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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

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THE TYPE 726-A VACUUM-TUBE VOLTMETER AS A RADIO-FREQUENCY AMMETER

● AS A VOLTAGE-MEASURING DEVICE for use in parallel-resonance methods of admittance measurement the vacuum-tube voltmeter has been widely

adopted. In this service, because of the low input losses for a given voltage reading¹, the shunting effect of the voltmeter on a high-Q tuned circuit is generally small and high precision in the measurement of small conductances may be attained.

For series-resonance methods of impedance measurement, in which one point of the circuit is grounded, the vacuum-tube voltmeter may be used as a current-measuring device. In this service the voltage drop across a known impedance is used as a measure of the current.

The feature of low input losses is as important in the series-resonance methods as in the parallel-resonance methods, since it is necessary to maintain high-Q tuned circuits for precise measurements of small resistances. It is therefore essential to use, as the

FIGURE 1. Panel view of the TYPE 726-A Vacuum-Tube Voltmeter, showing the probe in which the diode is housed.



¹At low frequencies, the input conductance of the TYPE 726-A Vacuum-Tube Voltmeter is approximately 0.16 μ mho. At high frequencies the input admittance is approximately equal to that of a 6.9 μ mf condenser having a 2.5% power factor. For an excellent discussion of the input conductance of a diode rectifier at low frequencies, see C. B. Aiken, "Theory of the Diode Voltmeter," *Proc. I.R.E.*, Vol. 26, No. 7, p. 859, July, 1938.



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known impedance, a circuit element which has as nearly pure a reactance as can be obtained.

TYPE 505 Condensers make excellent shunts for use with the TYPE 726-A Vacuum-Tube Voltmeter. For any given capacitance, and at any one frequency, the lower limit of current which can be measured is fixed by the lowest voltage which can be read. The higher limit of current is fixed either by the highest voltage which can be read or by the maximum voltage which the condenser will stand at the particular frequency used. The curves of Figure 3 illustrate, as a function of frequency, the maximum current which can be measured by the TYPE 726-A Vacuum-Tube Voltmeter with four standard TYPE 505 Condensers as shunts. Below 4 Mc the maximum current which can be measured is seen to be limited by the 150-volt maximum reading of the voltmeter. Above 4 Mc the maximum current is

FIGURE 3. Plot of maximum current, as a function of frequency, which can be read with the TYPE 726-A Vacuum-Tube Voltmeter and four different TYPE 505 Condenser shunts. The lines with positive slope correspond to a 150-volt reading of the voltmeter. The line with negative slope corresponds to 1 watt loss in the condensers.

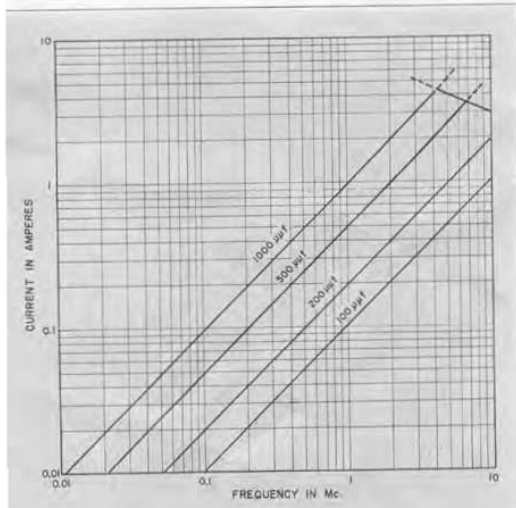


FIGURE 2. TYPE 505 Condenser has plug-in terminals as shown here. In a measuring circuit equipped with jacks, condensers can be easily changed, or stacked in parallel. The voltmeter probe plugs into the jack tops of the condenser terminals.

limited by losses in the condensers as shown.

When the TYPE 726-A Vacuum-Tube Voltmeter is used as an ammeter, the effective series resistance component of the input impedance is the pertinent loss representation. Figure 4 illustrates, as a function of frequency, the effective series resistance of a TYPE 726-A Vacuum-Tube Voltmeter when shunted with four typical TYPE 505 Condensers. By comparison with other types of radio-frequency ammeters, the extremely low losses introduced by the shunted TYPE 726-A Voltmeter are to be emphasized. Using the 1.5 volt range, with a 500 μf shunt, at a frequency of 1 Mc, the effective series resistance is 0.16Ω and the full-scale current reading is 4.8 ma. The radio-frequency power taken from the circuit is therefore 3.6 microwatts. A well-designed thermocouple for the same current range ordinarily requires a power input of the order of 6 milliwatts for a generated d-c voltage of 10 millivolts open-circuit and consequently has an effective series resistance

of approximately 260 Ω . The advantage to be gained through the use of the voltmeter with high-Q circuits is tremendous at low current levels.

