THE General Radio EXPERIMENTER

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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A 500-VOLT MEGOHMMETER FOR INSULATION TESTING

Also IN THIS ISSUE

THE NEW General Radio Megohmmeter, TYPE 1862-A, has been specifically designed for the rapid measurement of insulation resistance, as well as general resistance testing such as the measurement of high-valued resistors. Consequently, it has a considerably wider field of application than its predecessor, the TYPE 1861-A.

Since insulating materials usually exhibit a marked voltage coefficient of resistance, it is necessary for purposes of standardization that measurement be made at one of the accepted standard voltage levels, and the level most commonly agreed upon by professional and industrial groups is 500 volts.[1] The new megohmmeter applies a constant 500 volts to the resistance under test and is well suited to testing the insulation of rotating electrical machinery, transformers, capacitors, cables, and household appliances in production, in the repair shop, and in the field.

[1] A.S.T.M. Standards on Electrical Insulating Materials, D 257-49T.

Figure 1. View of the megohmmeter with cover removed to show panel.

The Type 1862-A Megohmmeter is contained in a cabinet designed for portability and ruggedness (see Figure 2) since it will be as useful in the field as in the laboratory. A cover provides a storage compartment for the power cord, test leads, and other accessories. The simplicity of the panel controls (see Figure 1) allows its use by untrained personnel. Resistance is indicated as the product of a meter reading and a multiplier setting. As seen from the photograph of Figure 3, each decade (0.5 to 5.0 on the meter) utilizes 90% of the meter scale length, and the remaining 10% provides overlap. There are six multiplier positions. The full range of the instrument is from 0.5 megohm to 2,000,000 megohms.

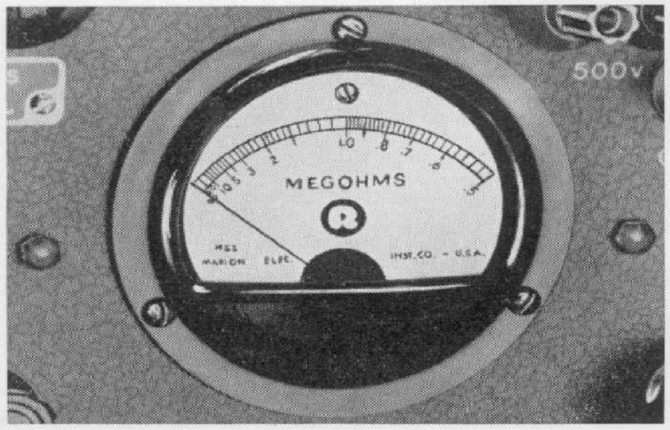


Figure 2. View of the meter scale.

Other Features

This new instrument has a number of features that contribute to its speed of operation, its accuracy, and its safety from shock.

(1) In the DISCHARGE switch position, all voltage is removed from the terminals to allow connecting and disconnecting the unknown resistance with complete safety from electric shock.

(2) At this same switch position, a shunt resistor is automatically connected across the UNKNOWN terminals to remove any residual charge in the capacitive component of the unknown resistance. This feature, which is especially useful when the leakage resistance of capacitors is measured, was adopted because the relatively low resistance of the megohmmeter circuit has made the rapid measurement of capacitor leakage resistance a major application of the instrument.

Figure 3. The Type 1862-A Megohmmeter is small, compact, and easily portable.

(3) The circuit resistance in series with the unknown is directly proportional to the multiplier setting and at the lowest setting is so small that it has a negligible effect on the charging time for even the largest capacitors. Therefore, it is not necessary to charge the unknown as a separate operation before starting the measurement.

(4) This instrument is very convenient for observing the apparent leakage resistance after one and ten minutes of charging time as is sometimes done as a routine procedure for monitoring the condition of installations where dielectric absorption is appreciable,[1] as on large electrical machinery.

(5) Voltage-stabilized power supplies for both the 500-volt source and the vacuum-tube voltmeter circuit contribute to a high degree of calibration stability. A CHECK switch position is provided for checking the calibration and controls are provided for readjustment. This is necessary usually only when tubes are changed.

(6) In addition to the two UNKNOWN terminals, a guard and a ground binding post are provided on the

panel for making three-terminal resistance measurements; a typical application is the measurement of insulation leakage between two specific wires of a multi-conductor cable: all other wires are connected to the guard terminal. The ground terminal can be connected to either the guard terminal or to one of the UNKNOWN terminals.

