The GENERAL RADIO EXPERIMENTER

VOL. X No. 4 SEPTEMBER, 1935

ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

In This Issue

AN A-C OPERATED RESISTANCE-COUPLED VOLTAGE AMPLIFIER

RESISTANCE-COUPLED amplifiers have been used for such a long time that at first glance there seems little to be said about them. Actually, however, tube developments in recent years have so changed design considerations as to introduce the paradox, startling to one whose amplifier designing stopped five years ago, that interstage transformers *reduce* the amplifier gain.

The introduction of screen-grid tubes has made the question of maximum gain per stage of no importance. It happens that nearly all commercial tubes have approximately the same mutual conductance. A little arithmetic shows that in a resistance-coupled amplifier the voltage gain per stage is equal to the product of the mutual conductance and the equivalent parallel impedance of the tube plate circuit (which is the internal resistance and capacity of the tube in parallel with the impedance of the load circuit). Lumping the tube capacity in Z_L, as shown schematically in Figure 1,

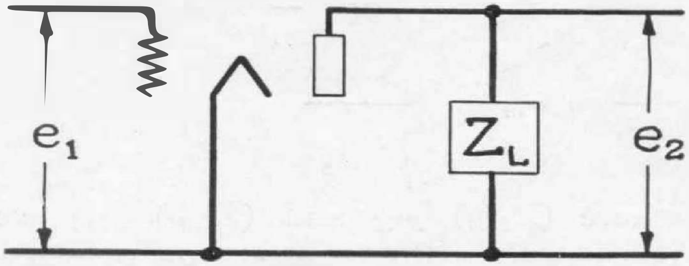

FIGURE 1. Schematic diagram of a vacuum-tube amplifier

$$\frac{e_2}{e_1} = \mu \frac{Z_L}{Z_L + R_P} = \frac{\mu}{R_P} \frac{Z_L R_P}{Z_L + R_P}$$

$$\frac{e_2}{e_1} = G_m Z_{L,P} \qquad (1)$$

where μ is the amplification constant, Rp is the internal plate resistance, and Gm is the transconductance of the vacuum tube.

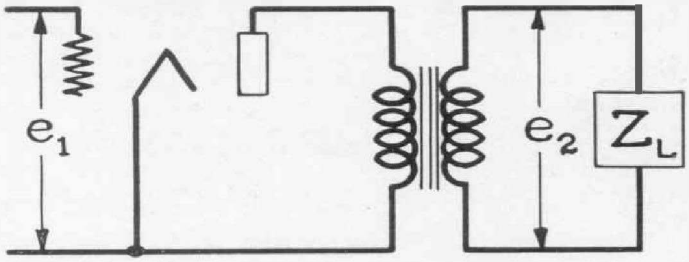

FIGURE 2. Schematic diagram of a single stage of transformer-coupled amplification

In an amplifier coupled by ideal transformers, as shown in Figure 2,

$$\frac{e_2}{e_1} = \mu \frac{Z_L \left(\frac{n_1}{n_2}\right)^2}{R_P + Z_L \frac{(n_1)^2}{n_2}} \frac{n_2}{n_1}$$

$$= G_m \frac{Z_L \left(\frac{n_1}{n_2}\right)^2 R_P}{R_P + Z_L \frac{(n_1)^2}{n_2}} \frac{n_2}{n_1}$$

$$= G_m (Z_{L,P})_{\ PRI} \frac{n_2}{n_1}$$

$$\frac{e_2}{e_1} = G_m \frac{(Z_{L,P})_{\ SEC}}{\frac{n_2}{n_1}} \qquad (2)$$

where $(Z_{L,P})_{\ PRI}$ and $(Z_{L,P})_{\ SEC}$ are the effective impedance due to plate and load as seen from the primary and secondary respectively.

Equation (1) shows that the gain of a resistance-coupled amplifier may be thought of as proportional to the effective impedance built up in the plate circuit; equation (2) shows that the gain of a transformer-coupled amplifier is proportional to the effective impedance built up in the secondary circuit *but is reduced by the step-up ratio of the transformer*. Before the introduction of high-impedance tubes, transformers were desirable, since the internal plate impedance was the true limiting factor. At that time a transformer could profitably be used to step up this impedance even at the expense of the enormously increased shunting capacities and the loss in voltage amplification (as compared with the later ideal cases) due to the transformer step-up ratio. In addition to the other limitations, the older amplifiers were very much bothered by grid-to-plate capacitive regeneration.

