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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also

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A LOW-DISTORTION OSCILLATOR

• **VARIOUS FEEDBACK ARRANGEMENTS** have been used to obtain new operating conditions for vacuum-tube circuits. Regeneration, or positive feedback, in which a voltage from the output circuit is fed back to the input in phase with the input voltage, was used to obtain a high degree of sensitivity in most of the early vacuum-tube radio receivers and is used in most ordinary vacuum-tube oscillator circuits. Within the past few years the principle of degeneration, also known as inverse or negative feedback, in which the voltage fed back is opposite in phase to the input voltage, has been applied to vacuum-tube circuits in order to provide wide frequency response and a low order of distortion. Following the original work of Black[1] and others, the application of this principle to communication equipment has resulted in higher-fidelity transmission.

More recently inverse feedback has been applied to the problem of providing sharply selective circuits.[2] A basic selective amplifier cir-

[1] See H. S. Black, "Stabilized Feedback Amplifiers," *Electrical Engineering*, Volume 53, pages 114–120, January, 1934; or *Bell System Technical Journal*, Volume 13, pages 1–18, January, 1934.

[2] See H. H. Scott, "A New Type of Selective Circuit and Some Applications," *The Proceedings of the Institute of Radio Engineers*, Volume 26, No. 2, pages 226–235, February, 1938.

FIGURE 1. Panel view of the TYPE 608-A Oscillator. Both frequency and output impedance are selected by means of push-button switches.

cuit has been developed which can be used either as a wave analyzer or as an oscillator. The use of the selective degeneration principle in the design of a commercial wave analyzer for noise and other purposes has already been described.[3] A basically similar circuit has been used in the development of a new oscillator, which has unusually desirable characteristics, particularly in the low-frequency range.

THE FEEDBACK CIRCUIT

The circuit used in the oscillator includes three separate sections, as shown in Figure 2. The amplifier section represented by *A* has both a substantially flat frequency response and a negligible phase shift over a range extending from below 20 cycles to above 15 kilocycles. Section *B* is the degeneration network, which balances to a sharp null at the oscillation frequency, thus providing full amplifier gain at this frequency and cancellation of the gain at other frequencies. Section *C* represents the regenerative feedback network, which is fed through a phase-reversing vacuum tube *D* in order to provide the proper regenerative action. This circuit is flat in its transmission characteristics and is adjusted to provide just sufficient regeneration to produce self-oscillation in the circuit.

[3] See H. H. Scott, "An Analyzer for Noise Measurement," General Radio *Experimenter*, Volume XIII, No. 9, February, 1939.

The actual results obtained with the circuit are considerably better, from several viewpoints, than those obtained with more conventional oscillators.

(1) The frequency can be controlled by a relatively inexpensive resistance-capacitance network, smaller and lighter than the usual inductance-capacitance arrangements.

(2) The extremely high selectivity of the combination of the amplifier *A* and the feedback network *B* produces a high degree of stability and suppression of harmonics, as well as of any hum and tube noise which may be developed in the circuits themselves.

(3) The possibility of appreciable distortion occurring in the power output stage is eliminated by taking the inverse feedback voltage directly from the output of that stage so that the net amplification is practically zero for all frequencies other than the oscillation fundamental. Thus, as contrasted with conventional oscillator circuits, the use of a power amplifier stage does not noticeably increase the distortion in the output voltage.

(4) Since the regenerative network has a flat transmission characteristic, it has no appreciable effect upon the oscillation frequency and provides a far better degree of control over the amplitude of oscillation than is possible with most conventional circuits.

