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JULY 16th NUCLEAR EXPLOSION:
BLAST MEASUREMENTS WITH CONDENSER GAUGES

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ABSTRACT

A system of measuring shock-wave pressure and impulse is described. Condenser microphones are employed as frequency modulators for high-frequency transmitters. Data are recorded by means of FM receivers and recording oscilloscopes. Results for the July 16th, nuclear-bomb test are given.

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JULY 16th NUCLEAR EXPLOSION:
BLAST MEASUREMENTS WITH CONDENSER GAUGES

INTRODUCTION

Condenser pressure gauges were used in connection with the July 16th test primarily because they required no wire lines from the gauges to the shelter. The effect of the nuclear explosion upon the lines necessary for other electrical measuring methods was not precisely known. It was felt that this wireless system, employing direct frequency modulation of a transmitter, might function even in the presence of intense ionization.

The condenser-gauge system is described because it appears to have definite advantages in measurements of this type of explosion and because the gauges can be made to respond to shock waves with very small peak pressures and to impulses of very long duration. The electrical disturbances which did upset many of the wire lines did not detectably disturb this apparatus.

Lack of sufficient time properly to prepare and install the equipment resulted in the omission of some of the necessary precautions against failure. Of a total of eight gauges, only one gave a good record. Three of the transmitters failed to operate because of the rain preceding the explosion. In addition, because of accidental misadjustment of the recording oscillographs, traces appeared for only two of the gauges. One of these could not be interpreted because of some trouble with the transmitter. The remaining record was complete and useful and is discussed under RESULTS. In spite of these difficulties, it is believed that the system is essentially sound and useful for shock wave measurements with peak pressures ranging from a few hundredths to eight or ten pounds per square inch.

The system consists essentially of a condenser microphone whose capacitance changes modulate the frequency of an oscillator operating at 30 to 35 megacycles. The oscillator output is doubled in frequency, amplified and transmitted to an FM receiver.

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The discriminator output of the receiver is applied to a recording oscilloscope.

MICROPHONES

The condenser microphones used in these shock wave measurements were made at the California Institute of Technology. Their intended use is in Firing Error Indicator equipment (NDRC Project, Physics 6). This is a binaural radio-informing system for determining the accuracy of fire directed at plane-towed targets. In this application, accurate scoring demanded rugged and stable microphones with flat frequency response from 0 to 10,000 cycles per second. In addition, they had to be produced in volume with accurately duplicated characteristics. These requirements had been met and satisfied the requirements of shock wave pressure and impulse measurements.

Through the cooperation of Dr. Jesse W. M. DuMond, director of the F.E.I. project and Dr. W.K.H. Panofsky, in charge of production and field testing of the apparatus, quantities of the microphones were made available.

The original microphones were useful in the pressure range from a few hundredths to about one pound per square inch. With the help of Dr. Panofsky, a modified unit for pressure measurements from 0.5 to 8 P.S.I. was designed and produced.

Parts of the microphones in various stages of assembly are shown in Fig. 1. Fig. 2 shows a sketch, in cross section, of an assembled unit and of the jig used for pre-sketching the diaphragms.

Section A of Fig. 1 shows a diaphragm and its clamping ring. The diaphragms are 0.0016" beryllium-copper sheet. A diaphragm is inserted into the stretching jig of Fig. 2 and firmly clamped around its edge as shown. The inner threaded cylinder is turned up against the diaphragm until the natural frequency of the exposed portion is 3000 cycles per second. The diaphragm, in the stretching device, is then applied to the bronze casting at B in Fig. 1 and clamped as at C. Excess diaphragm stock is then trimmed away.

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D shows the brass microphone electrodes. The one at the left is for a low-pressure unit and the one at the right is for the modified high-pressure unit. The ceramic insulator(E) is inserted into the brass stretching ring at F and the protruding back of the stretching ring is spun over the back of the ceramic to hold it firmly in place. A completed electrode assembly is shown at G. The profile of the stretching ring is carefully machined so that it cannot cause undue strains in the diaphragm. The electrode is machined so that its surface is slightly below that of the stretching ring. When the electrode assembly is screwed up into the microphone casting, the stretching ring touches the diaphragm and the diaphragm-electrode spacing remains constant as the diaphragm tension is adjusted. Completed microphones from which the diaphragms have been removed are shown at H and I.

The frequency characteristics and sensitivity of the microphone are determined by the active diaphragm diameter and its tension and by the electrode diameter and spacing. The diaphragm to electrode spacing is such that, at the resonance frequency, there is sufficient air damping to prevent appreciable increase in sensitivity.

Active diameter of the diaphragm of the low-pressure microphone is 0.750"; electrode diameter, 0.375"; spacing of electrode and diaphragm, 0.001"; resonance frequency, 10 Kc. Dimensions of the high-pressure unit are: diaphragm diameter, 0.360"; electrode diameter, 0.300"; spacing, 0.00085"; resonance frequency, 18 Kc.

Details concerning the design of the microphones and the ingenious devices developed at C.I.T. for adjusting and testing them may be found in Appendices to Special Informal Report on the Aperiodic Firing Error indicator -- N.D.R.C. Physics 6.

TIME CONSTANTS

In order to respond faithfully to the profile of the shock wave, the diaphragm of the microphone must be backed by a constant pressure or, at least, the

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rate of change of pressure back of the diaphragm must be small compared to the rates associated with the shock wave. The air space back of the diaphragm was not entirely sealed because of capacitance changes which would have been caused by barometric and temperature changes. The expected size of the bomb explosion and extrapolated impulse duration data indicated that 30 seconds time constant for leakage of the trapped air was about the minimum which could be tolerated.

The microphones, as constructed, all had very short time constants. They were lengthened by painting the back of the electrode assembly with dilute Glyptal lacquer and baking the microphones for a few hours at about 80°C. Usually the microphones had acceptable time constants after this treatment. Lack of time prevented the development of a more elaborate method for controlling the leak.

Time constants were measured by using the microphone as part of the tuning capacitance of a high-frequency oscillator and placing both under a bell jar. The pressure around the whole unit was reduced by about 30 cm of mercury for the high-pressure microphones or by 5 cm in the case of the low pressure units. Time was allowe for pressure equilization on the two sides of the diaphragm and an FM receiver with a vacuum-tube voltmeter on its discriminator output was tuned to the oscillator signal. Air was suddenly readmitted to the system and the meter reading was noted. The rate of change of pressure back of the diaphragm was thus transformed to a rate of change of voltage and the time constants were measured by observing the meter readings as a function of time.