At present the situation is entirely different since the early limitations of tube design have been overcome and we are now limited in gain almost solely by the shunt capacities.

The new problem consists in effecting a compromise between the gain per stage and the frequency characteristic; in other words the total impedance-to-ground must be chosen at a value sufficiently low to make the effect of the shunt capacity negligible at the required high frequency limit. In this connection, it is worth mentioning that designers of television amplifiers have gone a step further and partially neutralized the shunt capacities by means of series inductors in the load circuits and by regenerative schemes.

One practical drawback is present with resistance-coupled amplifiers; due to the voltage drop in the load resistors, higher supply voltages are necessary and if batteries are used the whole amplifier becomes a bit unwieldy. This is particularly true if high output voltages are required. When a rectifier is used for plate supply, difficulty is experienced due t coupling between the various stages through the impedance of the supply and if no consideration is given to

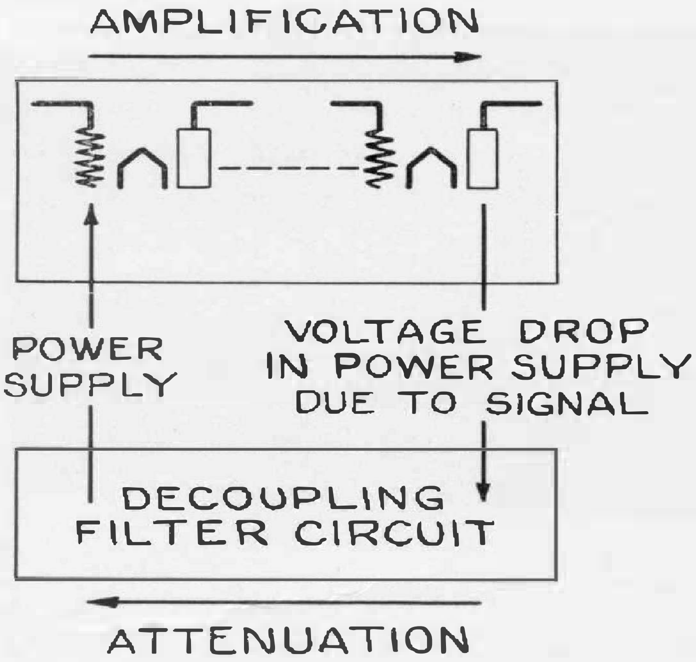

FIGURE 3. Block diagram showing how self-oscillation occurs in amplifiers

this, low-frequency oscillations can and do occur, the so-called "motor-boating." How this comes about is readily seen by reference to Figure 3.

If the voltage introduced into the early stages of an amplifier due to coupling with the last stages through the supply is equal at any frequency to the input signal required to produce that voltage, oscillation can occur. To prevent this, the attenuation of the supply circuit at all frequencies must be greater than the amplification. Figure 4 shows this condition graphically.

This means that the amplification at low frequencies must be limited to the attenuation possible at those frequencies with the condenser-resistance circuits that are economically available. In other words, in practice the lower end of the frequency scale is not at all limited by the availability of large grid coupling condensers and resistors but by the values which may be required to isolate the power-supply circuits. To avoid this limitation, it would be necessary to use several separate power supplies for the different stages.

There is still another limitation to the amplification which can be used at low frequency, that is, the presence of fluctuations in the commercial power lines. Such fluctuations appearing at the output of the rectifier may be considered as a low-frequency spectrum which must be attenuated by the filter circuit in such a way that the resultant voltage applied to the amplifier will not have components of sufficiently high amplitude and frequency to be amplified to an objectionable degree.

The foregoing discussion has been given to outline the problems which have been dealt with in designing the TYPE 714-A Amplifier which has recently been announced by the General Radio Company. This amplifier is intended as a commercial compromise between all of the foregoing factors and the amount of equipment required.