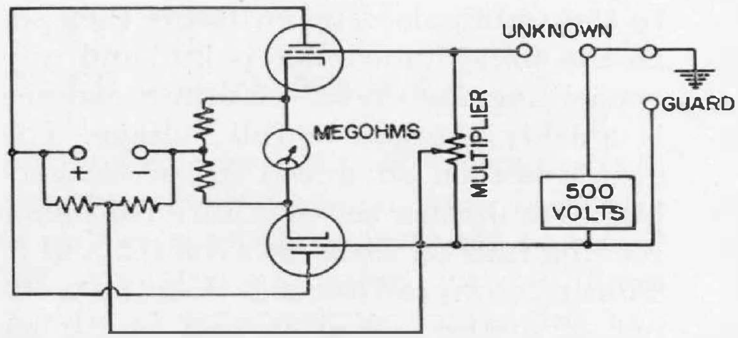


Figure 4. Elementary schematic circuit diagram of the Type 1862-A Megohmmeter.

Circuit

Schematically, the circuit is exceedingly simple: a 500-volt supply and a resistance standard are connected across the UNKNOWN terminals; a vacuum-tube voltmeter across the resistance standard is calibrated in megohms (see Figure 4). Many of the design features stem from the fact that the resistance standard is only one five-hundredth of the mid-scale resistance of the unknown. In the usual ohmmeter circuit they are equal. This large ratio is possible here because of the high-voltage of the supply (500 volts) and the high sensitivity of the meter. The vacuum-tube voltmeter sensitivity is one volt at mid-scale. The circuit comprises two balanced triodes (the 12AU7 twin triode) in a fully degenerated arrangement.

Because of the large ratio between unknown and standard, each decade covers 90% of the meter scale. In the usual ohmmeter arrangement, the central decade covers only half of the meter scale. Since the standard resistance is relatively small, a standard of high stability can be obtained, grid-current effects in the vacuum-tube voltmeter are easily controlled, and circuit leakage resistance across the standard is negligible.

Even though a balanced circuit is used, the plate supply of the vacuum-tube voltmeter is stabilized by a glow-discharge type of voltage-regulator tube (OB2) to eliminate all possible errors due to line-voltage fluctuations.

Similarly, the 500-volt supply is stabilized against line-voltage fluctuations. The degenerative series-regulator type of stabilizing circuit is used. The circuit constants are selected to maintain 500 volts across the unknown resistor for all resistance values within the range of the instrument but, if a resistance appreciably less than ½ megohm is connected, the voltage of the supply will drop rapidly to limit the current to a safe value (less than 30-ma d-c at short circuit in the worst case).

The six resistance standards are accurate to 1% or better. A check position of the control switch simplifies any readjustment of the calibration occasioned by aging or replacement of tubes. Complete degeneration in the voltmeter circuit has resulted in very small tracking error between tubes. As a consequence, the accuracy at the low-resistance end of the meter scale is 3%; it is 8% at mid-scale and 12% at the higher-resistance end of the scale ("5" on the meter). There can be an additional 2% error at the highest multiplier setting.

Operation

To measure resistance, the multiplier switch is set at DISCHARGE, and the resistance to be measured is connected to the terminals. The switch is then set at the unity multiplier point, and any capacitance associated with the resistance is quickly charged to full voltage. The switch is then advanced to successively higher multiplier settings until the meter reading falls on scale between 0.5 and 5. The unknown resistance is then the product of meter indication and multiplier switch setting.

Figure 5 shows guard-terminal connections for measuring ungrounded and grounded 3-terminal resistances.

It is possible to measure the voltage coefficient of resistors if a variable-voltage external power source is available. For this purpose the TYPE 1204-B Unit Variable Power Supply[2] is recommended. The method of connection is detailed in the instruction book supplied with the megohmmeter.

—A. G. BOUSQUET

[2]See General Radio *Experimenter*, July, 1951.

SPECIFICATIONS

Range: 0.5 megohm to 2,000,000 megohms. There are six decade ranges, as selected by a multiplier switch.

Scale: Each resistance decade up to 500,000 megohms utilizes 90% of the meter scale. Center-scale values are 1, 10, 100, 1000, 10,000, and 100,000 megohms.