TRANSMITTERS

Each transmitter consisted of two units. The microphones were mounted on a unit containing the oscillator and frequency doubler. This unit is shown in Fig. 3. The two-stage power amplifier, delivering about 60 watts to the antenna, is pictured in Fig. 4. The circuits are quite conventional and are not described. Great care was taken in the construction of the units, especially of the oscillator and doubler stages,

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so that the shock wave would not seriously affect the frequency of the oscillator by spurious capacity and inductance changes.

A section of the oscillator circuit is shown in Fig. 5. The effect of changes in capacitance of the microphone on the frequency of the oscillator are determined by condensers C_p and C_s. These condensers also determine the frequency of the oscillator and, since the transmitter frequencies had been definitely allocated, they had to be adjusted both for the required transmitter frequencies and for the desired frequency changes to be caused by the microphones. It was possible to calculate approximate values of C_p and C_s so that most of the capacitance was supplied by fixed ceramic condensers. Final adjustments were made with small variable ceramic condensers in parallel with the fixed ones. This was done to avoid, as much as possible, the effects of mechanical shock on adjustable condensers.

Condenser C_c is a small ceramic whose value is approximately that of the capacitance change expected from the microphone. Its function was to provide a standard deviation in the frequency of the oscillator so that the pressure calibrations of the units could be correlated with the data obtained from the shock wave. This condenser is applied, at will, across the microphone by the relay L_1 which is mounted on the oscillator unit as shown in Fig. 3.

RECEIVERS AND RECORDERS

Slightly modified Hallicrafter S-36 receivers were used for detecting the transmitter signals. The limiter stage of each set was adjusted to saturate at a lower signal level than did the unmodified stage. Its plate and screen voltages were taken from the VR-150 voltage regulator tube for better stability. Careful alignment of the I.F. transformers extended the [illegible] pass band to ± 100 Kc with fairly good linearity. The discriminator output of the receiver was connected to the recording unit.

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The oscilloscope unit contained a DC amplifier for the discriminator. This amplifier was connected directly to one pair of deflecting plates in the 3" oscilloscope tube. The other pair of deflecting plates was used only for setting the position of the electron beam.

CineKodak Model K cameras were used for photographing the oscill scope screen These were 16-mm movie cameras driven by 24-volt DC speed-regulated motors. The cameras were modified to give continuous film motion at 5 inches per second. Film speed calibrations were made before and after the blast by photographing 50-cycle sine waves from a tuning fork.

In order to conserve space, the camera and oscilloscope units were mounted side by side and a reflex-mirror system was used to reflect the spot on the oscilloscope screen into the camera.

INSTALLATION

Condenser gauges were placed at 8 positions west of the bomb tower. The transmitter units were mounted on the 15-foot poles which served as antenna masts. The antennas were 3-element parasitic arrays aimed at the shelter at 10,000 yards west of the tower. Each antenna was adjusted to the frequency of its transmitter to insure maximum signal at the receiver. The half-wave dipole of each array was fed by link coupling to the power stage of the transmitter through a length of Twinax cable a quarter-wavelength long at the transmitter frequency. The power stage was mounted down the pole at the end of this cable. Below the power stage was mounted the microphone-oscillator-doubler unit. This unit was mounted 6 feet above ground in such a position that the shock wave would strike the microphone from the side rather than from the front. A length of RG9/U cable connected this unit with the power stage.

Preliminary tests on the transmitters showed that, in spite of careful design, the frequency of the oscillator varied seriously when it was subjected to mechanical shock. Fig. 6 shows an effective shock mounting designed to reduce the effects of

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mechanically conducted and direct air shocks on the oscillator. The outer box was mounted directly on the antenna pole. The inner box, in which the oscillator unit was mounted, was made practically air-tight to prevent the shock wave from reaching the oscillator components.

The power supply for the transmitter consisted of storage and heavy-duty "B" batteries housed in a sturdy wooden box at the base of the pole. In each battery box was a small metal cabinet which housed the control circuit for the transmitter. This circuit is shown within the dashed lines of Fig. 5. A control line, extending from the shelter to the most distant transmitter, permitted the transmitters to be turned on and off at will and also allowed the calibration condenser C_c to be placed across the microphone when desired.

Resistances in the control boxes were adjusted so that, with 0.030 amp flowing into each box from the control line, the battery relay held all transmitter filament circuits open. The transmitters were placed on the air by removing the power supply in the shelter from the control line. Calibrations could be accomplished by virtue of the greater sensitivity of the calibration relays. These relays closed on 18 to 20 ma while the battery relays did not.

Receivers in the shelters were fed by antennas matching the corresponding transmitter antennas. Lengths of RG9/U cable ran from the receivers to the antennas. This 50-ohm cable was matched to the 10-ohm impedance of the dipole in each array by means of a coaxial quarter-wave transformer, whose characteristic impedance was approximately the geometric mean of 10 and 50 ohms. The antennas were mounted on 20 foot poles spaced 8 feet apart on a line perpendicular to the direction of the tower.

The frequencies at which the transmitters were operated were at intervals of one megacycle from 63 to 70 Mc inclusive. Lower frequencies would have been more satisfactory because the frequency deviation produced by the microphone would have been a larger fraction of the oscillator frequency and shock excitation of the

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oscillator components would have caused smaller frequency changes. On the other hand, at these frequencies the antenna arrays were reasonably compact and could be made strong enough to withstand severe shocks. In addition, interference from other transmitters was less likely to be a serious problem at these high frequencies.

CALIBRATIONS

Condensers C_s and C_p in the oscillator section of the transmitter (Fig. 5) were so adjusted that, at the designated transmitter frequency, the expected microphone capacity change would produce a frequency deviation of about 60 Kc. This is, because of the frequency-doubling stage, twice the actual change in oscillator frequency. The condenser placed across the microphone by the "calibrate" relay (C_c) was adjusted to produce a similar deviation.