It has been built of three stages, all

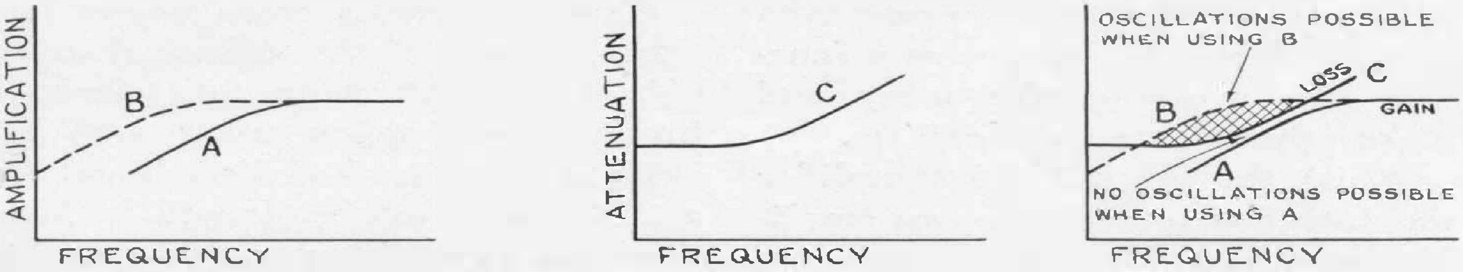

FIGURE 4. Plots showing graphically the conditions for self-oscillation

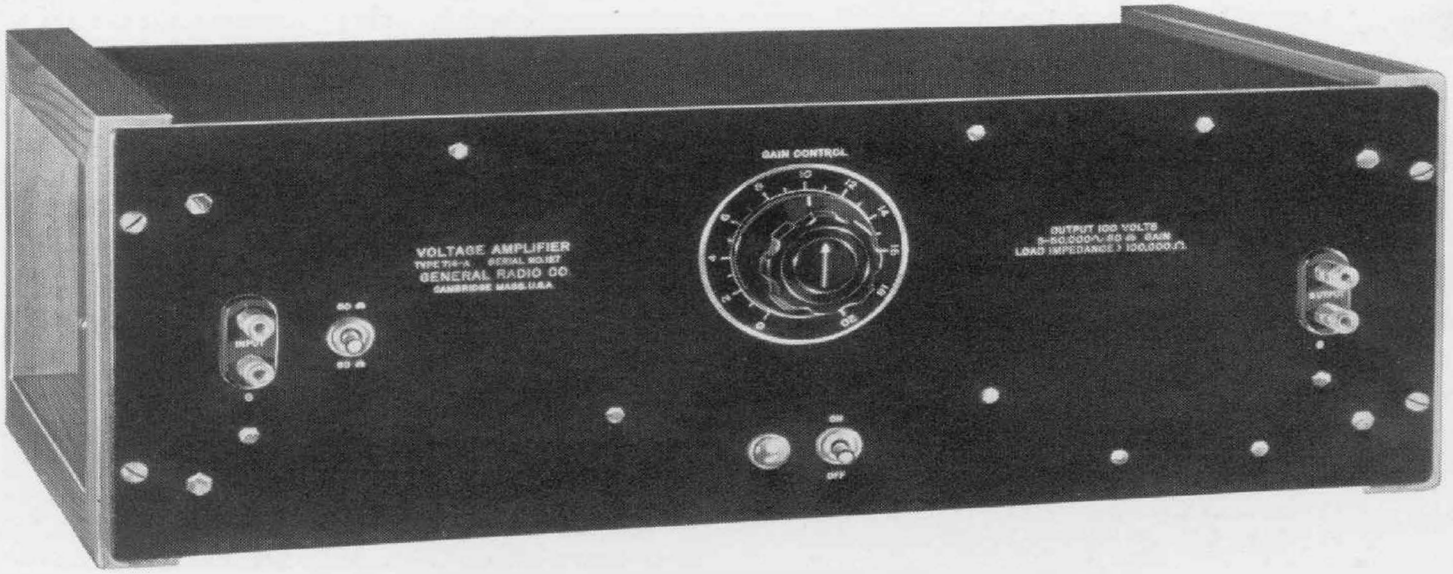

FIGURE 5. Panel view of the TYPE 714-A Amplifier

pentodes, and the gain has been kept to about 27 db per stage, giving a total gain between 80 and 90 db. By carefully keeping wiring capacities at a minimum, this gain was achieved with a drop of only 3 db at 50,000 cycles without using neutralization.