In resonance methods of measurement the absolute value of current is generally not needed for calculations since the equations are expressed in terms of current and voltage ratios. When the voltmeter is used in such circuits it is therefore unnecessary to know the variation of effective capacitance of the shunts with frequency in anything except a general way.

When it is necessary to measure the absolute value of the current, the variation of effective capacitance with frequency must be known. This can be easily computed for any TYPE 505 Condenser by means of the equation

$$C_e = \frac{C}{1 - \omega^2 LC}$$

where C_e is the effective capacitance, C the static capacitance, and L the inductance. For TYPE 505 Condensers mounted in small cases, the inductance is approximately 0.055 μh and, in large cases, 0.085 μh .²

Certain limitations and precautions should be noted in connection with the use of the condenser-shunted vacuum-tube voltmeter as an ammeter.

The TYPE 726-A Vacuum-Tube Voltmeter, while calibrated in r-m-s volts, actually responds to peak values. If used to measure distorted current waves, with a condenser shunt, the relation between various harmonic components will be destroyed because of the frequency dependence of the input impedance. The meter-scale reading when multiplied by $\sqrt{2}$ will not, in this case, give correct results for peak values and the instrument should therefore be used to measure only currents of nearly

²Curves of power factor and capacitance rise for typical TYPE 505 Condensers are given in the *General Radio Experimenter*, Vol. 12, No. 11, p. 4, April, 1938.

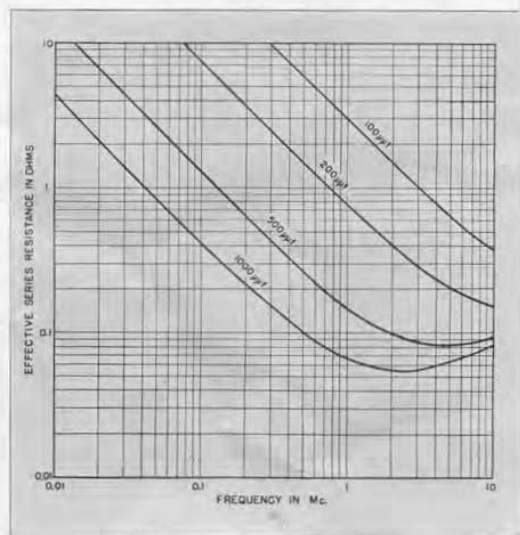
pure waveform, such as are encountered in resonant circuits.

Because of the unbalanced input circuit of the voltmeter, the shunted combination should only be used when one side can be grounded. Otherwise the high capacitance of the low side of the voltmeter circuit to ground will shunt that part of the circuit under test which lies between that point and ground.

In series-resonance circuits, capacitances to ground are usually the most troublesome residual parameters encountered. When it is necessary to measure absolute values of current with the shunted voltmeter, the magnitude of any shunting residual capacitance should be determined and included in the total effective capacitance. Two positions in which the shunted voltmeter may be used with series-resonance circuits are shown in Figure 5.

For applications in which a flat frequency response is required, the TYPE 726-A Vacuum-Tube Voltmeter can be

FIGURE 4. Plot of effective series resistance of TYPE 726-A Vacuum-Tube Voltmeter when used as an ammeter with four different TYPE 505 Condenser shunts.



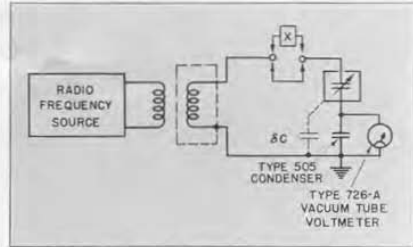
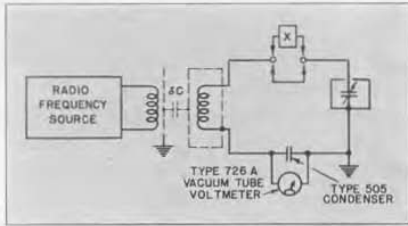


FIGURE 5. Two ways in which the shunted TYPE 726-A Vacuum-Tube Voltmeter can be connected in series-resonant circuits. The residual capacitances shown as δC in the two cases shunt the voltmeter combination and must be included in the effective capacitance.

used with TYPE 500 Resistors for shunts. The power required for full-scale deflection on the low range is considerably greater than that required with TYPE 505 Condensers. For a full-scale deflection on the 1.5-volt scale with a current of 4.8 ma, a resistance of 313Ω is required. The resistance and, consequently, driving power are in this case practically the same as those encountered with a thermocouple. At lower currents less power is required with the

resistance-shunted vacuum-tube voltmeter than with a thermocouple, while at higher currents the reverse is true.

