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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also IN THIS ISSUE

MULTI-FREQUENCY DISTORTION MEASUREMENTS ON THE BROADCAST TRANSMITTER

• IT HAS BEEN the general practice to assume that an audio-frequency distortion measurement of a broadcast transmitter taken somewhere near the middle of the audio-frequency spectrum is indicative of the distortion that may be expected at all frequencies in the spectrum.

The advent of the inverse feedback type of transmitter with its lower over-all distortion has altered this situation considerably, because a relatively small amount of misadjustment in the phase of the feedback system may cause a serious increase in distortion, particularly at the

FIGURE 1. Panel view of TYPE 732-B Distortion and Noise Meter and TYPE 732-P1 Range-Extension Filters.

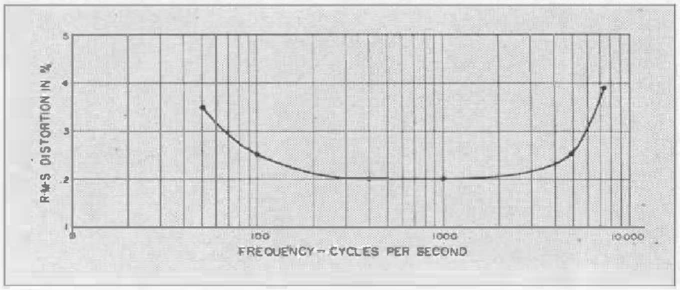


FIGURE 2. Distortion vs. frequency curve for a typical transmitter.

high end of the audio-frequency range.

There are two methods for the measurement of distortion over the audio-frequency range. One is by the use of a continuously variable analyzer which permits measurements at any selected audio frequency, and the other by a discrete step system. Each method has its uses.

In the original design of the transmitter the use of the continuous method is almost essential. Design engineers rely upon these measurements to guide them in making circuit modifications to reduce non-linearity to a minimum. Generally they need to know not only the amount of total distortion at various test frequencies, but also the value of each individual harmonic that is present. For this purpose the General Radio TYPES 636-A or 736-A Wave Analyzers are used in the laboratories of virtually every transmitter manufacturer.

The wave analyzer is also used in many broadcasting stations as an aid in maintaining extremely high quality for test purposes and in making detailed studies of transmitter performance. For routine test purposes, however, these elaborate and somewhat time-consuming measurements are not necessary. The effects of aging and drift in circuit elements, and of incorrect adjustment of controls, can be detected by measurements at a series of fixed frequencies through the audio range. Another important consideration is the time required for the tests. The discrete-frequency method is simple, rapid, and accurate.

In "Standards of Good Engineering Practice," published by the FCC, it is stated that distortion should be measured at six test frequencies: 50, 100, 400, 1000, 5000, and 7500 cycles. These frequencies are chosen to give the desired information about the transmitter. The distortion curve plotted against frequency for a typical transmitter is shown in Figure 2. Distortion nearly always rises rapidly at both the low and high frequencies. It is necessary to keep it low at the low-frequency end, because harmonics of these frequencies will be present in the transmitter's own signal, and thus will adversely affect its quality. Distortion is lowest in the band from 200 to 2000 cycles. Two check points are provided in this range, one at 400 cycles, the other at 1000 cycles.

The two high-frequency testing points of 5000 and 7500 cycles are especially important because harmonics of these frequencies will fall into adjacent channels, causing interchannel crosstalk. In feedback-type transmitters low distortion at these frequencies is critically maintained at a low value by the feedback adjustment, and slight changes in the adjustment may result in a rapid increase in distortion.

In order to provide a simple and accurate means for making distortion tests at the FCC test frequencies over the wide frequency range, a multi-frequency filter panel has been developed for use with the TYPE 732-B Distortion and Noise Meter.

The original TYPE 732-A Distortion and Noise Meter, which was announced*

* L. B. Arguimbau, "Monitoring of Broadcasting Stations," *Experimenter*, January and February, 1935.

about four years ago, was the first instrument designed around the particular requirements for distortion and noise measurement of broadcast transmitters. Hundreds have been in constant service since that time.

The new TYPE 732-B Distortion and Noise Meter employs all of the good features of the original instrument, but has been redesigned to operate in conjunction with the TYPE 732-P1 Range-Extension Filters. The distortion meter itself contains the 400-cycle band-pass filter for measurements at this frequency, and the auxiliary filter panel contains the other filters for 50, 100, 1000, 5000, and 7500 cycles. The two instruments are both rack-mounting and interconnect with convenient Jones plugs. A schematic diagram of the distortion and noise meter, showing the principle of operation, is given in Figure 3.