In order to obtain an undistorted output of 100 volts rms for use with cathode-ray oscillographs, it was found desirable to use a plate supply of 600 volts. With this supply and proper use of the 43 μf which was available for the filter unit it was found possible to extend the range of the amplifier downward to 5 cycles with a drop of only 3 db at this frequency. The effect of line voltage variations was studied with the assistance of a motor-driven *VARIAC* with varying-speed voltage fluctuations to exaggerate dynamic line voltage changes. Thus it was possible to plot *low*-frequency output as a function of fluctuation frequency and make appropriate compromises.

While the TYPE 714-A Amplifier was intended primarily as an amplifier for cathode-ray use, the question of its application for bridge balancing naturally comes up. Is the hum sufficiently large so that headphone use is prohibited?

The residual power supply hum has been found to be equivalent to approximately 10 μv on the grid of the first tube. Tests with a wave analyzer show that this arises partly from mutual inductance between the power transformer and the circuit wiring. (This is mainly 180 cycles rather than 60 cycles.) The remainder is due to the heater of the first tube and varies considerably from tube to tube so that some little selection is desirable.

The indirectly-heated-cathode tubes are much less microphonic than most filament-type tubes so that the a-c operated amplifier is actually somewhat quieter than the usual battery-operated type of equal gain.

Figure 6 shows average curves for two observers of the voltage threshold of hearing in a quiet room. Curve *A* was taken using a W.E. 509-W headset worked directly out of a 20,000-ohm source. It will be noticed that about 20 μv could be heard at 900 cycles whereas 300,000 μv were