THE OSCILLATOR

This new oscillator (TYPE 608-A) covers the range from 20 cycles to 15 kilocycles in 27 steps, the exact frequency being selected by means of two push-button switches. Other frequencies

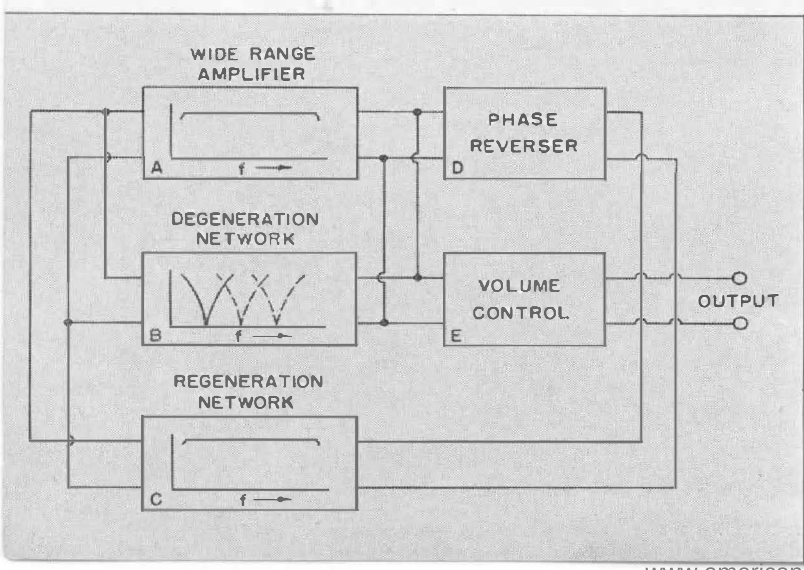


FIGURE 2. Block diagram showing functionally how the TYPE 608-A Oscillator operates.

within this range can be obtained by plugging in three resistances, which may be decade boxes, rheostats, or fixed units. Under normal operating conditions approximately ¼ watt of power can be obtained from the unit with less than 0.1% of distortion, even at 20 cycles. For bridge measurements and other applications, where such a low degree of distortion is not required, the output can be increased to ½ watt.

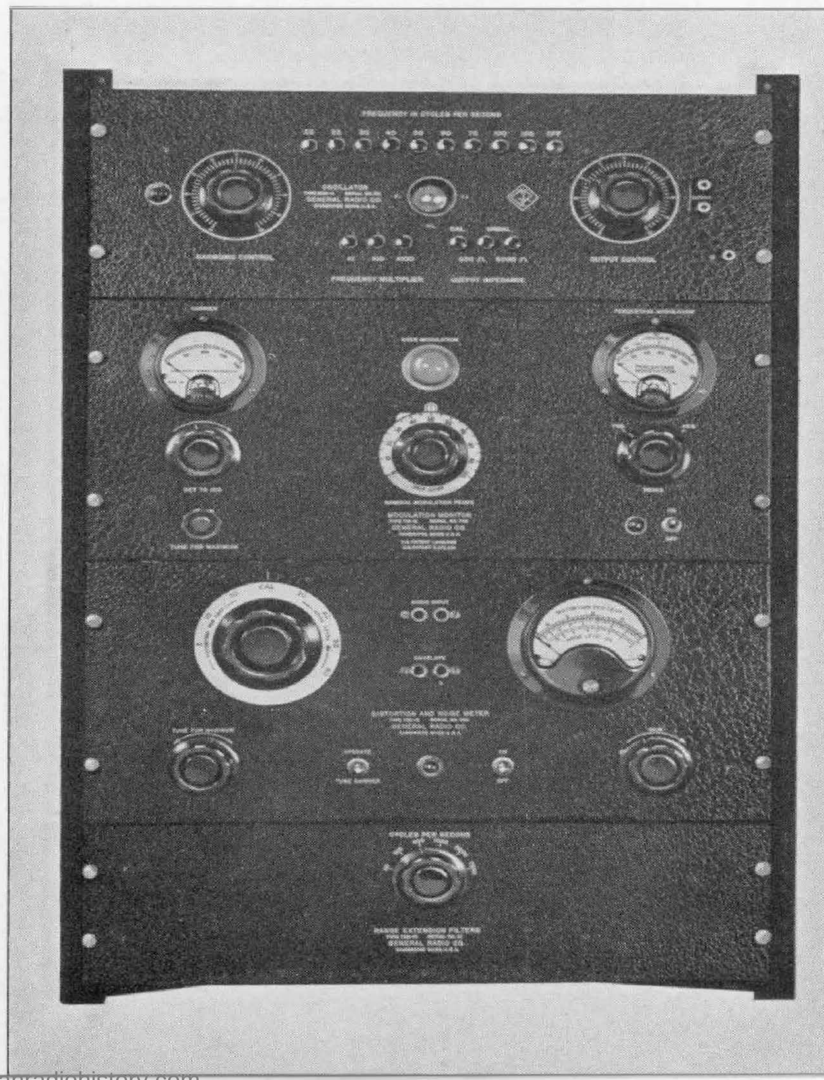
The unit is provided with a 500-600 ohm output circuit, which may be operated either balanced or unbalanced. This output circuit includes a constant-impedance pad which maintains the correct impedance at all settings of the volume control and reduces the output to approximately 80 milliwatts maximum, which is more suitable for use with the average 500- or 600-ohm line.