Accuracy: The accuracy in per cent of indicated value up to 50,000 megohms is ±3% at the low-resistance end of each decade, increasing to ±12% at the high-resistance end. There can be an additional ±2% error over the top decade.

Voltage on Unknown: 500 volts. Over a 105-125 volt range in supply-line voltage and over the resistance range of the instrument, the variation in voltage across the unknown resistor will be less than ±2%. At resistance values below 0.5 megohm, the applied voltage drops to limit the current to safe values.

Terminals: In addition to terminals for connecting the unknown, ground and guard terminals are provided. At two positions of the panel switch, all voltage is removed from all terminals to permit connection of the unknown in safety. In one of the positions, the UNKNOWN terminals are shunted to discharge the capacitive component of the unknown. All but the ground terminal are insulated.

Calibration Check: A switch position is provided for standardizing the calibration.

Design: Since field applications are more severe than laboratory use, the instrument, including its panel meter, was designed to be unusually rugged. The carrying case can be completely closed; accessory power cable and test leads are carried in the case. Controls are simplified for use by untrained personnel.

Tubes: Supplied with the instrument:

1 — 12AU7	1 — 2X2-A	1 — 6AU6
1 — OB2	1 — 6C4	1 — 5651
1 — 6X4		

Controls: A switch for selecting the multiplying factor, a control for standardizing the calibration, a control for setting the meter to the infinity reading, and a power switch.

Mounting: The instrument is assembled on an aluminum panel finished in black-crackle lacquer and is mounted in an aluminum cabinet with black-wrinkle finish and with black-phenolic protective sides. The aluminum-cover finish is black wrinkle. The case is provided with a carrying handle.

Power Supply: 105 to 125 (or 210 to 250) volts at 40 to 60 cycles. The power input is approximately 25 watts.

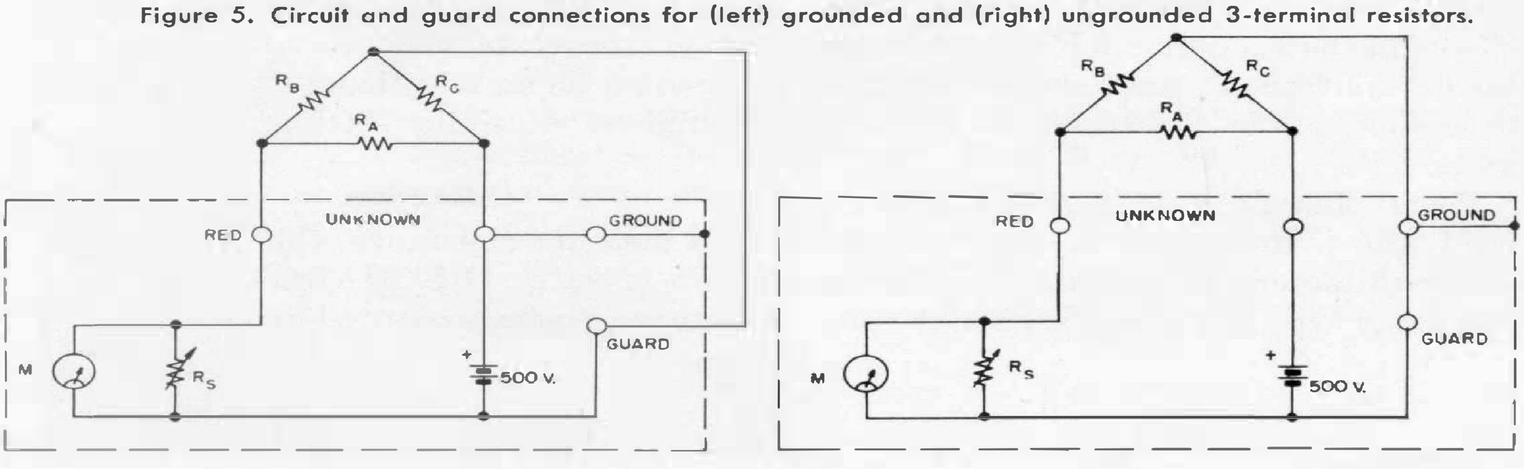
Accessories Supplied: Two color-coded test leads with phone tips, two insulated probes, two alligator clips and a TYPE 274-MB Plug.

Dimensions: (Height) 10⅛" x (width) 9⅛" x (depth) 11¾", over-all.

Net Weight: 15½ pounds.