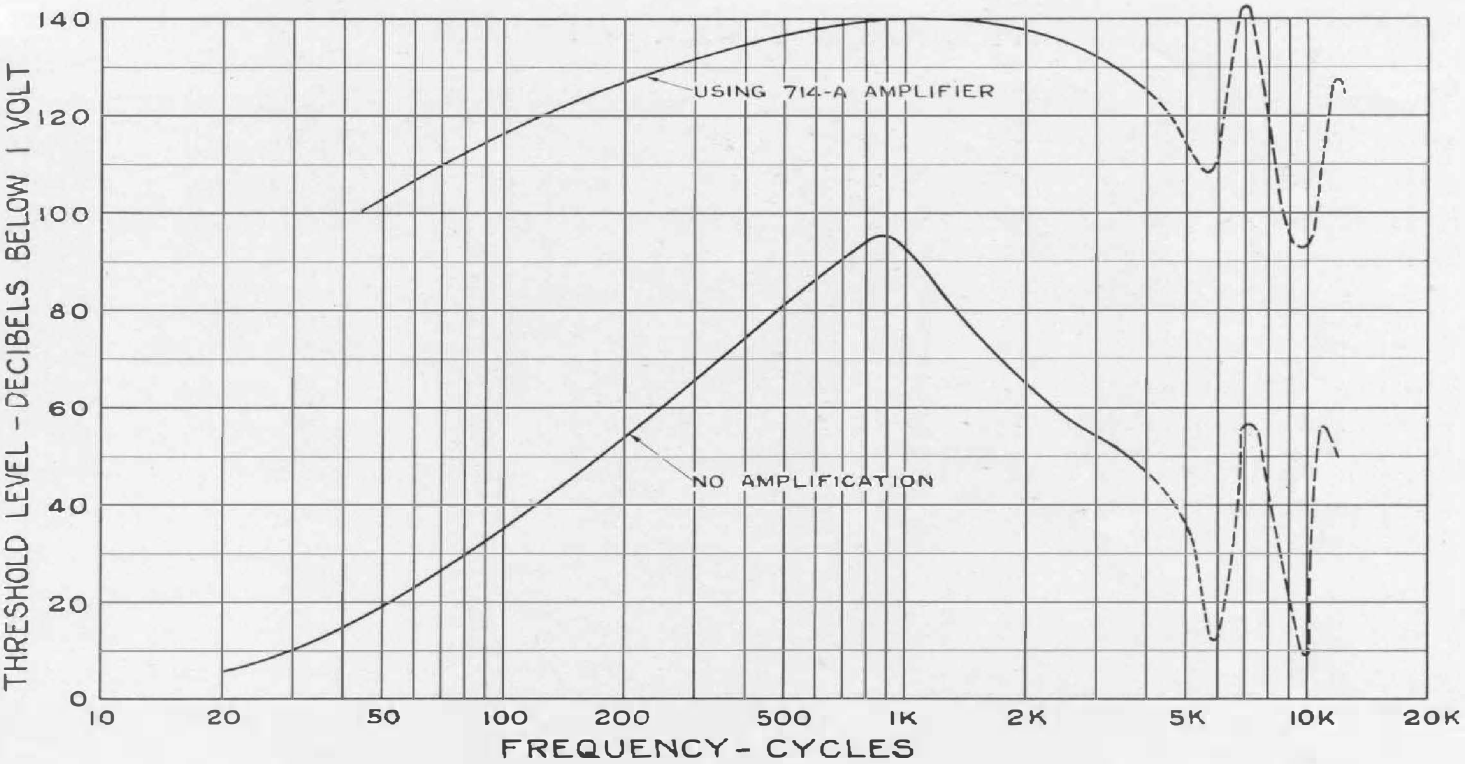

FIGURE 6. Plots showing how TYPE 714-A Amplifier improves the frequency characteristic in bridge measurements

required at 40 cycles and at 10 kilocycles. Curve *B* shows the corresponding curve taken with the amplifier inserted between the source and telephones. At 40 cycles the full gain is effective; at 1000 cycles acoustic masking cuts the gain to 50 db; at 10,000 the full gain is again available. From similar curves taken on other amplifiers it looks as though a signal (if above the threshold of hearing) can be heard if, and only if, it has higher energy than the continuous spectrum in the neighborhood which is sensibly indistinguishable in pitch from it. This would account for the broadening of the telephone response curve when the amplifier is inserted. It will be noticed that the effective acoustic gain of the amplifier is at least 50 db over the spectrum so that no amplifier of lower gain can be as satisfactory.

— L. B. ARGUIMBAU

SPECIFICATIONS

Gain: 80 db maximum, continuously adjustable between 20 db and 80 db.

Frequency Characteristic: Within 3 db between 5 cycles and 50 kc.

Output Voltage: 140 volts maximum peak (100 volts rms on sinusoidal wave).

Load Impedance: 100,000 ohms or greater (one terminal grounded).

Input Resistance: Over one megohm (one terminal grounded).

Power Supply: 115 volts, 40-60 cycles.

Tubes: Two 6C6, one 89, one 80 (all supplied with instrument).

Dimensions: (Length) 19 x (height) 7 x (depth) 10½ inches, over-all.

Net Weight: 40 pounds.

Code Word: AURAL.

Price: $190.00.

This instrument is licensed 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.