USES

The availability of this new oscillator has made possible many measurements which were hitherto impracticable. Because of the low hum level and low distortion, bridge measurements can be made at low frequencies with a higher degree of accuracy than has been possible in the past, and the low-distortion feature allows accurate measurements of harmonic distortion to be made at the lowest audible frequencies. Compared to conventional oscillators of the beat-frequency type, the new unit drifts considerably less with temperature, particularly at low frequencies. This feature is a great convenience in applications where a large number of low-frequency measurements must be made.

FIGURE 3. In broadcasting stations, the TYPE 608-A Oscillator is used as a source of test voltage for distortion measurements and for measurements of over-all frequency response. This photograph shows the oscillator mounted on a relay rack as part of the CLASS 730 Transmission Monitoring Assembly.

One important use of this oscillator is found in radio-broadcasting stations as a test-signal source for distortion measurements with the TYPE 732-B Distortion and Noise Meter and the TYPE 732-P1 Range-Extension Filters. The push-button frequency-selector system is rapid in operation and, for this use, is even more convenient than the single-dial control of the usual beat-frequency oscillator. Since the TYPE 608-A Oscillator supplies frequencies over the entire audio range, it can also be used with the TYPE 731-A Modulation Monitor to measure the over-all frequency characteristic of the transmitter. For making harmonic analyses, the oscillator can be used in conjunction with the TYPE 736-A Wave Analyzer, which provides a high degree of selectivity and discrim-



ination, as well as a high order of accuracy.

For bridge measurements it is recommended that the TYPE 608-A Oscillator be used in conjunction with the new TYPE 707-A Cathode-Ray Null Detector (described in this issue of the *Experimenter*), or, as an alternative, with the TYPE 760-A Noise Analyzer used as a detector. Both of these instruments provide a high degree of selectivity and operate also on the inverse-feedback principle. Either of these combinations provides an unusual degree of accuracy in low-frequency bridge measurements.

— H. H. SCOTT

SPECIFICATIONS

Frequency Range: 20 to 15,000 cycles.

Frequency Control: The frequency is controlled by two push-button switches. The first provides frequencies of 20, 25, 30, 40, 50, 60, 75, 100, and 150 cycles, while the second multiplies these frequencies by 1, 10, and 100.

Other frequencies within the operating range of the instrument may be obtained by plugging in external resistances.

Frequency Calibration: Each instrument is adjusted within ±2% or 1 cycle, whichever is the greater, of the frequency engraved on the panel.

Frequency Stability: When this oscillator is operated at normal room temperatures, the frequency will not drift by more than 1% over a period of several hours. The harmonic control provides a means whereby the operating conditions of the oscillator may be brought back to the correct values regardless of ordinary changes in load or line voltage.