Both TYPE 505 Condensers and TYPE 500 Resistors are equipped with terminals which permit stacking up of units in parallel. The TYPE 726-A Vacuum-Tube Voltmeter probe can, therefore, be plugged into the shunt and TYPE 274 Plugs in the shunt used as the composite probe terminals.

— D. B. SINCLAIR

TYPE 739 LOGARITHMIC CONDENSERS

● ELECTRICAL MEASUREMENTS into which frequency enters as a variable ordinarily require that the frequency be known to the same fractional accuracy throughout the range of the

oscillator. Older oscillator designs have not met this requirement merely because the necessary means were not available. With the advent of direct-reading instruments, the need has become, not more urgent, but more apparent.

In order to give a constant fractional accuracy, the variable air condenser, which is the frequency-controlling element in most oscillators, must have plates shaped to give a logarithmic variation in frequency with angular dial rotation. TYPE 739 Logarithmic Air Condenser fulfills this requirement.

Since oscillators are usually of the beat-frequency type or of the "tuned

FIGURE 1. This dial is used with TYPE 739-A Logarithmic Condenser in the TYPE 713-B Beat-Frequency Oscillator. The scale is logarithmic between 20 and 20,000 cycles.



circuit" type, two logarithmic condenser designs have been made available, one to meet the particular requirements of each type of oscillator. The TYPE 739-A Logarithmic Condenser, when associated with the proper circuit constants in a beat-frequency oscillator, will cover three frequency decades logarithmically, 20 to 20,000 cycles, for example. The TYPE 739-B Logarithmic Condenser will provide a constant accuracy calibration in the tuned circuit type of oscillator over a half decade, 1 Mc to 3.16 Mc, for example.

Mechanically, TYPE 739 Condensers are constructed to have a high degree of stability. The cast-aluminum frame and the ball-bearing type of assembly found indispensable in the design of the TYPE 722 Precision Condensers was adopted for the TYPE 739 Logarithmic Condensers. Contact rings provide a low impedance path for grounding the rotor to the frame. Isolantite insulators provide a four-point support for extra stability in alignment of stator stack.

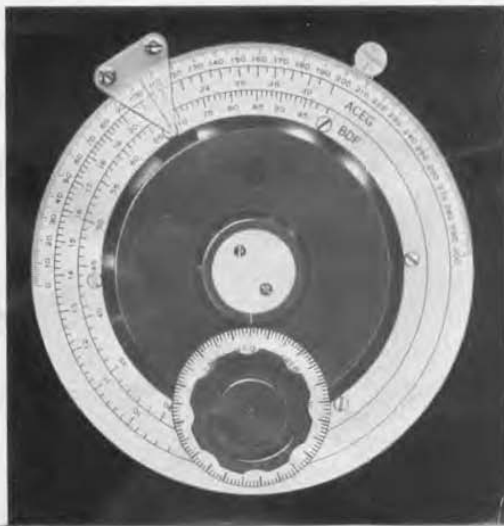
The different applications of the two logarithmic condensers require widely different plate shapes. This will be evident when it is realized that a given angular rotation of the TYPE 739-B Condenser at one end of the scale produces ten times as much capacitance change as it does at the other end, whereas, in the TYPE 739-A Condenser, the ratio of maximum to minimum capacitance increment is 1400.

FIGURE 2. In TYPE 605-B Standard-Signal Generator and TYPE 484-A Modulated Oscillator, this dial is used with TYPE 739-B Logarithmic Condenser. Each scale covers a frequency ratio of $\sqrt{10}$, so that each pair of scales (A and B, C and D, etc.) gives a spread of 10:1. A scale selector switch (not shown) is used to select the inductance for each range. One property of the logarithmic scale is that equal angles of rotation correspond to equal fractional (or percentage) frequency increments. This permits the use of the percentage increment dial shown on the slow-motion drive.

To obtain the 1400 to 1 ratio of incremental capacitance, the TYPE 739-A Logarithmic Condenser, essentially, is built up of two variable condenser sections on the same shaft. The larger section does not introduce any capacitance change over an appreciable portion of the range of the condenser. It functions at the medium and high capacitance range. The smaller section, consisting of two rotors and two stators, functions primarily over the low capacitance portion of the range. The two rotors of the smaller section are slotted at an angle to provide many sectors for individual adjustment at any portion of the scale. Thus any irregularities in the calibration are easily corrected, and any possible discontinuity at the overlap region of the two sections is avoided.