Overall calibration of each set from microphone to film was accomplished by impressing on the microphone a series of static gas pressures alternated by condenser "calibrate" signals. Six values of pressure, appropriate to each microphone, were applied so that explosions ranging from a few hundred to 20,000 tons of TNT were covered by each microphone. These data were recorded on the 16-mm film and from these records complete calibration curves were plotted.

Fig. 7 shows the pressure calibration apparatus as used in the field. The rubber-walled pressure cap is pushed over the front of the microphone and the applied pressure is read from the manometer. Gas was provided by the small tank of CO_2. The three numbered valves are used to control the pressure applied to the microphone. Because of almost inevitable gas leaks around the rubber cap, the true pressure on the microphone diaphragm is measured by running a separate line of rubber tubing from the cap to the manometer. Gas is allowed to leak from Valve 1 continuously. Valves 2 and 3 limit the rate at which gas may flow. By gradually reducing the leak at Valve 1, the pressure in the system may be built up to the desired value regardless of small leaks around the microphone. The reducing valve on the gas tank is adjusted to limit the maximum pressure to about 12 psi.

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RESULTS

As mentioned previously, only one good record was obtained from the condenser gauges. Even this trace was so faint that difficulty was experienced in measuring deflections on the record. The 16-mm film was placed in a microfilm "reader" and deflections were measured with respect to the sprocket perforations of the film. The 50-cycle timing marks filmed before the shot determined the time scale of the pressure-time trace. Previous runs had demonstrated that the speed of the camera motors remained quite constant. The static pressure calibration of the gauge was measured on the same film reader and these measurements were used to convert deflections on the shock wave record into corresponding values of pressure.

The impulse curve for this gauge appears in Fig. 8. It will be noted that the pressure at the time of arrival of the shock wave at the microphone does not appear. The trace was invisible at this point, indicating that the spot on the oscilloscope screen was moving rapidly at this time. Extrapolation of the smooth curve to the time of arrival of the shock wave gives a peak pressure at the 6000 yard station, of 0.6 psi. Because of the low value of the first measured point, it would appear that such extrapolation is not justified. As a reasonable compromise, the peak pressure is assumed to be 0.55 psi. The positive impulse of the shock wave, determined by the area under the positive phase of the pressure-time curve, is 0.43 psi-seconds. It is believed that the value given for the peak pressure is correct to within plus or minus 10 percent and that the impulse value is good to plus or minus 5 percent.

Evaluation of shock wave measurements at large distances from a blast is rather uncertain because of the scarcity of reliable data. Hirschfelder, Littler and Sheard (LA-316) point out the uncertainties and give a table of the best available estimates of pressures and impulses at large distances from TNT charges of up to 10,000 tons. On the basis of these estimates, a peak pressure of 0.55 psi at 6000 yards indicates an explosion equivalent to about 9000 tons of TNT. The impulse of 0.43 psi-seconds corresponds to approximately 12,000 tons of TNT.