Output Impedance: Three output circuits are provided. Selection among them is obtained by means of a push-button switch on the panel. The output impedances are as follows:

1. 500-ohm balanced to ground.
2. 500-ohm unbalanced.
3. 5000-ohm unbalanced.

The volume control is a potentiometer in the 5000-ohm circuit. The actual output impedance of the 5000-ohm output circuit will vary between 1000 and 8500 ohms, depending upon the setting of the volume control. Suitable resistance pads keep the impedance of the 500-ohm output circuit between 400 and 600 ohms regardless of the volume control setting.

Output Power: The 5000-ohm output circuit provides an output power of approximately 0.5 watt into a matched load when the instrument is operated on a 115-volt line. The maximum power obtainable from the 500-ohm output circuit is approximately 80 milliwatts.

Waveform: With the harmonic control set at maximum and the oscillator delivering its maximum power output, the harmonics will be approximately 5% of the output voltage.

The harmonic control provides a means of obtaining unusually pure waveform at some sacrifice in output voltage. When this control is adjusted to reduce the output voltage by approximately 10%, the total harmonic content will be reduced to approximately 0.2% of the fundamental voltage. A further reduction in the output voltage reduces the total harmonic content to less than 0.1% for all output frequencies on the 5000-ohm output circuit. Because of the impedance-matching transformer, the harmonic distortion on the 500-ohm output terminals is slightly greater at frequencies below 50 cycles.

Hum Level: When the oscillator is properly grounded and operated from a 60-cycle line, the hum level is less than 0.05% or 0.1 millivolt, whichever is the greater.

Mounting: The instrument is designed for either table or relay-rack mounting. The wooden ends supplied with the oscillator are removed when it is used on a relay rack. A perforated metal shield is provided.

Power Supply: 110 to 120 volts, 25 to 60 cycles, ac. A simple change in the connections to the power transformer allows the instrument to be used on 220 to 240 volts. The total power consumption is approximately 60 watts.

Tubes: The following tubes are used: 1 6F5G, 1 6Y6G, 1 6X5G, 1 6E5. A complete set of tubes is supplied with each instrument.

Accessories: A 7-foot connecting cord and spare fuses and pilot bulb are supplied.

Dimensions: (Length) 19½ x (depth) 11½ x (height) 7⅜ inches, over-all. Panel, 19 x 7 inches.

Net Weight: 35 pounds.

Type		*Code Word*	*Price*
608-A	. . . .	ORBIT	$260.00

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.

Patent applied for.

A NEW NULL DETECTOR FOR A-C IMPEDANCE BRIDGES

THE DETERMINATION of the resistive and reactive components of an unknown impedance by the use of an impedance bridge requires some form of null detector for indicating when the potential difference between two junctions of the bridge network is zero. The types of null detectors ordinarily used for this purpose are: (1) headphones, (2) tuned vibration galvanometers, (3) a–c galvanometers, and (4) electronic visual indicators such as the electron-ray tube and the cathode-ray oscillograph.