The TYPE 739-A Logarithmic Condenser provides the main frequency control for the TYPE 713-B Beat-Frequency Oscillator¹. The frequency range of this instrument is 0 to 40 kc, and the frequency calibration is logarithmic from 20 to 20,000 cycles. A photo-etched dial is used, and the condenser is adjusted to meet the direct-

¹See *General Radio Experimenter*, April, 1938.



reading calibration on the dial. A recorder, using logarithmic or semi-logarithmic paper can be geared directly to the oscillator dial for rapid and highly accurate testing.

When the TYPE 739-A Logarithmic Condenser is the tuning element of a beat-frequency oscillator, the frequency of the fixed oscillator must be 9.3 times the required maximum beat frequency. Thus, in the TYPE 713-B Oscillator, the fixed frequency is 186,000 cycles and the variable oscillator frequency is changed from 186,000 cycles for zero beat to 166,000 cycles for the 20,000 cycle setting. The logarithmic condenser must be padded with enough capacitance to obtain a ratio of 1.256 between the net maximum and minimum capacitance in the variable oscillator circuit. Since the capacitance change in the TYPE 739-A Condenser is about $440 \mu\mu\text{f}$, the net padding capacitance must therefore be about $1720 \mu\mu\text{f}$, irrespective of the value of fixed frequency and of the frequency range. The $1720 \mu\mu\text{f}$ includes the zero capacitance of the condenser, the distributed capacitance of the coil, wiring capacitance, and, of course, the fixed padding capacitance. The total frequency range is covered in an angular rotation of 250° and the logarithmic portion, three decades, is covered in 240° .

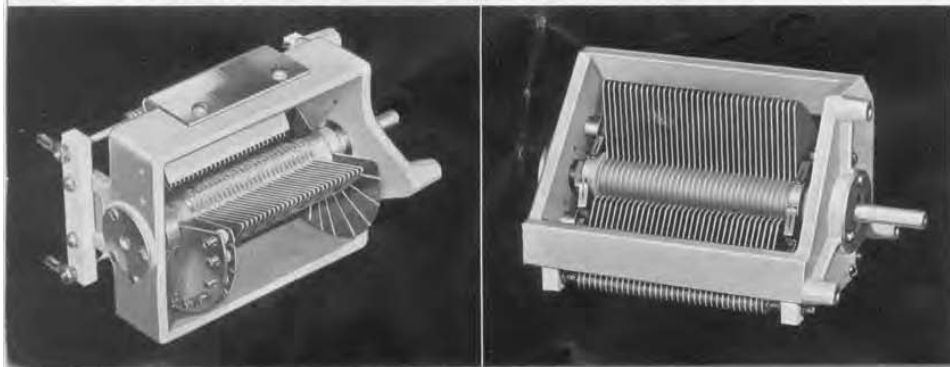
Since the ratio of maximum to minimum incremental capacitance in the TYPE 739-B Logarithmic Condenser is appreciably less than in the other model, the design is somewhat simpler. The logarithmic frequency characteristic is obtained with a single plate shape and no adjusting mechanism is necessary.

Here again, the logarithmic feature not only provides the highly desirable constant fractional accuracy for the calibration of a tuned-circuit oscillator but also simplifies a direct-reading design and permits the use of pre-engraved or photo-etched dials. The condenser covers a half decade in frequency. Therefore, if the dial is calibrated for the two half decades, the same calibration will apply over a very wide frequency range simply by switching the tuning coils. This is well illustrated in the TYPE 605-B Standard-Signal Generator² and in the TYPE 684-A Modulated Oscillator³. Both of these instruments make use of the TYPE 739-B Logarithmic Condenser and both cover a frequency range of from 9.5 to 30,000 kilocycles with direct-reading logarithmic calibration. The accompanying figure shows the dial calibration for these instruments. One calibration is for the 9.5 to 30 half decade and the other calibration is for the 30 to 95 half decade. Both instruments have further taken advantage of the logarithmic feature of the

²See General Radio *Experimenter*, June, 1936.

³See General Radio *Experimenter*, November, 1937.

FIGURE 3. (Left) TYPE 739-A Logarithmic Condenser; (right) TYPE 739-B.