Type		*Code Word*	*Price*
1862-A	Megohmmeter	JUROR	$225.00

Figure 5. Circuit and guard connections for (left) grounded and (right) ungrounded 3-terminal resistors.



A HIGH-POWER TOROIDAL OUTPUT TRANSFORMER

The advantages of the toroidal core transformer[1] over one using a shell-type core are becoming more generally recognized. Chief among these are the high degree of astaticism and the extremely tight coupling which can be attained between windings extending around the complete circumference of the toroid. An impedance-matching toroidal transformer, Type 941-A, was announced a year ago.[2] This article describes a high-power model, the Type 942-A Output Transformer, designed primarily for coupling push-pull output tubes to a voice coil or other low-impedance load.

This transformer combines excellent frequency response, low distortion, high power-handling capacity, and flexibility of impedance ratios in a convenient, compact unit. Leakage reactance between primary sections is very small, to give minimum distortion from switching transients in conventional push-pull amplifier circuits, and connections to individual primaries are provided for use in the single-ended push-pull amplifier described in the October *Experimenter*.[3]

The Type 942-A is wound on the same high-quality toroidal core that is used for the Type V-5 Variacs and is capable of handling peak powers up to 100 watts with a minimum of harmonic distortion. The core carries eight individual windings, four identical duplex (semi-circumferential), banked, primary windings, and two pairs of duplex, single-layer, secondary windings. These windings terminate in four sets-of-4 terminals on the upper face of the housing. Each pair of duplex windings is precisely balanced to eliminate circulating current losses when they are connected in parallel. The terminals are arranged to facilitate parallel or series connections.

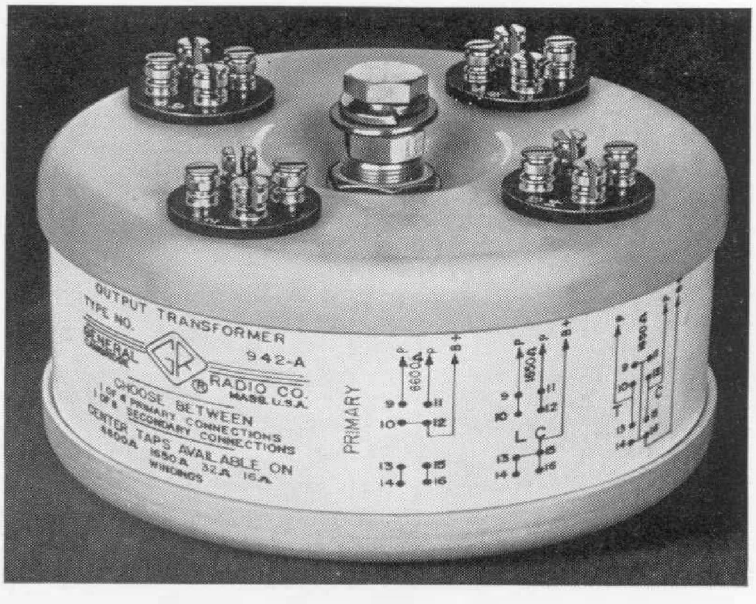
Impedance Ratios

The nominal impedance values specified in the connection diagrams printed on the case of the transformer are based on a generator impedance of 6600 ohms for all four primary windings in series. This is the recommended value for a pair of 6L6's operating push-pull class AB. If these primary windings are connected in series-parallel, or all in parallel, the corresponding generator impedances should be 1650 and 413 ohms respectively.

Series and parallel combinations of secondary windings can be connected for matching loads of 4, 8, 16, 23, 32, 47, 59, and 93 ohms.

Matching generator and load impedances are not limited to the values specified above, provided that they have the

Figure 1. View of the Type 942-A Output Transformer.



[1] Horatio W. Lamson, "Some Advantages of the Toroidal Transformer in Communication Engineering," *Tele-Tech*, May, 1950. Reprints available on request.

[2] Horatio W. Lamson, "The Type 941-A Toroidal Transformer," General Radio *Experimenter*, September, 1950.

[3] A. P. G. Peterson, "A New Push-Pull Amplifier Circuit," General Radio *Exerimenter*, October, 1951.

corresponding ratios. Eighteen impedance ratios are obtainable with this transformer, varying from 4.42 to 1650.