The radio-frequency input system has been redesigned to allow its operation over the wide carrier ranges from 0.5 to 8 megacycles or from 3 to 60 megacycles, depending upon the input coil selected. The input volume control used on the older instrument was a capacitance voltage divider which operates well over the standard broadcast range, but draws excessive power from the transmitter at high and ultra-high carrier frequencies. The new input arrangement is a tuned-circuit system which requires about the same power over the entire range from 0.5 to 60 megacycles. Two sets of coils are used to cover this

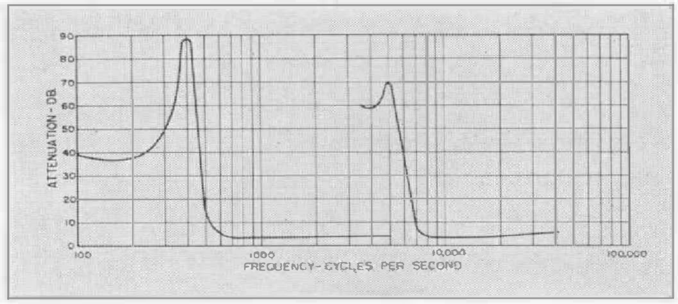
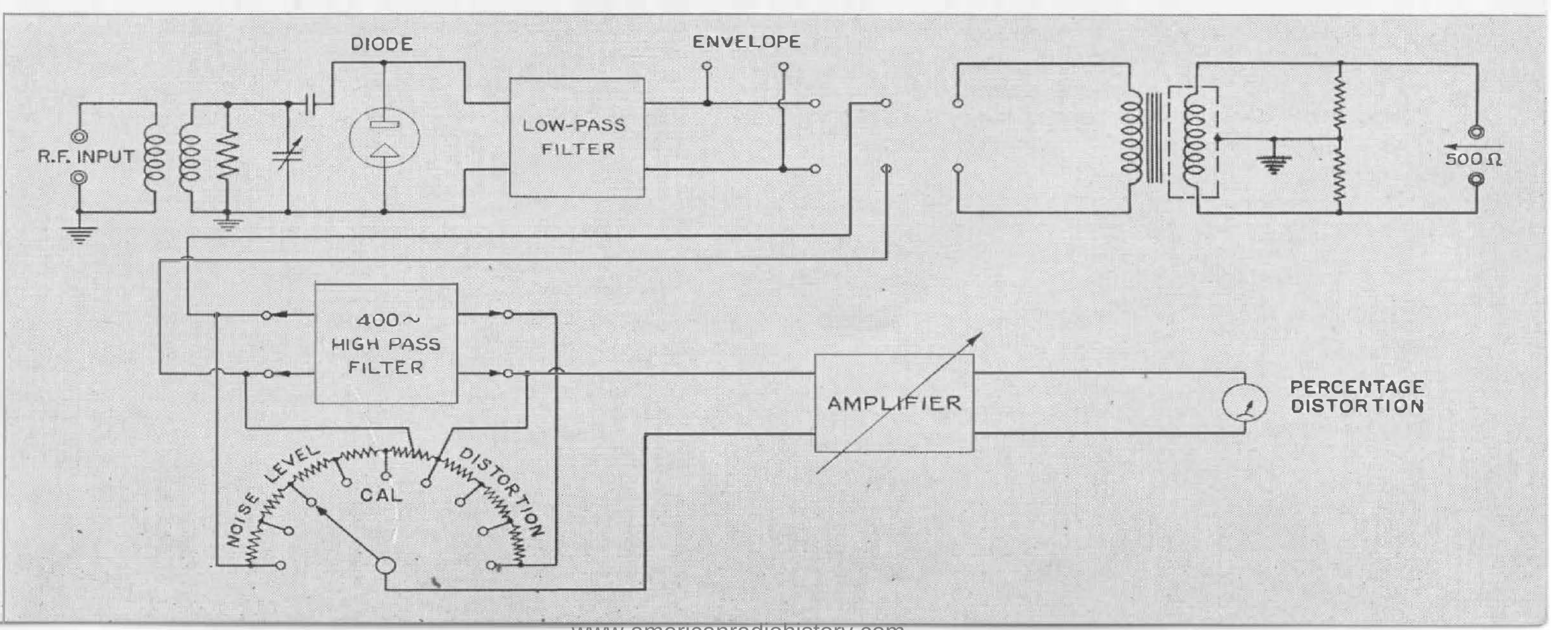


FIGURE 4. Attenuation characteristics of the 400-cycle and 5000-cycle filters. Characteristics of the other filters are similar.