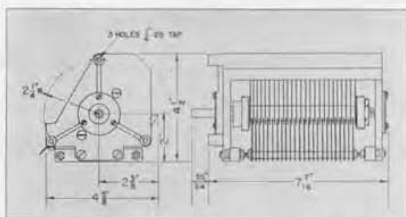
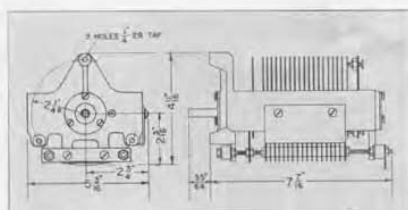


FIG. 4. Mounting dimensions for TYPE 739 Condensers. (Left) TYPE 739-A; (right) TYPE 739-B.

TYPE 739-B Logarithmic Condenser in providing a fine control calibrated in frequency increments of 0.1% per division which facilitates the type of measurement where percentage frequency change is more important than the absolute value of the frequency.

When the TYPE 739-B Logarithmic Condenser is the tuning control of a tuned-circuit oscillator, the total capacitance at the low-frequency end of the scale must be ten times as great as the total capacitance that obtains at a frequency higher by a factor of $\sqrt{10}$. The actual values are about 1400 $\mu\mu\text{f}$ and 140 $\mu\mu\text{f}$ and must include the zero capacitance of the condenser, the distributed capacitance of the tuning coil, and capacitance due to wiring and trimmers. In the TYPE 605-A Standard-Signal

Generator and in the TYPE 684-A Modulated Oscillator, a rather simple procedure is followed to adjust the circuit constants. For each coil setting, an individual trimmer condenser is provided and the inductance of each coil is determined by an iron dust core. With the condenser dial set at the low-frequency end, each inductor is adjusted to match the frequency on the dial. Then, with the dial set at the high-frequency end, the correct frequency is obtained by means of the trimmer condenser across the coil.

The angular rotation of the TYPE 739-B Logarithmic Condenser for a frequency range of $\sqrt{10} : 1$ is 165° and it is logarithmic to within 1% for 150° of this range. The net angular rotation is 180° to allow for overlap between coils.

— A. G. BOUSQUET

SPECIFICATIONS

Capacitance Range: The nominal capacitance ranges are given in the price list.

Plate Shape and Frequency Characteristics: The TYPE 739-A is to be used as the tuning condenser of the variable oscillator of a beat-frequency oscillator. Slotted plates are provided on the TYPE 739-A with adjusting screws. When these plates and the effective zero capacitance are correctly adjusted, the variation of frequency with dial setting will be logarithmic within 2%.

The TYPE 739-B is for use in a tuned-circuit radio-frequency oscillator. It has no adjustable

plates, but, by proper adjustment of the padding condenser and circuit inductance, the variation in frequency with dial setting, over 150° , can be made logarithmic within 1%.

Maximum Voltage: 500 volts, peak.

Losses: The figure of merit, R_0C^2 , is approximately 0.04×10^{-12} .

Terminals: Soldering lugs are provided.

Mounting: See sketch above.

Dimensions: See sketch above.

Net Weight: $3\frac{1}{5}$ pounds.

Type	Nominal Capacitance		Code Word	Price
	Maximum	Minimum		
739-A	468 $\mu\mu\text{f}$	28 $\mu\mu\text{f}$	COUPE	\$28.00
739-B	1460 $\mu\mu\text{f}$	35 $\mu\mu\text{f}$	COILY	28.00



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● INSTRUMENTATION CONTEST.

Have you read of the prize contest being conducted by the Industrial Instrument Section, Scientific Apparatus Makers of America, 20 North Wacker Drive, Chicago, Illinois?

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"THEME. Each contestant is to write about an unusual application of a standard instrument or control device, telling briefly what conditions or need impelled the application. By instrument or control device is meant any device used for measurement and control or any accessory used with a device for measurement and control."

If you are interested, it is suggested that you write directly to the Scientific Apparatus Makers of America at the address given above for details. There is no entry fee or restriction based on purchasing any particular instrument.

● JOINING US LATE LAST

SPRING, the newest member of our engineering staff is Dr. Stephen A. Buckingham. After graduating from Harvard University eleven years ago, Dr. Buckingham joined the Radio Section of the U. S. Bureau of Standards, where he remained for two years, returning to Harvard University to take up graduate work, and later serving as an instructor in Physics. He received his degree of Ph.D. in 1934. In the subsequent four years he has served as physicist and as engineer with the S. D. Warren Company and the Western Electric Company. Dr. Buckingham is specializing in the design of Variacs, as well as our general line of transformers and filters.

● AS A MEANS of inducing hypnosis, the Strobotac, we feel, has been overlooked by psychologists, for, unless our eyes deceive us, it is a Strobotac by which Ginger Rogers is hypnotized in the current RKO production "Carefree." To possessors of Strobotacs, this should open up an interesting field of experiment.

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