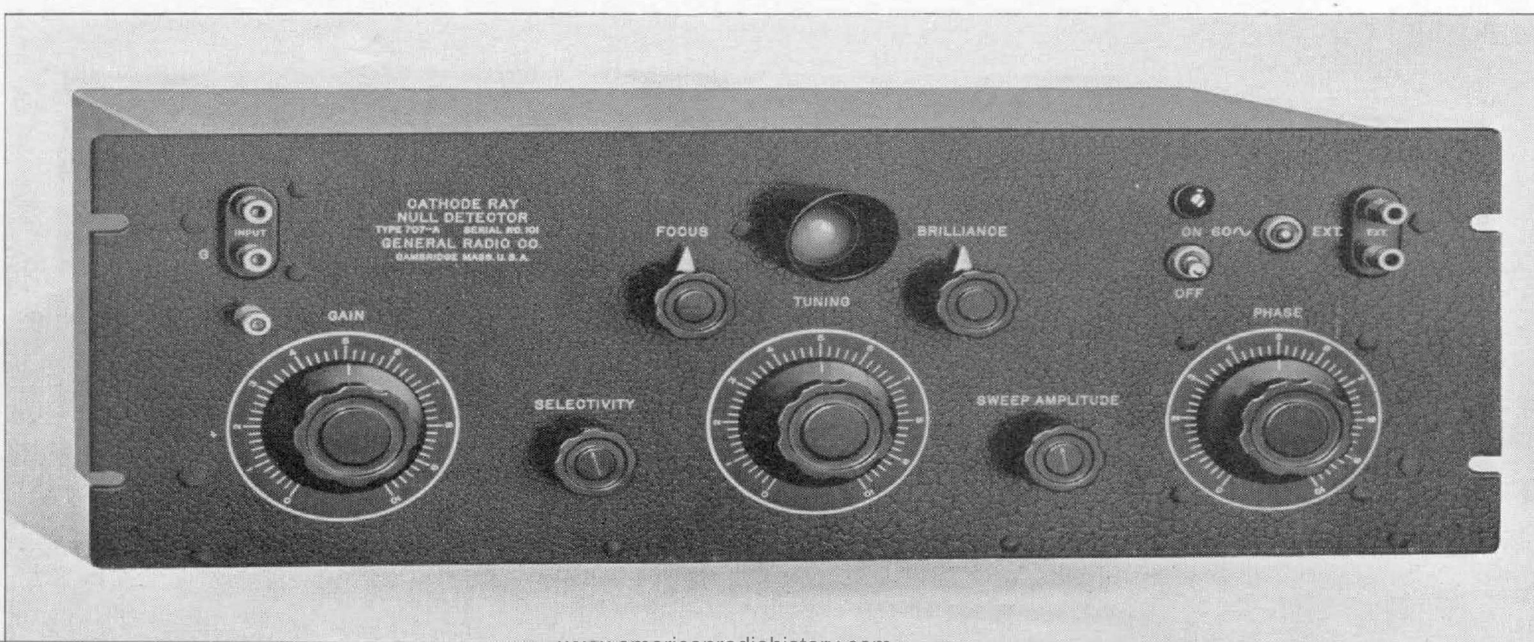
Headphones require a relatively quiet environment, and their use is limited to the audible frequency range. The remaining types, being visual indicators, can be used in a noisy location and can operate at lower and higher frequencies than those for which headphones are satisfactory.

The complete balance of any impedance bridge requires the separate adjustment of two bridge elements; the one to balance the resistive and the other the reactive component of the unknown impedance. The controls must be adjusted to give successively decreasing minima, until a sufficiently precise balance is obtained. The approach to balance usually necessitates also a progressive increase, as a separate adjustment, of the sensitivity of the null detector. While perfectly feasible, this technique is rather troublesome and time-consuming. In order to minimize these difficulties, the General Radio Company has developed the Type 707-A Cathode-Ray Null Detector, which can be used at any frequency up to the upper limit of the audible range (20 kc).

This null detector utilizes the one-inch 913-type cathode-ray tube. The output from the detector terminals of the bridge is amplified and applied to the vertical deflecting plates. A sinusoidal sweeping voltage from the bridge generator is applied to the horizontal plates. When the bridge is completely balanced there is no vertical deflecting voltage, and a horizontal line is seen on the screen (Figure 2a). If the bridge is unbalanced slightly, the pattern becomes an ellipse whose major axis is tilted from the horizontal (Figure 2b). The adjustment of either bridge control will, in general, simultaneously tilt the ellipse and open or close its minor axis.

By varying the phase relation between

FIGURE 1. Panel view of the TYPE 707-A Cathode-Ray Null Indicator.



the sweeping voltage and the terminal voltage of the generator, the phase of the sweeping voltage with respect to the output voltage of the bridge can be controlled. When the proper phase relation is obtained, the adjustment of the reactive balance control will merely tilt the ellipse without opening or closing it, and the resistive balance control will open or close the ellipse without tilting it. If the phase of the sweeping voltage is shifted by 90°, the resistive balance control will tilt the ellipse while the reactive balance control will open and close it.

The effect of adjusting either bridge control can be observed separately, and one can avoid the settings to successive minima that are necessary with any null detector which does not separate the two components of the detector voltage. Separation of the indications of resistive and reactive balance is especially helpful in balancing those types of bridge which have a "sliding zero," and in measuring non-linear impedances such as iron-core inductors. It is possible to make a precise balance of either the reactive or the resistive bridge balance control with only a moderately precise setting of the other control. If either the resistive or the reactive component of the unknown impedance is varying erratically, a precise measurement of the steady component can still be made. Furthermore, without disturbing the bridge controls, it is possible to observe which component of the unknown impedance may be drifting progressively with time.

It is evident that merely noting whether the tilt is up-to-the-right or down-to-the-right gives a definite indication of the direction off balance. The other control, which opens or closes the ellipse, gives no indication of direction. If desired, the angle of tilt and the length of the minor axis may each be calibrated to indicate the degree of unbalance in order to establish tolerance limits for both the resistive and the reactive components of the unknown impedance.

After the correct phase relationship between the sweeping voltage and the terminal voltage of the generator has been established, the technique for using the null detector consists of setting one bridge control to make the ellipse horizontal (see Figure 2c), and then adjusting the other bridge control to close the ellipse into a straight line (Figure 2a).

With the bridge far off balance, and the detector at maximum sensitivity, a distorted ellipse will appear on the screen. Then, as the reactive bridge control is changed, a sudden, pronounced, and easily detected shift in the shape of the distorted ellipse will occur when the control passes through its approximately correct position. Thereafter, the balancing of the bridge, even with maximum sensitivity, is easily accomplished. Comparable operation of other types of null detectors is usually impossible because, with full sensitivity, the initial balance of one component cannot be detected.

The Type 707-A Null Detector has the advantage, common to all electronic devices, of being instantaneous in its response. This feature permits one to disregard transients which are introduced into the bridge or detector circuit

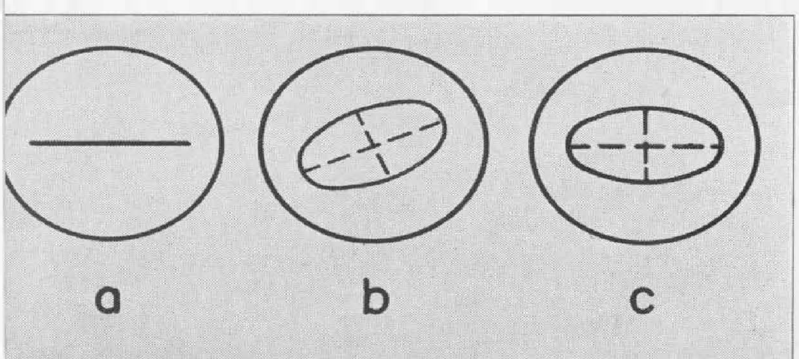


Figure 2. Diagram showing the screen patterns for balance and out-of-balance conditions. Pattern *a* is seen when the bridge is perfectly balanced.

and which cause considerable annoyance and confusion when a more sluggish indicator such as a meter is used. Another advantage of this null detector is its ability to withstand, without injury, any degree of overloading such as might be caused by a pronounced lack of balance of the bridge circuit.

For shifting the phase of the sweeping voltage, the TYPE 707-A Null Detector includes a bridge network[1,2] consisting of two capacitive and two resistive arms, the latter being simultaneously adjustable by a single control knob to permit a total phase shift of nearly 180° with essentially constant amplitude of sweeping voltage.