FIGURE 3. Schematic circuit diagram of the TYPE 732-B Distortion and Noise Meter. The carrier modulated at the test frequency is applied to the tuned input and is rectified by a linear diode detector. The r-f components are removed by a filter, and the audio-frequency envelope is applied to a filter which removes the fundamental. The harmonic voltage is passed through an attenuator and amplifier to a meter which reads per cent distortion directly. The scales are standardized by applying a known fraction of the audio-frequency voltage to the amplifier and adjusting the gain for full-scale deflection of the meter. This is done at the CAL position of the attenuator. The high-pass filter for 400 cycles is included in the distortion and noise meter. Filters for other frequencies are switched into the circuit externally. For noise measurement, the gain adjustment is made as before with the transmitter modulated. The modulation is then removed from the transmitter and the residual audio (noise) component in the carrier envelope is impressed on the amplifier. The ratio of noise to signal is indicated directly in db on the meter.



range; one set is used for carrier frequencies between 0.5 Mc and 8 Mc; the other set is for frequencies between 3 Mc and 60 Mc. One set is supplied with the instrument.

The test signal for use with the new distortion meter can be supplied by any low-distortion audio oscillator which covers the desired frequency range. A particular advantage of the TYPE 732-B Distortion and Noise Meter is that the distortion of the oscillator can be measured prior to the measurement of the transmitter and allowance made for it in the result.

The TYPE 608-A Oscillator* is designed for this use and has the advantage of convenience in operation because of its push-button frequency control. The TYPE 713-B Beat-Frequency Oscillator is also satisfactory for this use.

To make a complete set of distortion measurements, the input to the instrument is adjusted as in the present unit to a fixed reference level, and readings of distortion are made directly from meter and multiplier as the single control switch of the filter panel is shifted in turn to each of the six test frequencies. The exciting oscillator is, of course, simultaneously adjusted to the same frequencies. The whole test can be made in about a minute and *by personnel who have had very little experience*. The simplicity and speed of the measurement mean that it can be worked into the station's routine as readily as the required daily meter readings.

— ARTHUR E. THIESSEN

* To be described in the April, 1939, *Experimenter*.

SPECIFICATIONS FOR TYPE 732-B DISTORTION AND NOISE METER

Distortion Range: Distortion is read directly from a large meter. Full-scale values of 30%, 10%, 3%, and 1% are provided, and are selected by a multiplier switch. The range for carrier-noise measurement is from 30 to 70 db below 100% modulation or 65 db below an audio-frequency signal of zero level.

Audio-Frequency Range: 380 to 420 cycles for distortion measurements; 30 to 24,000 cycles for noise or hum measurements. For extending the frequency range, use TYPE 732-P1 Range-Extension Filters.

Carrier Frequency Range: From 0.5 to 60 megacycles. This range is covered by two coils. A single coil (either for the 0.5- to 8-Mc range or for the 3- to 60-Mc range) is supplied with the instrument unless both coils are specifically ordered. The coils are readily interchanged. (See price list.)

Accuracy: The over-all accuracy of measurement of each distortion range is better than ±5% of full scale ±0.1% distortion.

Vacuum Tubes: One 37, two 6C6, one 1-V, and one 84 are supplied.

Other Accessories Supplied: Spare fuses and pilot lamps. Two dummy plugs to be used if the TYPE 732-P1 Range-Extension Filters are not connected. One carrier input coil.

Terminals: In addition to the radio-frequency input binding posts at the rear, two normal-through Western Electric output double jacks are provided on the panel, one at high impedance for the modulated envelope from the rectifier, and one at 500 ohms for use in audio-frequency testing.

Power Supply: 115 or 230 volts, 40 to 60 cycles.

Mounting: The instrument is relay-rack mounted. The panel is aluminum with the standard General Radio black-crackle lacquer finish.

Dimensions: Panel, 19 x 8¾ inches; depth behind panel, 12 inches.

Net Weight: 40 pounds.