Primary windings can be separated as is required by the amplifier described in last month's *Experimenter* or used with a center tap in conventional push-pull operation. Center taps are also available on the 32-ohm and 16-ohm secondary windings.

Coupling Coefficient

Two different terminal connections are indicated for obtaining the 1650-ohm primary, designated respectively as TC and LC. With the TC (tight-coupled) arrangement, each half of the primary winding covers the complete circumference of the toroid, giving thereby an extremely tight coupling between the two halves of the primary. Switching transients occurring with class AB operation in conventional push-pull systems are thereby minimized, and this TC arrangement is recommended when conventional push-pull circuits are used.

With the LC (loose-coupled) connections, each half of the primary winding is on a separate semi-circumference of the toroid. Such an arrangement gives more leakage reactance between the two halves of the primary but, on the other hand, produces a lower capacitance and a more extended high frequency range than the TC connections. Choice depends upon the more important criterion. The 6600-ohm primary and all of the secondaries are tight-coupled.

The degree of coupling attained is indicated by the data in Table I.

The 6600-ohm primary has an inductance of about 24 henrys *at initial permeability* and increases with the operating level, see Figure 5. The tight coupling achieved between primary and secondary windings permits feed-back to be taken from the secondary circuit with a minimum of phase shift at high frequencies.

TABLE I

Windings	*Leakage Inductance*	$(1-r^2)$*
Half Primary to Half Primary		
Tight-Coupled	2.8 mh	0.00047
Loose-Coupled	58. mh	0.0097
Full Primary to 4 or 16-ohm Secondaries	18.0 mh	0.00075
Full Primary to 8 or 32-ohm Secondaries	14.2 mh	0.00059
Full Primary to Composite Secondaries	6.4 mh	0.00027

Power Rating and Distortion

The copper efficiency is indicated by the following ratios of d-c resistance to nominal source or load impedance (Z).

Winding	$R_{d\text{-}c}/Z$
Primary	0.046
4 or 16-ohm Secondary	0.062
8 or 32-ohm Secondary	0.066
Composite Secondaries	0.034

When operating at *constant level,* the power rating of an output transformer is determined by: (1) temperature rise due to internal losses, (2) the level of distortion introduced by the transformer at low frequencies and (3), ulti-

*The coupling coefficient, r, varies with the permeability of the core and, hence, with the operating level. r is measured at initial permeability and is greater at higher power levels. Note that leakage inductance is referred to the primary.

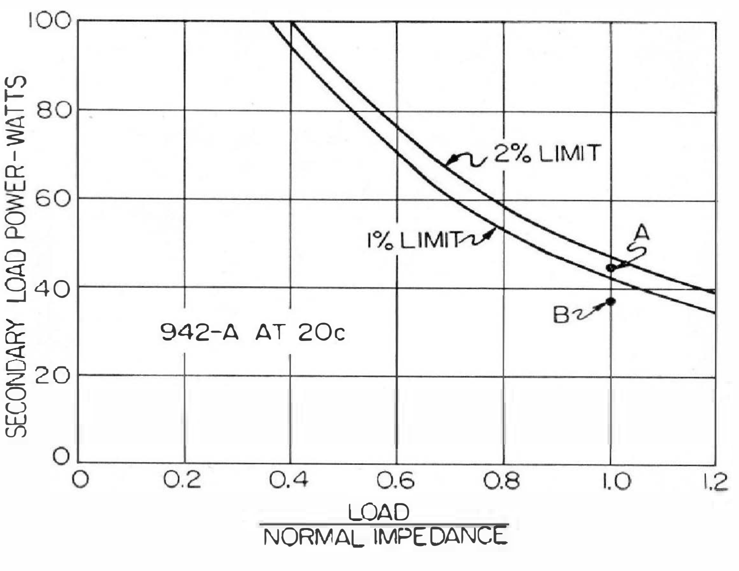


Figure 2. Showing 1% and 2% 20-cycle distortion limits as output load is varied. Taken with source impedance 0.14 × nominal primary impedance. Two-per cent limit points A and B correspond to
A — Source impedonce = 0.22 nominal primary impedance
B — Source impedance = 0.65 nominal primary impedance

