated $D < 20 \times 10^{-6}$; except, for 1422-CD, $< 10 \times 10^{-6}$. INSULATION RESISTANCE: $> 10^{12}\ \Omega$, under standard conditions (23°C, RH < 50%).

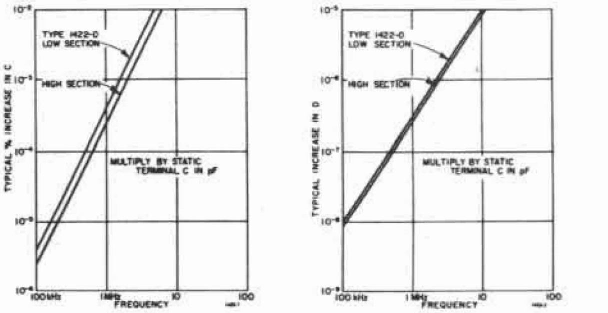
Max Voltage: 1000 V pk (all models).

Terminals: 2-TERMINAL MODEL: Jack-top binding posts at standard (0.75-in.) spacing. Rotor terminal connected to panel and shield. 3-TERMINAL MODELS: Locking GR874® coaxial connectors.

Required: For 3-terminal models, two GR874 Patch Cords, or equivalent.

Available: For 2-terminal model, 777-Q3 Adaptor. (See "Calibration," above.)

Mechanical: Lab-bench cabinet. DIMENSIONS (wxhxd): 9.5x7x8.5 in. (242x178x216 mm). WEIGHT (depending on model): 10.5 to 12.5 lb (4.8 to 5.7 kg) net, 15 lb (7 kg) shipping.



Variation with frequency of effective capacitance and dissipation factor per pF of capacitance for two-terminal 1422 Precision Capacitors.

Description	Catalog Number
Precision Capacitors	
with precision calibration (≈ 100 points)	
1422-CLP	**1422-9508**
1422-CDP	**1422-9925**
with standard calibration (12 points)	
1422-CL	**1422-9933**
1422-CD	**1422-9823**
direct-reading only	
1422-D	**1422-9704**
1422-CB	**1422-9916**

STANDARD CAPACITORS

Capacitor Type

A properly designed air capacitor approaches the ideal standard reactance in that it has very low loss and very small changes with time, frequency, and environment. Capacitance changes with changes in atmospheric pressure and in relative humidity can be eliminated by hermetic sealing of the capacitor. Changes with temperature can be reduced to a few ppm per °C by the use of low-temperature-coefficient materials in the capacitor. The maximum capacitance for an air-dielectric unit of practical size is of the order of 1000 pF.

Two-Terminal and Three-Terminal Connections

Most capacitors can be represented by the three capacitances shown in Figure 1: the direct capacitance, C_{HL}, capacitance between the plates of the capacitor and the two terminal capacitances, C_{HG} and C_{LG}, which are capacitances from the corresponding terminals and plates to the capacitor case, surrounding objects, and to ground (to which the case is connected either conductively or by its relatively high capacitance to ground).

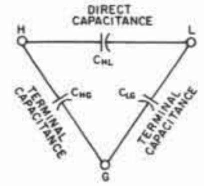


Figure 1.

In the two-terminal connection, the capacitor has the L and G terminals connected together, i.e., the L terminal is connected to the case. The terminal capacitance, C_{LG}, is thus shorted, and the total capacitance is the sum of C_{HL} and C_{HG}. Since one component of the terminal capacitance C_{HG} is the capacitance between the H terminal and surrounding objects, the total capacitance can be changed by changes in the environment, particularly by the introduction of connecting wires.

The uncertainties in the calibrated value of a two-terminal capacitor can be of the order of tenths of a picofarad if the geometry, not only of the capacitor plates but of the environment and of the connections, is not defined and specified with sufficient precision. For capacitors of 100 pF and more, the capacitance is usually adequately defined for an accuracy of a few hundredths percent if the terminals and method of connection used for calibration are specified. For smaller capacitances or for higher accuracy, the two terminal capacitor is seldom practical and the three-terminal arrangement is preferred.*

A three-terminal capacitor has connected to the G terminal a shield that completely surrounds at least one of the terminals (H), its connecting wires, and its plates except for the area that produces the desired direct capacitance to the other terminal (L). Changes in the environment and the connections can vary the terminal capacitances, C_{HG} and C_{LG}, but the direct capacitance C_{HL} is determined only by the internal geometry.

This direct capacitance can be calibrated by three-terminal measurement methods, which use guard circuits or transformer-ratio-arm bridges to exclude the terminal capacitances.