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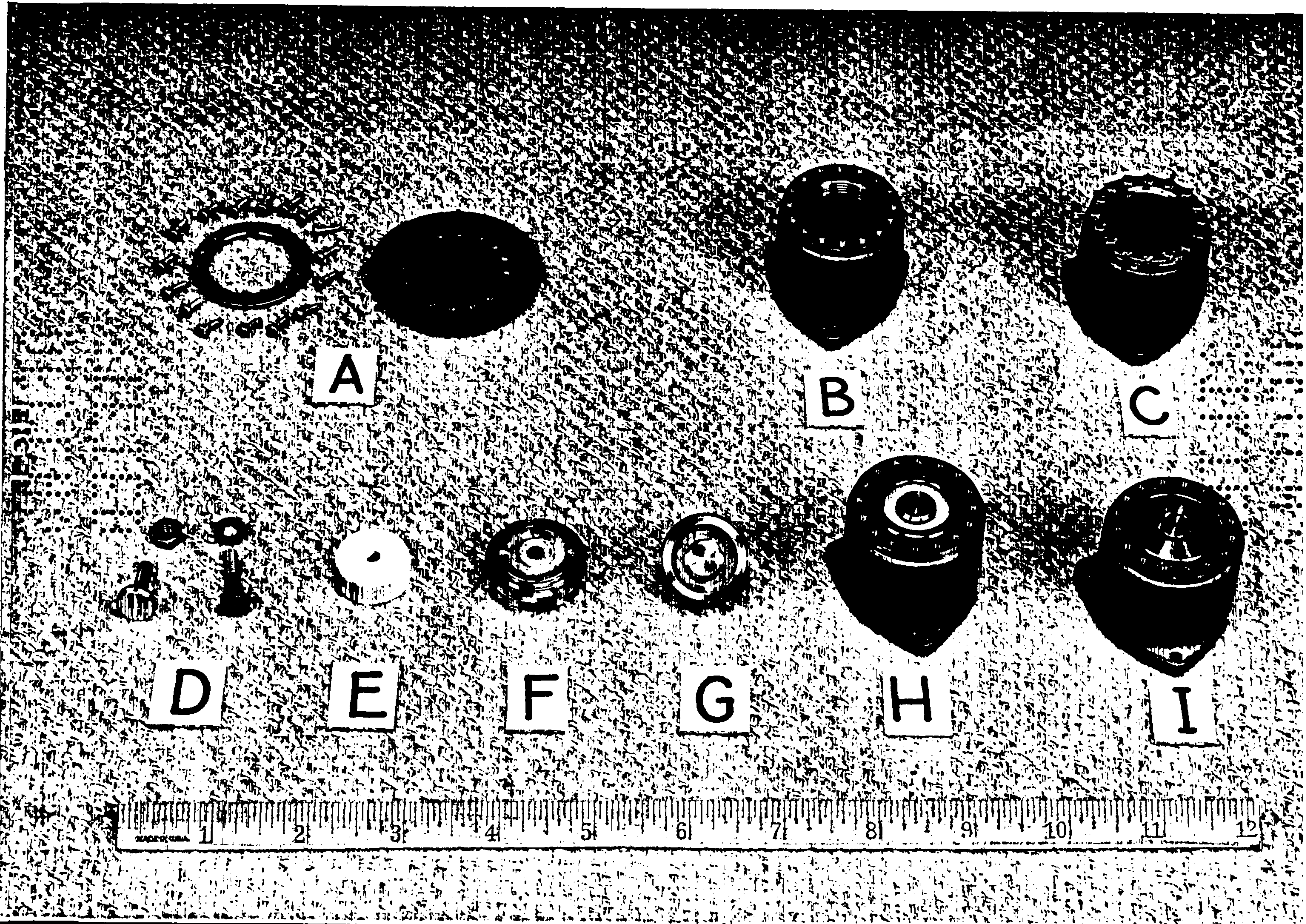
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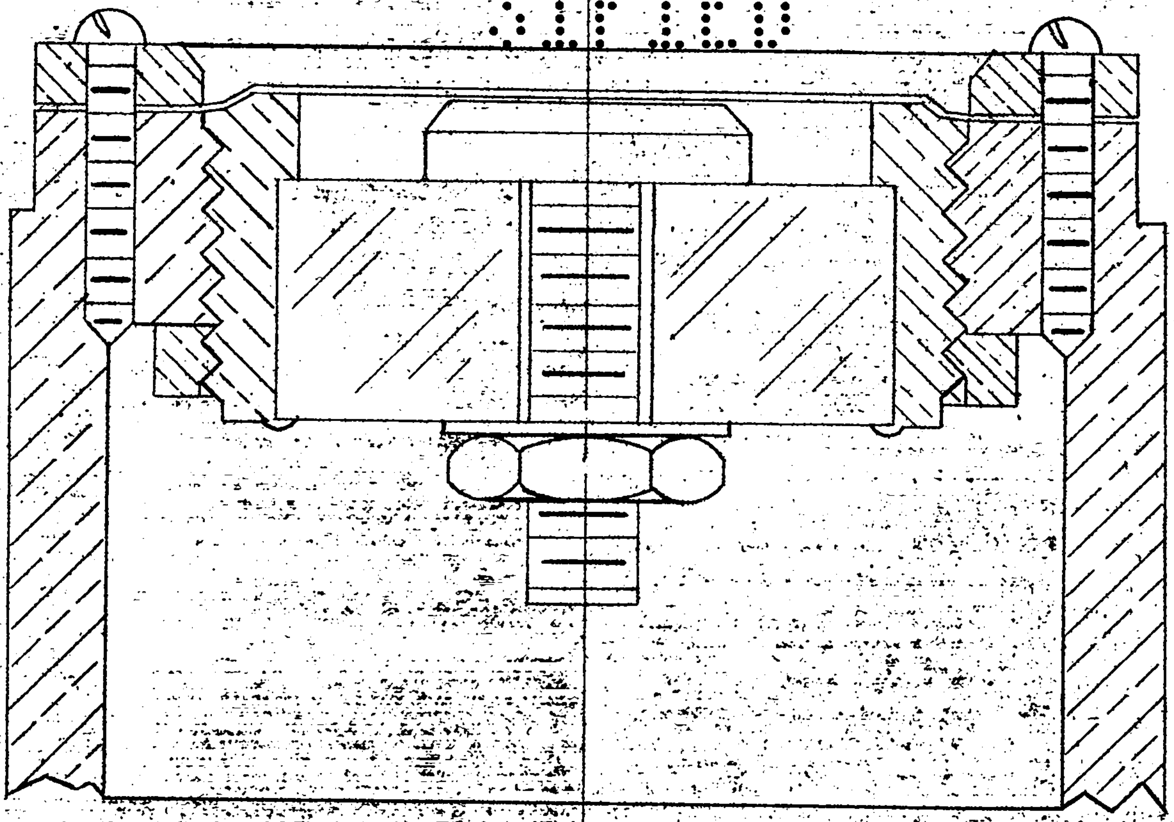
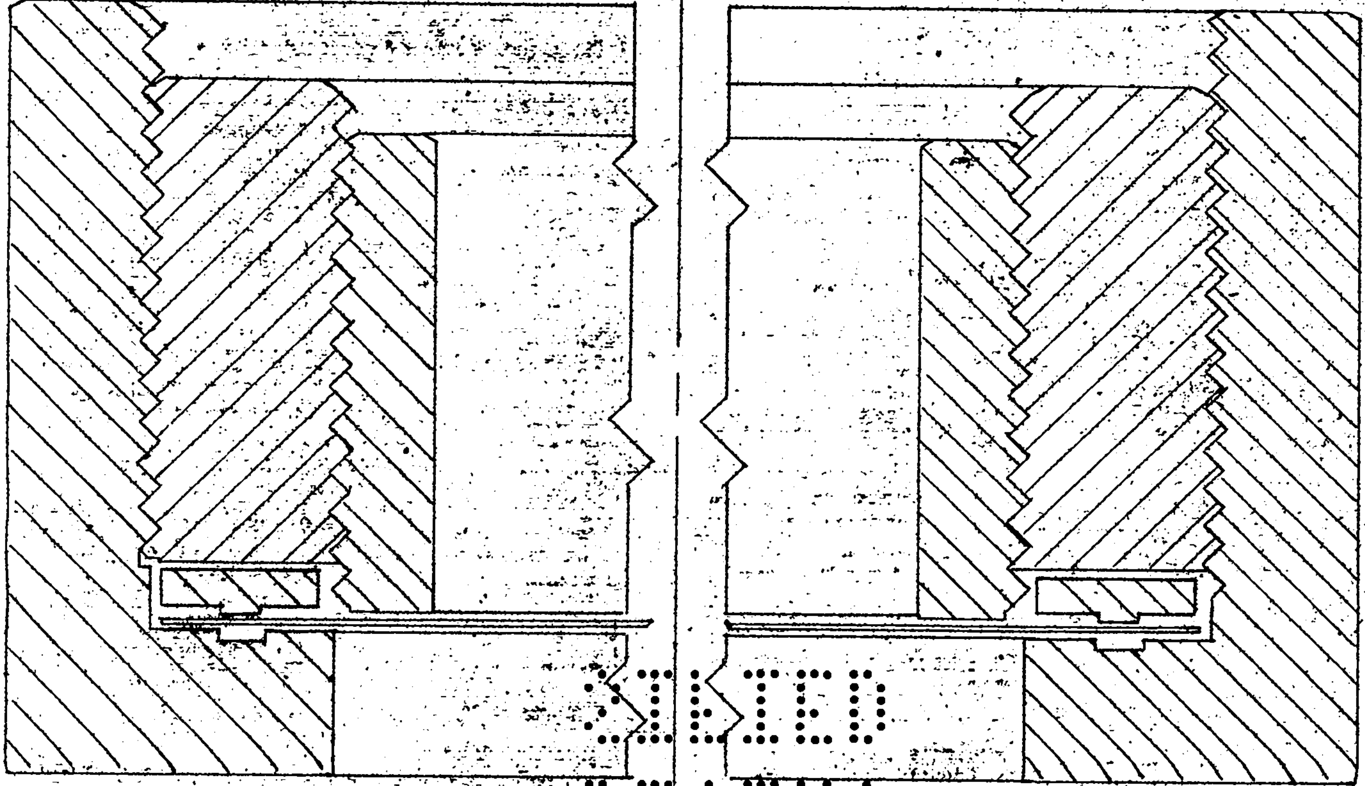
Fig. 2