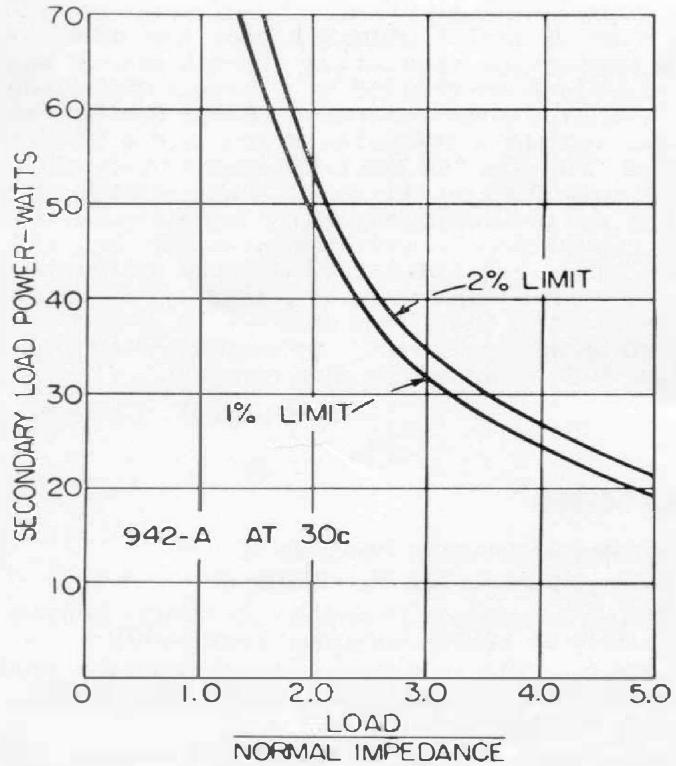


Figure 3. Showing 1% and 2% 30-cycle distortion limits as output load is varied. Taken with source impedance 0.38 × nominal primary impedance.

mately, the voltage rating of the insulation. In *speech or music* high levels occur intermittently so that the heating effect is usually not important, and the rating is determined chiefly by the distortion introduced by the non-linear magnetic characteristics of the core.

The level at which serious distortion occurs depends both upon the core material used and the peak flux density, which varies inversely with the frequency. At a specific frequency, an arbitrary value of permissible distortion may be chosen to specify the rated level.

Since transformer distortion rises abruptly above a certain voltage level, only a small change in rating occurs for a considerable range of permissible values of distortion. Likewise, the impedance of the source driving the transformer does not change the rating appreciably. Reducing the source impedance reduces the distortion values but makes little change in the level at which the abrupt rise in distortion occurs.

The data for Figures 2 and 3, illustrating a typical application of the Type 942-A, were taken on the amplifier described last month.[3] As anticipated, the *low-frequency* power rating varies, to a first approximation, inversely with the resistance load applied to the secondary. At the *nominal* impedance, the transformer can be expected, as shown in Figure 2, to handle over 40 watts at 20 cps with a distortion less than 1%. This level increases as the square of the frequency to 160 watts at 40 cps. When supplying a load which is one-half the nominal impedance, the transformer can handle 80 watts at 20 cps. However, the efficiency at higher audio frequencies is reduced by using less than the rated load.

At *higher frequencies*, above 50 cps, the power limit for continuous operation is set by copper loss, since eddy current losses in this transformer are generally negligible, and reduced flux density minimizes hysteresis losses.

The maximum allowable temperature is 65°C., which permits 8 watts internal dissipation with an ambient temperature of 35°C. Since the over-all copper efficiency is of the order of 92%, the *continuous rating* is specified as 90 watts at this ambient. The rating will then be proportional to the difference between 65°C. and the actual ambient. When an appreciable direct current is in the windings, the d-c power dissipated must also be included in determining the continuous rating for a given application.

A check of this transformer by the standard RTMA test[4] for speaker-matching transformers indicated a rating appreciably in excess of 100 watts.

Adequate secondary windings have been provided to make this output transformer suitable for supplying constant-voltage audio distribution systems.[5] For example, the standard 70-volt operating level may be obtained from the 93-ohm secondary for 50 watts or from the 47-ohm secondary for 100 watts.

The lower voltage systems or higher power levels, or both, are provided for by the lower impedance windings.

[3] Loc. cit.

[4] RTMA Standard SE-106, Sound Systems, July, 1949, Engineering Department, Radio-Television Manufacturers Association, Section V.

[5] RTMA Standard SE-101, Amplifiers, December, 1947, Engineering Department, Radio-Television Manufacturers Association, Section III. Also, RTMA Standard SE-106, Sound Systems, July, 1949, Engineering Department, Radio-Television Manufacturers Association, Section II.