Type	*Description*	*Code Word*	*Price*
732-B	Equipped for 0.5- to 8-Mc Carrier Range	EXPEL	$245.00
732-B	Equipped for 3- to 60-Mc Carrier Range	EQUAL	245.00
732-P5	Coils for 0.5- to 8-Mc Carrier Range	CULER	10.00
732-P6	Coils for 3- to 60-Mc Carrier Range	CYNIC	10.00

This instrument is manufactured and sold under patents of the American Telephone and Telegraph Company, solely for utilization in research, investigation, measurement, testing, instruction and development work in pure and applied science, including industrial and engineering fields.

SPECIFICATIONS FOR TYPE 732-P1 RANGE-EXTENSION FILTERS

Audio-Frequency Range: 50, 100, 1000, 5000, and 7500 cycles ±5%.

Accuracy: At distortions greater than 0.5%, the error is less than 10% of the true value ±0.15% distortion.

Test Voltage: Type 608-A Oscillator is recommended as a source of test voltage.

Accessories: Two shielded cables are supplied for connecting the Type 732-P1 Range-Extension Filters to a Type 732-B Distortion and Noise Meter.

Mounting: The instrument is relay-rack mounted. The panel is aluminum with standard General Radio black-crackle lacquer finish.

Dimensions: Panel, 19 x 5¼ inches; depth behind panel, 12 inches.

Net Weight: 25 pounds.

Type	*Description*	*Code Word*	*Price*
732-P1	Range-Extension Filters	ESSAY	$150.00

This instrument is manufactured and sold under patents of the American Telephone and Telegraph Company, solely for utilization in research, investigation, measurement, testing, instruction and development work in pure and applied science, including industrial and engineering fields.

MODIFICATION OF TYPE 732-A DISTORTION AND NOISE METERS

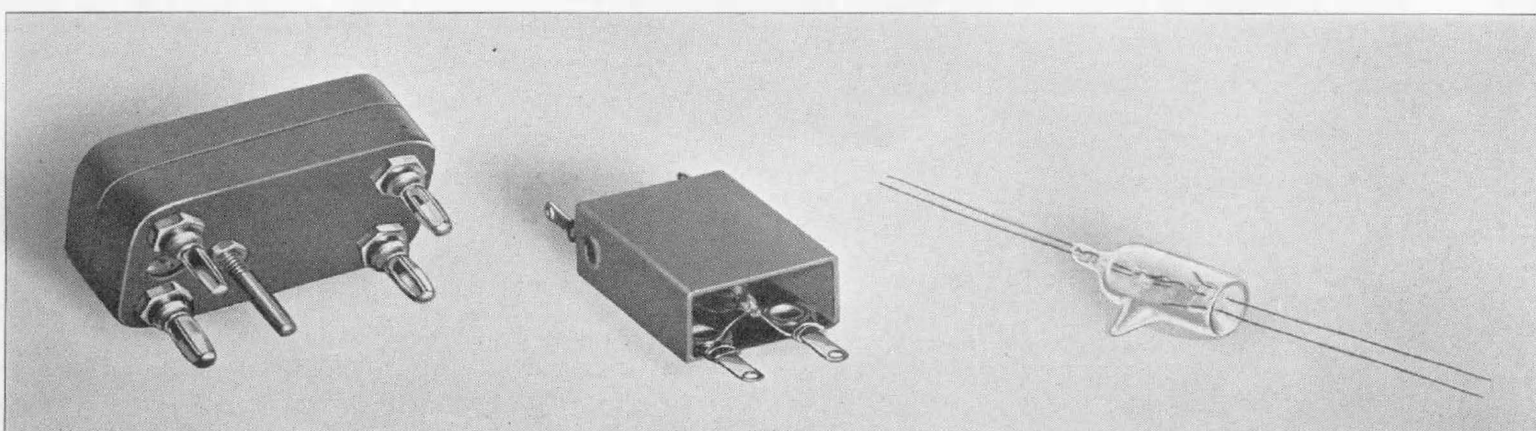
• **TYPE 732-A** Distortion and Noise Meters can be modified for operation with the Type 732-P1 Range-Extension Filters at a price of $60. This does not include the change in the radio-frequency input circuit. The r-f circuit change can be made for $50. The price for both modifications, if made at the same time, is $85. Before returning instruments for modification, write the Service Department for shipping instructions.