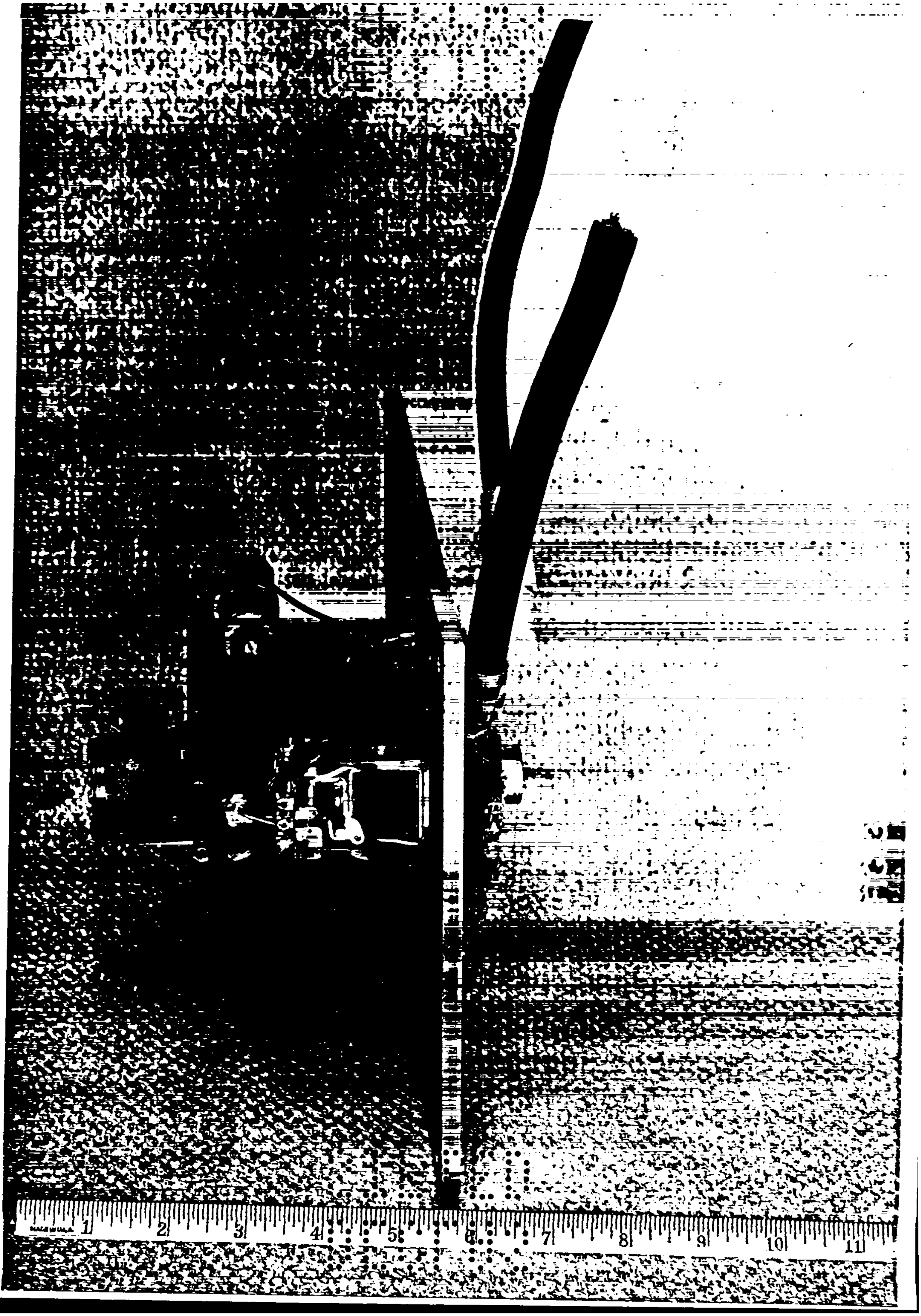


MICROPHONE ASSEMBLY



DIAPHRAGM STRETCHING JIG

CDJ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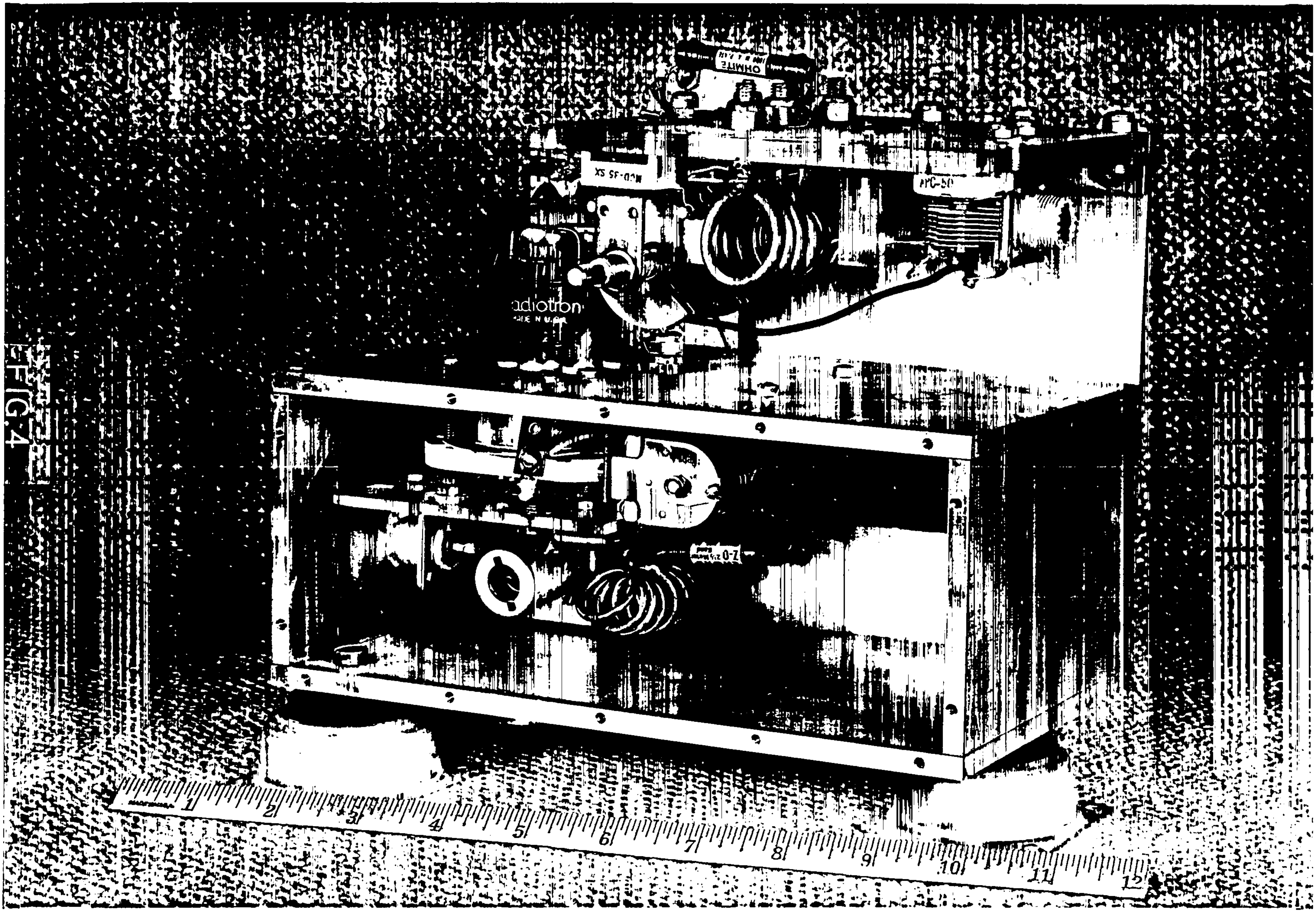
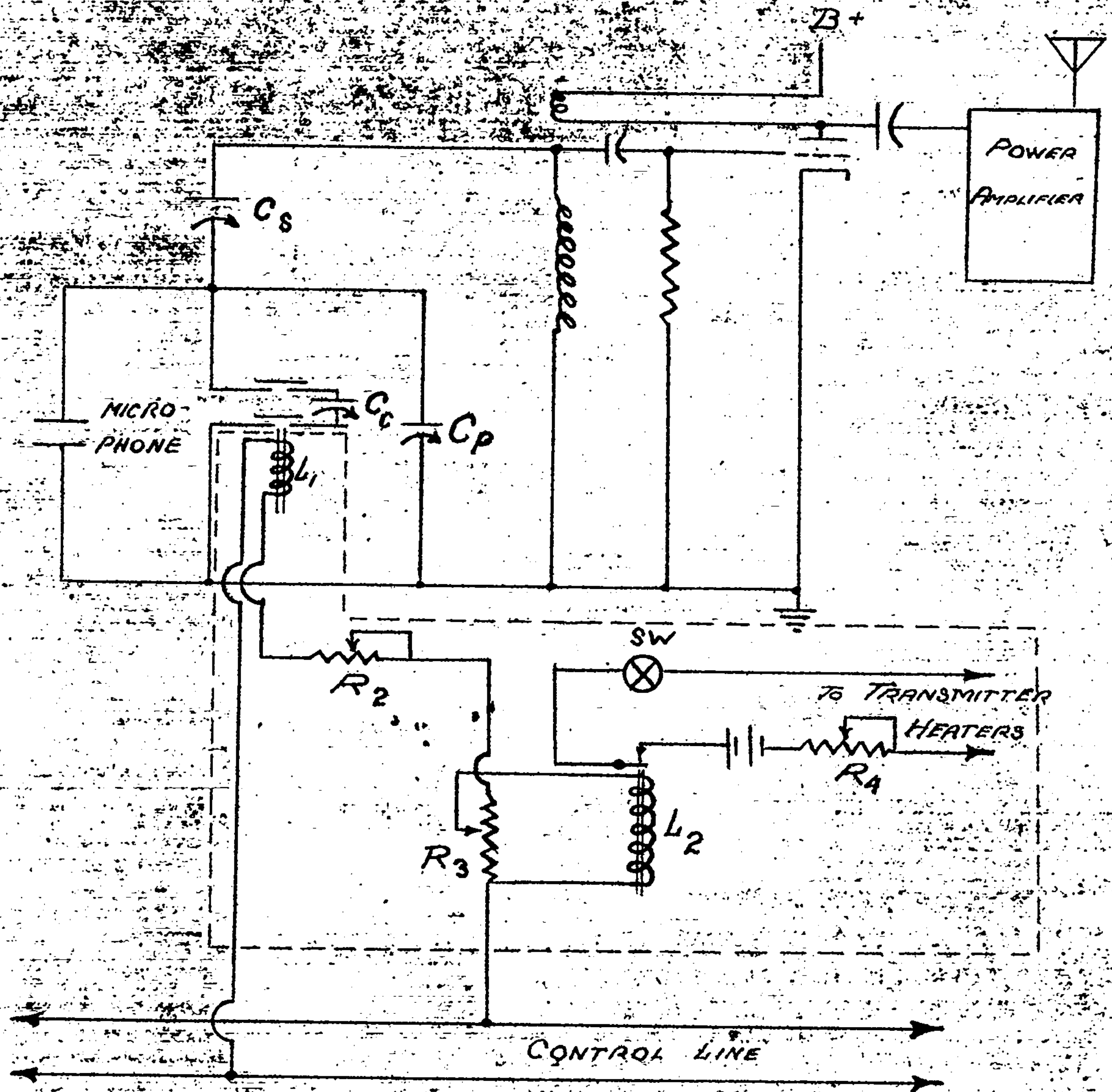