McGRAW PRIZE WINNER

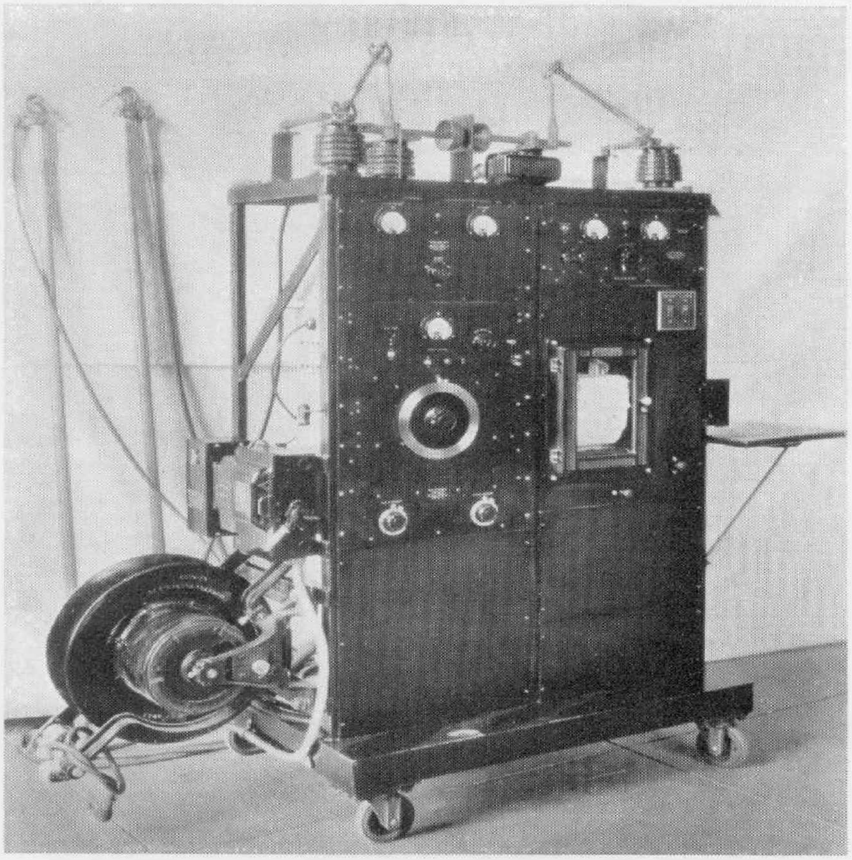

FIGURE 1. Panel view of the fault-locating equipment, showing the beat-frequency oscillator, power amplifier, and recorder

THE above illustration shows an interesting application of General Radio equipment. This assembly is used for locating faults, such as shorts, grounds, or open circuits, in overhead power transmission lines by a method developed by J. E. Allen and C. J. Gross of the Pennsylvania Water and Power Company, Baltimore, Maryland. The equipment consists of a high-powered, high-frequency, beat-frequency oscillator and power amplifier designed and manufactured by the General Radio Company to meet the specifications of the Pennsylvania Water and Power Company. Also included in the assembly are a recording rectifier-galvanometer, various protective and coupling devices, and a motor drive arrangement for operating the recorder and the oscillator control simultaneously.

The beat oscillator covers the range from 100 to 100,000 cycles per second with a substantially constant output of four watts. This drives a power amplifier containing two 203-A type tubes which may be operated either Class A or Class B. A-C operated power supply equipment provides all necessary operating voltages and is controlled by an automatic time switch which allows the filaments to heat before any plate voltage is applied.

In operation the equipment is coupled to the transmission line which is to be tested and the motor drives the oscillator and the recorder throughout the oscillator frequency range. The recording galvanometer draws a curve showing the current into the transmission line versus frequency. This curve will be a series of peaks separated by equal increments of frequency. The frequency increment between successive peaks is inversely proportional to the length of the line. Accordingly, it is only necessary to measure this frequency increment for the various transmission lines in normal operating conditions to determine the line constants. Then when a fault occurs (effecting a new termination of the line) its location can be immediately determined by measuring the frequency increments on the defective line. The same method is valid for a shorted or grounded line. Under some conditions the locations of the peaks in the curve are shifted, but the frequency increments remain the same.

With this equipment it is possible to locate in a few minutes a fault on a three-phase transmission line which it might otherwise take many hours to find. The arrangement works equally well for opens, short-circuits, or grounds in the line and no communication is needed with the line patrolmen or with any other station on the line. The apparatus can be operated by the regular station attendants and the accuracy of location is 2% or better. It can be used on lines up to 100 miles in length.

It is of interest to note that a paper by Messrs. Allen and Gross describing this equipment was awarded first prize last March in the McGraw prize competition of the Edison Electric Institute as the most meritorious paper on an engineering or technical subject relating to the electric light and power industry.*

The apparatus described is not commercially available as a complete installation. A beat-frequency oscillator of characteristics similar to that used can, however, be built to order by the General Radio Company. —H. H. Scott