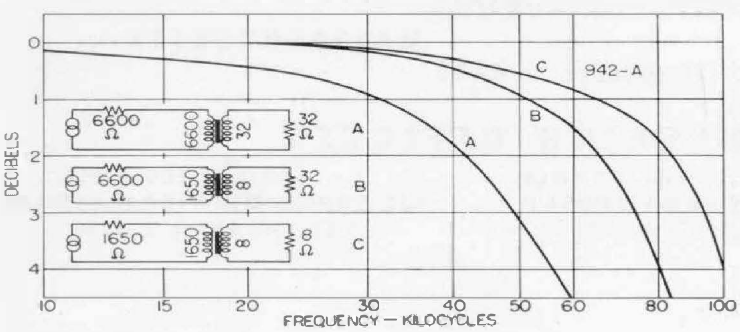
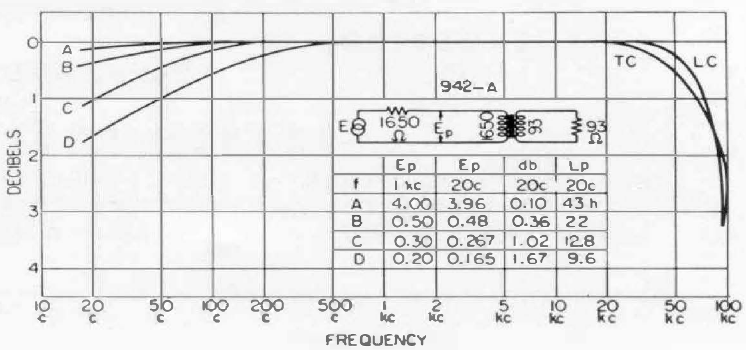


Figure 4. High-frequency characteristics of the Type 942-A Output Transformer.



	E_p	E_p	db	L_p
f	1 kc	20c	20c	20c
A	4.00	3.96	0.10	43 h
B	0.50	0.48	0.36	22
C	0.30	0.267	1.02	12.8
D	0.20	0.165	1.67	9.6

Figure 5. Over-all frequency characteristics of the transformer.

Frequency Characteristic

The frequency characteristic of an audio transformer depends, in part, upon the source and load impedances and the turns ratio. The leakage reactance between primary and secondary, and the winding capacitances, determines the high frequency cut-off, while the low frequency characteristic is determined by the primary reactance which, in turn, is a function of both frequency and operating level.

Typical high frequency characteristics for the TYPE 942-A, using matching turns ratios and tight-coupled primaries, are shown in Figure 4. A comparison of Curves *A* and *B* shows the effect of changing the nominal impedance level of a transformer which is coupling a given source and load, while a comparison of curves *B* and *C* demonstrates the effect of changing the impedances of both source and load which are coupled by a given transformer.

Figure 5 gives the over-all frequency characteristic with a 1650-ohm source and a 93-ohm load. The effect of the lower capacitance of the LC primaries on the upper range is indicated, and the low-frequency range is depressed, due to a reduction in operating level and the corresponding drop in effective primary inductance.

A typical application of this transformer was discussed in the article entitled "A New Push-Pull Amplifier Circuit," appearing in the October, 1951, issue of the *Experimenter*.

—HORATIO W. LAMSON

SPECIFICATIONS

Impedance Ratios: See page 5.

Frequency Range: See Figures 4 and 5.

Distortion: 1% at nominal impedance and continuous power rating above 30 cycles. See Figure 3.

Power Rating: 90 watts continuous for an ambient of 35°C., with no dc in windings. With dc in windings rating must be reduced so as not to exceed allowable power loss.

Allowable Power Loss: 8 watts for 30°C. rise over ambient.

Maximum Transformer Temperature: 65°C.

Winding Resistances: See page 6.

Leakage Inductances: See Table I.

Primary Inductance: Primaries in series, approximately 24 henries at initial permeability.

Insulation: The transformer is insulated for 2000 volts between individual windings and between each winding and the case.

Dimensions: (Height) 3¾ x (diameter) 5¼ inches, over-all.

Mounting: Above or below shelf, with single center bolt supplied.

Net Weight: 7 pounds.

Type		*Code Word*	*Price*
942-A	**Output Transformer**	TRANTORDOG	**$55.00**

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