Most impedance bridges, when balanced for the fundamental frequency of the applied voltage, are not balanced for the harmonics. Consequently, a considerable degree of frequency discrimination is desirable for all types of null detectors. One way of obtaining the desired selectivity is by using tuned filters in the amplifier circuit. Inductance elements, however, are exceedingly susceptible to electromagnetic pickup from stray fields, particularly at commercial power frequencies.

[1] Horatio W. Lamson, "An Electronic Null Detector for Impedance Bridges," *The Review of Scientific Instruments*, Vol. 9, No. 9, September, 1938.

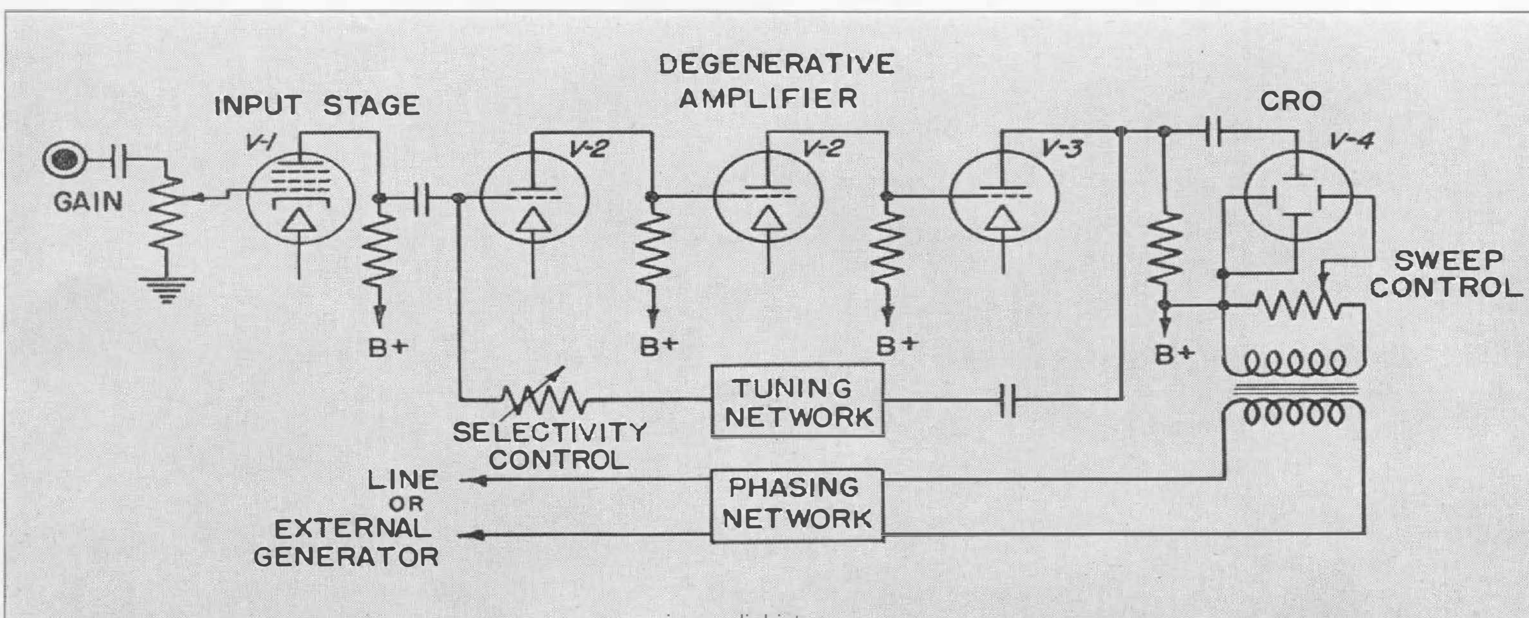
[2] H. M. Turner and F. T. McNamara, "An Electron Tube Wattmeter and Voltmeter and a Phase Shifting Bridge," *Proc. I. R. E.*, 18, 1743 (1930).