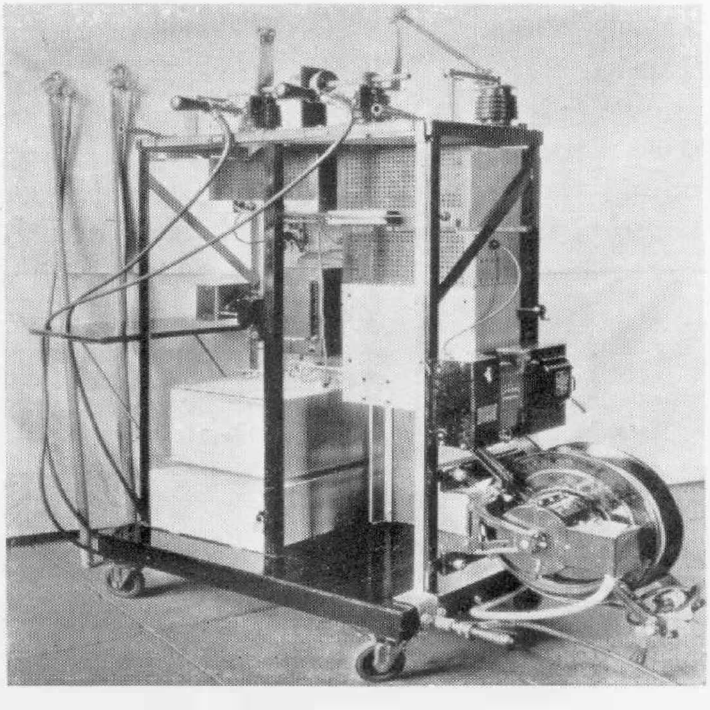

Figure 2. Rear view of the equipment, showing the type of construction used. The beat-frequency oscillator and power amplifier were designed and manufactured by the General Radio Company. The recording equipment, motor drive, and the protective and coupling devices were built by the Pennsylvania Water and Power Company

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* *E. E. I. Bulletin*, Aug., 1935; *Electrical World*, July 20, 1935.

NEW DECADE CONDENSER UNITS

Type 380 Decade Condenser Units are now furnished with a new type of cam switch which is more stable mechanically than that previously used. An all-mica 1.0 μf decade (in steps of 0.1 μf), Type 380-F, is now available and is made up of Type 505 Condensers. Types 380-L, 380-M, and 380-N listed below, replace the older Types 380-A, 380-B, and 380-C, respectively.

Electrical specifications are listed below. The maximum voltage listed holds for frequencies below those specified. For higher frequencies, the maximum safe voltage decreases and is inversely proportional to frequency.

Type	*Capacitance*	*Accuracy*	*Dielectric*	*Power Factor*	*Maximum Voltage at Frequency*	
380-F	1.0 μf in 0.1 μf steps	1%	Mica	0.05%	500	4 kc
380-L	1.0 μf in 0.1 μf steps	2%	Paper	1.0%	300	1 kc
380-M	0.1 μf in 0.01 μf steps	1%	Mica	0.1%	300	100 kc
380-N	0.01 μf in 0.001 μf steps	1%	Mica	0.2%	300	1000 kc

Dimensions: Type 380-F, panel space, 4 7/32 x 4 21/31 inches; behind panel, 3 15/16 inches. Types 380-L, 380-M, and 380-N, panel space, 3 5/10 x 2 13/16 inches; behind panel, 4 1/16 inches.

Net Weight: Type 380-F, 3⅝ pounds; Types 380-L and 380-M, 1½ pounds; Type 380-N, 1⅜ pounds.

Type	*Code Word*	*Price*
380-F	ACUTE	**$58.00**
380-L	ADAGE	**10.00**
380-M	ADDER	**12.00**
380-N	ADDLE	**10.00**

TYPE 219 DECADE CONDENSER

New models of Type 219 Decade Condensers are now available, using the Type 380 Decade Condenser Units described above. Types 219-L 219-M, and 219-N replace the older Types 219-F, 219-G, and 219-J, respectively. Type 219-K is a new three-dial box in which mica dielectric is used throughout. All cabinets are lined with copper, effectively shielding the condensers from external fields.

Dimensions: Types 219-K and 219-M, 13¾ x 5 13/16 x 5½ inches, over-all; Types 219-L and 219-N, 10⅝ x 5 13/16 x 5½ inches, over-all.

Net Weight: Type 219-K, 10¾ pounds; Type 219-L, 6½ pounds; Type 219-M, 8⅝ pounds; Type 219-N, 6⅜ pounds.

Type	*Capacitance*	*No. of Dials*	*Type* 380 *Decades Used*	*Code Word*	*Price*
219-K	1.110 μf in 0.001 μf steps	3	F, M, N	CROSS	**$90.00**
219-L	1.10 μf in 0.01 μf steps	2	L, M	COVER	**35.00**
219-M	1.110 μf in 0.001 μf steps	3	L, M, N	BRIER	**45.00**
219-N	0.110 μf in 0.001 μf steps	2	M, N	CRONY	**35.00**

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PRINTED IN U.S.A.