NEW TYPE 493 VACUUM THERMOCOUPLES FOR USE AT HIGH FREQUENCIES

• **FOR ACCURATE MEASUREMENTS** of r-m-s values of current at radio frequencies, thermocouples have been universally accepted. Because of the small physical dimensions which can be realized in the construction of thermocouples, residual inductance and capacitance can be limited to very small values. Thermocouples may consequently be used at frequencies considerably higher than those at which more bulky devices become inaccurate.

General Radio Type 493 Vacuum Thermocouples, in the past, have been widely adopted for measurements of currents at frequencies up to the limit of the so-called high frequencies, in the neighborhood of 30 Mc. The contemporary interest in frequencies extending well into the ultra-high-frequency region has created a demand for accurate current measurements which are beyond the capabilities of the older units. In order to meet the exacting requirements

Figure 1. (*Left*) Mounted Type 493 Thermocouple; (*center*) unmounted model in shipping case; (*right*) unmounted model.



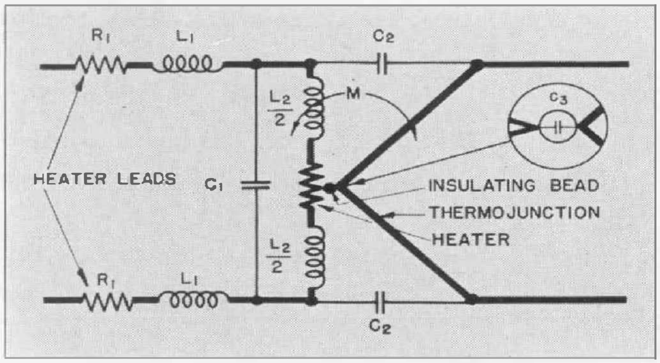


FIGURE 2. Equivalent circuit of the TYPE 493 Thermocouple.

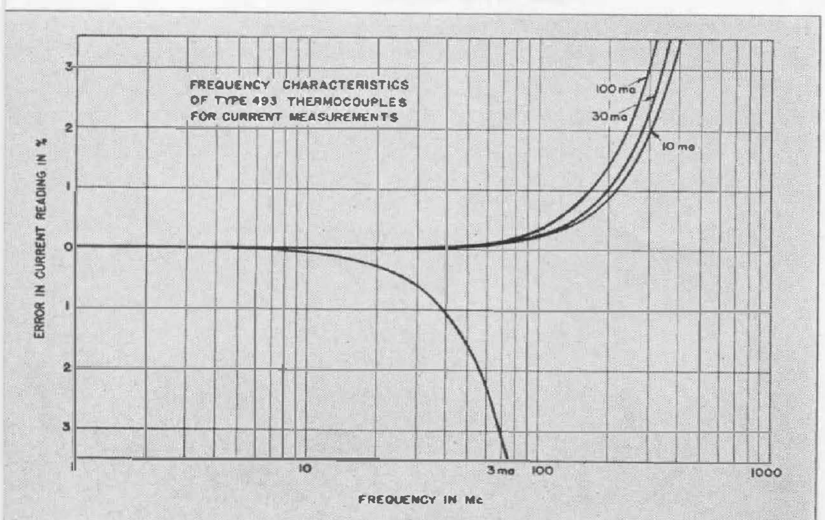
of ultra-high-frequency operation, the TYPE 493 Vacuum Thermocouples have been completely redesigned, and an improved new line is offered to supersede the old.

DESIGN FEATURES

The design of the new TYPE 493 Vacuum Thermocouples is directed especially toward good high-frequency operation. The constructional features which have been adopted to secure this performance are as follows:

(1) The heater and thermo-junction leads are brought out at opposite ends of the glass bulb as shown in Figure 1. The presses are so oriented that the planes in which the leads lie are normal to each other. This method of construction decreases to a minimum both capacitive and mutual inductive coupling between the heater and thermo-junction circuit.

FIGURE 3. Frequency error for current measurements.



(2) The separate-heater type of construction has been adopted for all models since it has proved so superior to the contact type. The advantage to be gained through use of the separate-heater type of construction, in which the thermojunction is spaced away from the heater wire by a small insulating bead, is that the heater and junction are electrically separated from each other except for a minute capacitance through the bead.

(3) The leads to the heater wire are made as short as possible and are led through only one glass press. The residual inductance and capacitance are thereby reduced to a minimum. The spacing between the lead wires is chosen to effect a compromise between inductance and capacitance. The lead wires may be considered as a transmission line of approximately 280 Ω characteristic impedance.