In the TYPE 707-A Null Detector this difficulty is avoided by the use of a non-inductive degenerative form of amplifier, which was proposed by H. H. Scott and is referred to elsewhere in this issue of the *Experimenter*. A functional diagram of the system is shown in Figure 3. The amplifier system has an input impedance of 1 megohm, a gain of 80 decibels, and a selectivity of 40 decibels against the second harmonic. The minimum observable deflection then occurs at 60 cycles, at about 100 microvolts r-m-s. At higher frequencies the sensitivity falls somewhat, being about 200-300 microvolts at 1000 cycles.

The tuning control permits a variation of ±5% about a mean frequency which is determined by a plug-in unit designed for a specified nominal frequency. For low frequencies another plug-in unit is required for the phase shifting network. These plug-in units should be ordered to meet the contemplated uses of the instrument; see specifications on page 8.

Many other uses of this device will doubtless occur to the reader. For example, it can be used as a cathode-ray oscillograph for comparing frequencies by means of Lissajous figures. The verti-

FIGURE 3. Schematic circuit diagram of TYPE 707-A Cathode-Ray Null Indicator.



cal deflection can be calibrated for a rough measurement of small a-c potentials, hum levels, harmonic components of voltages or currents, etc.

— Horatio W. Lamson

SPECIFICATIONS

Input Impedance: One megohm.

Sensitivity: 100 μv at 60 cycles; 200 to 300 μv at 1000 cycles.

Selectivity: 40 decibels against second harmonic.

Frequency Range: Plug-in units tune the amplifier for any desired operating frequency between 20 and 2000 cycles. Continuous tuning range ±5% for each unit.

Controls: Panel controls are provided for adjusting the focus and brilliance of the cathode-ray pattern, the phase and amplitude of the horizontal sweeping voltage, and the gain, selectivity, and tuning of the amplifier.

Accessories Supplied: One power cord and one shielded input cord.

Accessories Required: One plug-in phasing circuit is used at any frequency below 400 cycles; one plug-in tuning unit. These are not included in the price of the instrument.

Power Supply: 115 volts, 40 to 60 cycles.

Power Input: 20 watts at 60 cycles.

Vacuum Tubes: One 6K7G pentode, one 6F8G twin triode, one 6J5G triode, one 913 cathode-ray tube, and one 6X5 rectifier; all are supplied with the instrument.

Mounting: Standard 19-inch relay-rack panel.

Dimensions: Panel, 19 x 7 inches; depth behind panel, 9 inches.

Net Weight: 30½ pounds.

Type		*Code Word*	*Price*
707-A	....	NULTY	$195.00

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.

Patent applied for.

PLUG-IN UNITS FOR TYPE 707-A CATHODE-RAY NULL DETECTOR

These units are required for use with Type 707-A Cathode-Ray Null Detector and are not included in the price of that instrument.

A phasing unit is necessary for operation at any frequency *below* 400 cycles. At 400 cycles and above, none is required. A tuning unit is required for each operating frequency. The tuning range is ±5 per cent.

All units plug into mounting jacks provided inside the null detector.

PHASING UNITS

Type	*Description*	*Code Word*	*Price*
707-P1	For Frequencies below 100 Cycles........	NULLTECANT	$7.00
707-P2	For Frequencies between 100 and 400 Cycles..............................	NULLTECBOY	7.00

AMPLIFIER TUNING UNITS

Type	*Frequency*	*Code Word*	*Price*
707-P42	42 cycles	NULLTECCAT	$25.00
707-P50	50 cycles	NULLTECDOG	25.00
707-P60	60 cycles	NULLTECEYE	25.00
707-P400	400 cycles	NULLTECFIG	25.00
707-P1000	1000 cycles	NULLTECGUM	25.00
707-P2000	2000 cycles	NULLTECHIM	25.00

Units designed for use at any other frequency can be supplied on order.

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