FIG. 4

Fig. 5

MICROPHONE AND CONTROL CIRCUITS



TYPICAL VALUES

C_C 5 mmf

C_S 30 mmf

C_P 150 mmf

MICROPHONE 20 mmf

R_2 5KΩ 25W

R_3 10KΩ 25W

R_4 5 Ω 25W

L_1 18 ma, 3KΩ, D.P.S.T. N.O. D.C. RELAY ✓

L_2 20 ma, 6KΩ, S.P.S.T. N.C. D.C. RELAY

cdJ

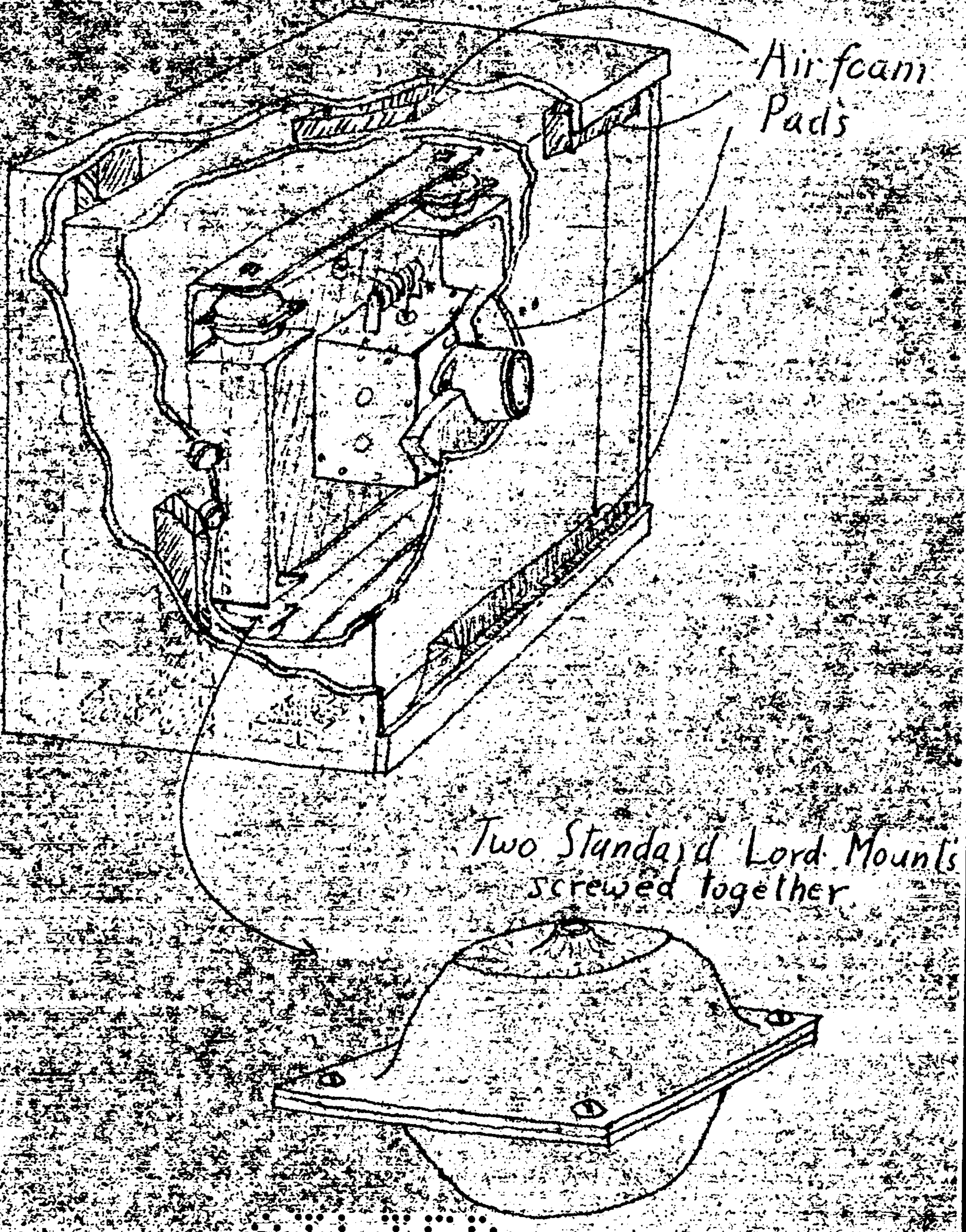


Fig. 6

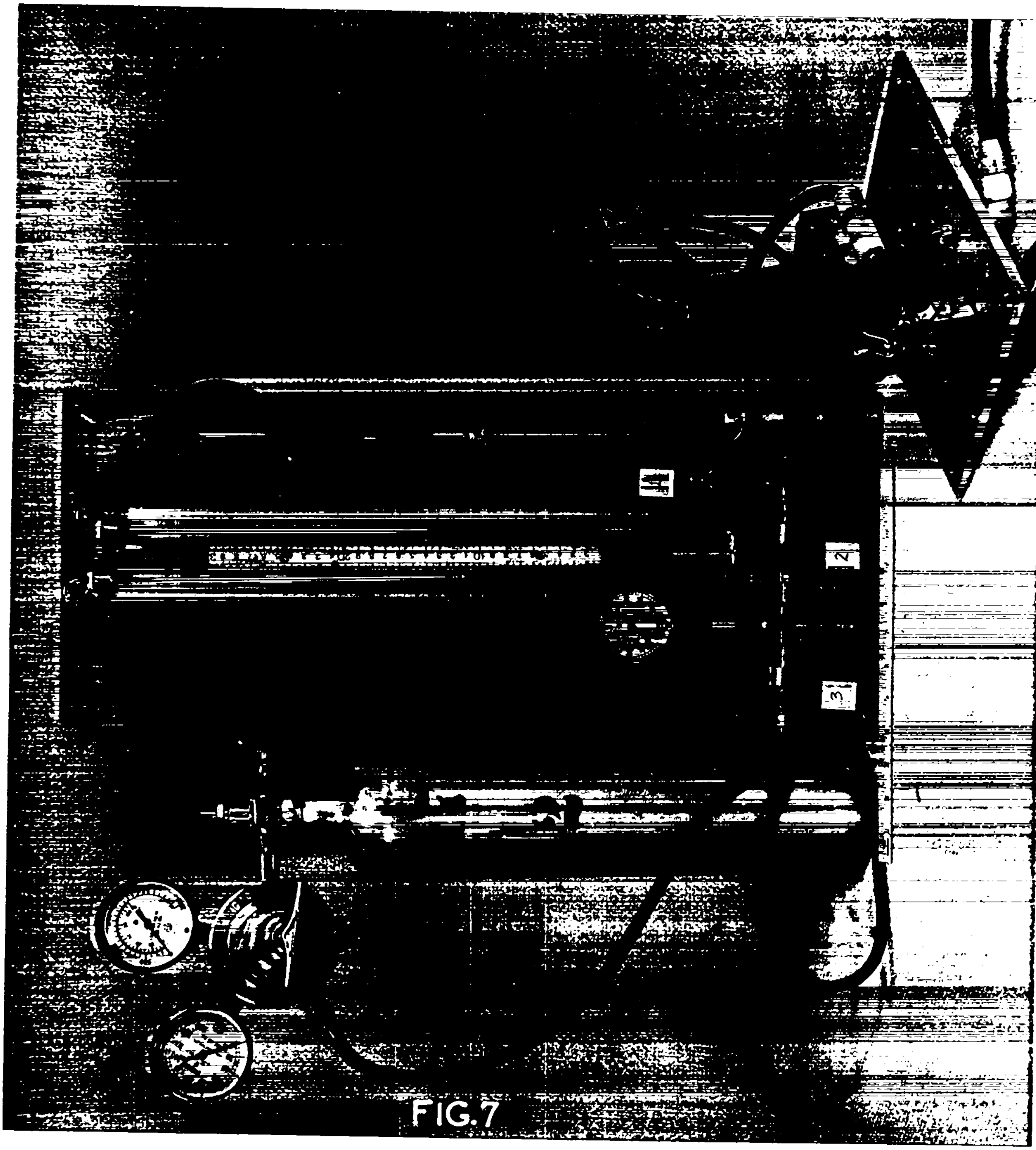


FIG.7

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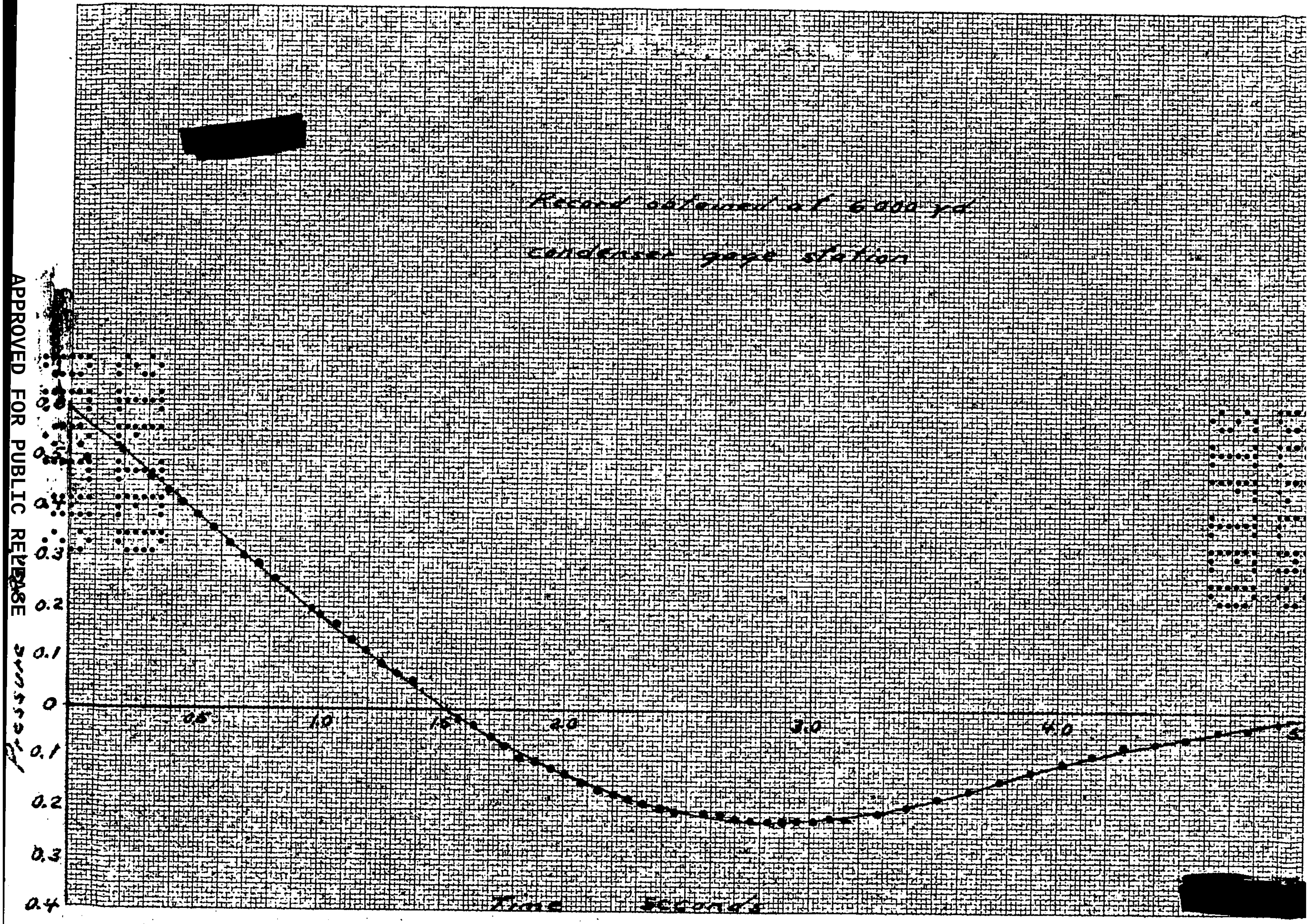

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