The direct capacitance can be made as small as desired, since the shield between terminals can be complete except for a suitably small aperture. The losses in the direct capacitance can also be made very low because the dielectric losses in the insulating materials can be made a part of the terminal impedances. When the three-terminal capacitor is connected as a two-terminal capacitance will exceed the calibrated three-terminal value (C_{HL}) by at least the terminal capacitance C_{HG}.

Frequency Characteristics

Although the characteristics of the high-quality capacitors used as standards closely approach those of the ideal capacitor, to obtain high accuracy the small deviations from ideal performance must be examined and evaluated. The residual parameters that cause such deviations are shown in the lumped-constant, two-terminal equivalent circuit of Figure 2. R represents the metallic resistance in the leads, supports and plates; L, the series inductance of the leads and plates; C, the capacitance between the plates; C_k the capacitance of the supporting structure. The conductance, G, represents the dielectric losses in the supporting insulators, the losses in the air or solid dielectric between capacitor plates, and the dc leakage conductance.

The effective terminal capacitance C_e of the capacitor becomes greater than the electrostatic or zero-frequency capacitance C_o as the frequency increases because of the inductance L. When the frequency, f, is well below the resonance frequency f_r (defined by $\omega_r^2 LC_o = 1$), the fractional increase in capacitance is approximately

$$\frac{\Delta C}{C_o} \approx \omega^2 LC_o = \left(\frac{f}{f_r}\right)^2 \qquad (1)$$

This change in capacitance with frequency for the capacitors described earlier is given either as a plot on logarithmic co-ordinates of the percent increase, $\Delta C/C$, versus frequency or as a tabulation of the values of L. Since the inductance is largely concentrated in the leads and supports, it is nearly independent of the setting of a variable capacitor. With this information, the increase in capacitance at, for example, a frequency of 1 MHz can be computed from the calibrated value at 1 kHz with high accuracy. For small increases, the accuracy may be greater than that of a

---

* John F. Hersh, "A Close Look at Connection Errors in Capacitance Measurements," *General Radio Experimenter*, July 1959.

measurement at 1 MHz because of the difficulties in determining the measurement errors produced by residuals in the connecting leads outside the capacitor.

The three-terminal capacitor has a similar increase in capacitance produced by inductance. The lowest resonance is determined not solely by the calibrated direct capacitance but also by the terminal capacitances, which may be much larger than the direct capacitances.

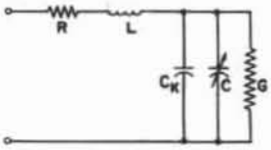


Figure 2.

Dissipation Factor

The dissipation factor of a capacitor is determined by the losses represented in Figure 2 by R and G. The resistance R is not usually significant until the frequency is high enough for the skin effect to be essentially complete. At such frequencies the resistance varies as the square root of the frequency and may be expressed as $R_1\sqrt{f}$, where R_1 is the resistance at one MHz and f is the frequency in MHz. The total dissipation factor at high frequencies is then

$$D = \frac{G}{\omega C} + R_1\sqrt{f}\,\omega C \qquad (2)$$

At low frequencies only the losses represented by G are important. The leakage conductance component is negligible at frequencies above a few cycles per second and is important only when the capacitor is used at dc for charge storage. The dominant components at audio frequencies are the dielectric losses in the insulating structure and in the dielectric material between the plates.

In the air capacitor the losses in the air dielectric and on the plate surfaces are negligible under conditions of moderate humidity and temperature. The loss is, therefore, largely in the insulating supports. When good-quality, low-loss materials, such as quartz, ceramics, and polystyrene, are used for insulation, the conductance varies approximately linearly with frequency and the dissipation factor, D_k, of the supports is nearly constant with frequency. The total low-frequency dissipation factor of an air capacitor whose equivalent circuit is that of Figure 2 may be expressed as

$$D = \frac{G}{\omega(C + C_k)} = \frac{D_k C_k}{C + C_k} \qquad (3)$$

When the capacitance C is variable, this D is then inversely proportional to the total terminal capacitance. Since the quantity $D_k C_k$ is nearly independent of both frequency and capacitance setting, it is a convenient figure of merit for a variable capacitor.

MECHANICAL PARTS LIST

Description	GR Part No.
1422's all	
Knob assembly, including retainer 5220-5402	5520-5530
Window:	0579-0910
Window gasket	0579-0730
Window frame	0579-0840
Handle	5360-0500
Cabinet assembly	1422-2040
Dial assembly	1422-1121
1422-C's only	
Panel locking connector asm. 1422-CB, HIGH; LOW 1422-CD, 11 pF; 1.1 pF 1422-CL, HIGH; LOW	0874-4511
Panel locking connector asm. 1422-CD, LOW	0874-4532
1422-D,	
Binding post 1422-D, 1150 pF; GND	0938-3000
Binding post 1422-D, 115 pF	0938-3046