(4) The heater wires are all made of absolutely non-magnetic materials — platinum, platinum-silver and carbon — in order to avoid the small magnetic effect sometimes exhibited by nickel alloy resistance materials. Skin-effect and inductance are thereby rendered as small as possible.

ERRORS IN THERMOCOUPLE MEASUREMENTS

The high-frequency errors which are found in measurements made with TYPE 493 Vacuum Thermocouples are caused principally by residual parameters. They can arise either because of inductance and capacitance in the heater circuit itself or because of mutual inductance and capacitance between the heater and thermo-junction circuits.

In the TYPE 493 Vacuum Thermocouples the errors caused by residual inductance and capacitance in the heater circuit have been reduced to as small a value as the present design will permit.

If the leads to the heater be clipped to as short a length as possible and the thermocouples used unmounted, best high frequency performance will be obtained. An equivalent circuit which represents the thermocouples to a first approximation under these conditions is shown in Figure 2.

In this diagram R_1 and L_1 are the resistance and inductance of the heater leads; C_1 is the capacitance between the heater leads, mostly concentrated in the glass press; R_2 and L_2 are the resistance and inductance of the heater wire; C_2 is the capacitance between heater and thermo-junction; M is the mutual inductance between heater and thermo-junction circuits; C_3 is the capacitance through the insulating bead.

With a length of 2 cm for the heater leads, typical values of the residual parameters are:

$$
\begin{aligned}
R_1 &= 0.1\ \Omega \text{ (at 300 Mc)} \\
L_1 &= 0.01 \\
C_1 &= 0.7\ \mu\mu f \\
L_2 &= 0.007\ \mu h \\
C_2 &= 0.3\ \mu\mu f \\
M &< 0.0003\ \mu h \\
C_3 &< 0.05\ \mu\mu f
\end{aligned}
$$

Frequency characteristics for stock types of thermocouples are shown in Figures 3 and 4. For current measurements the limiting error at high frequencies is largely caused by resonance between L_2 and C_1 in the high-current models and by the shunting effect of C_1 in the lowest current model.[1] For voltage measurements the error at high frequencies is mainly caused by the series impedance of R_1 and L_1 in the high-current models and by series resonance between L_1 and C_1 in the lowest-current model.

Errors caused by mutual inductance and capacitance between the heater and thermo-junction circuits cannot be readily predicted since they depend greatly upon the manner in which the thermocouple is used. Two conditions which can arise when a thermocouple is operated with one side grounded are as follows:

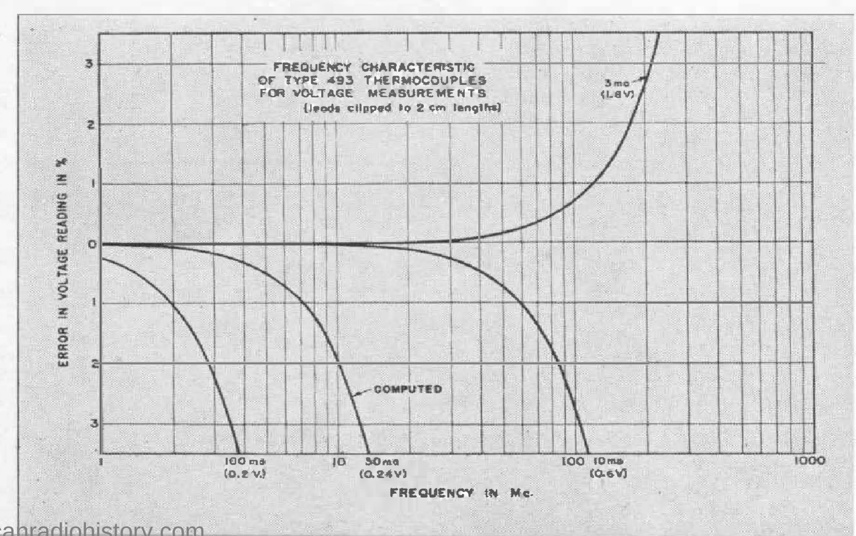
(1) Series resonance through L_1, C_2, and meter leads to ground.

(2) Series resonance around the thermo-junction circuit.

The first of these conditions causes current to be by-passed around the heater so that, as an ammeter, the meter reads low. A compensating effect may occur because of the concomitant heating of the thermo-junction caused by the passage of high-frequency current through it.

The second of these conditions also causes two effects. Mutual inductance between heater and thermo-junction circuits causes circulating current to flow in the thermo-junction circuit. This, in turn, reflects back into the heater circuit a component of resistance which causes the meter, as a voltmeter, to read low. The circulating current in the thermo-junction circuit, on the other hand, heats the junction and causes the meter to read high.

FIGURE 4. Frequency error for voltage measurements.



[1] The critical condition for which the frequency characteristic changes from the resonant-rise to the capacitive-shunted type occurs at a resistance value between that of the 10 ma and 30 ma units. The optimum location of this point with respect to a line of resistance values has been discussed in "The Type 663 Resistor," General Radio *Experimenter*, Volume XIII, No. 8, January, 1939.

The order of magnitude of these errors can be deduced from an exaggerated case. At 300 Mc, a mutual inductance of 0.0003 μh has a reactance of 0.6 Ω. With 100 ma flowing in the heater circuit, this induces a voltage of 0.06 volt in the thermo-junction circuit. Suppose the series resistance around the thermo-junction circuit is 20 Ω. For a condition of series resonance, 3 ma flows. This causes a loss of 0.09 mw in the 10 Ω thermo-junction itself compared to a loss of 20 mw in the heater wire. Since the 20 mw loss in the heater is only partly effective in heating the thermo-junction, the loss in the thermo-junction can cause an appreciable error.

Errors caused by coupling between thermo-junction and heater can be detected quite easily by observing the effects of connecting by-pass condensers across the meter leads and from the meter leads to ground. In order to minimize coupling it is recommended that the meter leads be kept as short as is feasible and that the meter and leads be isolated to as great an extent as possible from the r-f fields associated with the heater current, both by judicious spacing and by electro-magnetic shielding.

— D. B. Sinclair

SPECIFICATIONS

Heater Resistance: Heater resistances, at rated current, are adjusted approximately to the nominal values given in the table. The actual value, at rated heater current, is given within 5% for each thermocouple.

Temperature Coefficient: The temperature coefficient of resistance for the heaters is −0.0005 per degree Centigrade for Type 493-L, and +0.004 per degree Centigrade for Types 493-P, -Q, and -R.

Overload Characteristics: All heaters will withstand a continuous overload of 50% of rated heater current, given in table below.

Thermo-junction Resistance: The resistance is adjusted between 10 and 12 ohms for all couples. The actual value, accurate to 0.1 ohm, is given for each thermocouple.

Output Voltage: With rated heater current the open-circuit output voltage is 10 millivolts ±10%.

Thermal Sensitivity: 47 microvolts per °C.

Meter: The Type 588-AM Direct-Current Meter is specifically recommended for use with the Type 493 Thermocouples.

Mounting: The thermocouples are supplied either mounted or unmounted. (See price list.) The letter "M" distinguishes the mounted from the unmounted models. That is, Type 493-L is unmounted, and Type 493-ML is mounted.

The unmounted units are shipped in small rectangular tubes as shown in Figure 1. Lugs are provided so that the tube may be used as a protective mounting.

The mounted models are supplied in yellow bakelite cases with Type 274 Plugs. The Type 274-RJ Mounting Base is recommended for use with the mounted units.

Dimensions: Mounted models, (length) 2⅛ x (breadth) 1⅜ x (depth) ¾ inches, exclusive of plugs.

Unmounted models: Dimensions of thermocouple, length 1⅛ inches; diameter ½ inch. Over-all dimensions of packing tube, (length) 2½ x (breadth) 1 x (depth) 9/16 inches.

Net Weight: 2 ounces, all models.

Type	*Rated Current*	*Heater Resistance at Rated Current*	*Code Word*	*Price*
493-L	3 ma	600 Ω	ESTOP	$10.00
493-P	10 ma	40 Ω	EXCEL	10.00
493-Q	30 ma	8 Ω	EXERT	10.00
493-R	100 ma	2 Ω	EXULT	10.00
493-ML	3 ma	600 Ω	FABLE	12.50
493-MP	10 ma	40 Ω	FACET	12.50
493-MQ	30 ma	8 Ω	FAIRY	12.50
493-MR	100 ma	2 Ω	FATTY	12.50

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30 STATE STREET - CAMBRIDGE A, MASSACHUSETTS
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1000 NORTH SEWARD STREET, LOS ANGELES, CALIFORNIA