ERRATA

Quarterly Progress Report No. 9 Task-4

Page 5 line 2,	for "a field of 2 kv/cm," read "a field of 20 kv/cm,
Page 9 line 6,	for "field are both charged." read "field are both changed."
Page 11 line 17,	for "shifted to high fields" read "shifted to higher fields."
Page 19 line 2,	for "all Electronic Defense Group Projects" read "all Electronic Defense Group Projects except Task-6."

L. W. Orr
October 19, 1953

ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

USE OF FERROMAGNETIC AND FERROELECTRIC MATERIALS IN THE TUNING OF RF COMPONENTS

QUARTERLY PROGRESS REPORT NO. 9, TASK ORDER NO. EDG-4

Period Covering July 1, 1953 to September 30, 1953

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Department of Electrical Engineering

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October 1953

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ABSTRACT

This report reviews the progress of the Electronic Defense Group on Task Order No. EDG-4, Part I, for the quarter ending September 30, 1953. Plans are in progress for evaluating the usefulness in magnetic tuning of ferrite cores made on Task 6. The results of a continuing survey of certain properties of titanate materials are reported. An fm dielectric amplifier is described.

Part II of this Task has been terminated. A technical report describing in detail the results of the past several months work on this part is nearing completion. No work was done on Part III in the quarter.

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1. PURPOSE

This report summarizes the progress made by the Electronic Defense Group on the use of ferromagnetic and ferroelectric materials in the tuning of rf components (Task Order No. EDG-4, Part I) during the quarter ending September 30, 1953. Other methods of tuning which are being studied under Parts II and III of this Task are not discussed in this report. Part II under which a mechanical tuning method is being investigated has been terminated. A detailed report is nearing completion. No work was done during the period on the voltage-tunable magnetron which is being studied under Part III.

2. PUBLICATIONS AND REPORTS

There were no publications during the quarter.

3. FACTUAL DATA

3.1 Testing of Ferrite Cores (L. W. Orr and H. Alperin)

A testing method is being established for ferrite cores manufactured by the Task EDG-6 group. The tests will evaluate the usefulness of various materials in magnetic tuning, and include measurements of permeability and Q at various temperatures as the applied bias field is cycled over a range of values. The method of applying the variable bias must be such that it does not affect the measurement of μ and Q. It is highly desirable that the tests require only one core and that the core may be tested without machining the specimen or altering it in any way. Measurements will be made in a frequency range believed to be the best for cores presently being manufactured under Task 6.

Apparatus for the test set-up is now being designed and the required parts are on order. When the testing routine is running smoothly, comparisons will be made between our ferrite cores and those submitted by G. H. DeWitz of the C. G. S. Laboratories.

When a ferrite core is used as a tuning unit, it is subject to such a small ac magnetic field at the radio frequency that the incremental permeability arises entirely from reversible domain wall motions. In this case, no Barkhausen noise would be expected as there are no discontinuous jumps, and this is confirmed by experiment. However, when the same tuning unit is used in a search receiver, there is a large variation in applied bias field at the sweeping frequency. In this case, Barkhausen jumps would appear because of irreversible wall motions during the frequency sweep.

Because of the combined effect of the rf and sweeping magnetic fields, a relatively large proportion of the Barkhausen noise should fall within the acceptance band of the receiver. This is due to the correlation between the times of the majority of Barkhausen jumps and the times of maximum excursions of rf field in the same direction as the bias field is changing.

A study of Barkhausen noise in ferrite cores under cyclic magnetic field conditions is being planned. It is quite possible that some of the equipment now planned for the ferroelectric Barkhausen noise study (see below) may be adapted for this work.

3.2 Ferroelectric Materials Study

3.2.1 Curie Shift with Applied Field. Merz[1] has reported a rise in Curie temperature with applied electric field for single crystals of pure barium titanate. If this is true of single crystals, one might expect a similar effect with multicrystal ferroelectric ceramics. For a commercial titanate type capacitor the maximum capacity is generally observed at the Curie temperature for a given electric field. If such a capacitor is used as a tuning unit in a swept receiver, and there is a Curie shift, the tuning curves for temperatures above and below the zero-field-Curie temperature should cross. This is very nicely illustrated by the tuning curves for a Centralab K 6000 body which were published in the previous quarterly report.[2] The Curie temperature for this body is approximately 45°C.

3.2.2 Epsilon-Temperature Surface. The measured capacitance of a ferroelectric specimen is proportional to its dielectric constant, ϵ. If a three dimensional plot is made of the capacitance as both electric field E and temperature T are varied, an epsilon-temperature surface[3] is generated.

Figure 1 shows an isometric projection of the ϵ-T surface generated by a specimen of Aerovox Hi-Q 41. The measuring frequency was 1.0 mc, and the applied rf voltage was 1.0 volt (rms). Capacity measurements were made on a Boonton Q-meter with the dc field increasing slowly from zero through positive values and the temperature held constant for each run. In Fig. 1, curves of constant electric field show the variation of ϵ as the temperature varies. The point of maximum ϵ

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[1] Caspari and Merz: Phys. Rev., V.80, p 1082, (1950).

[2] Quarterly Progress Report No. 8, Task Order No. EDG-4, Part I, Page 17, July 1953.

[3] This term is to distinguish the surface from an "epsilon surface," discussed in a later section of this report.

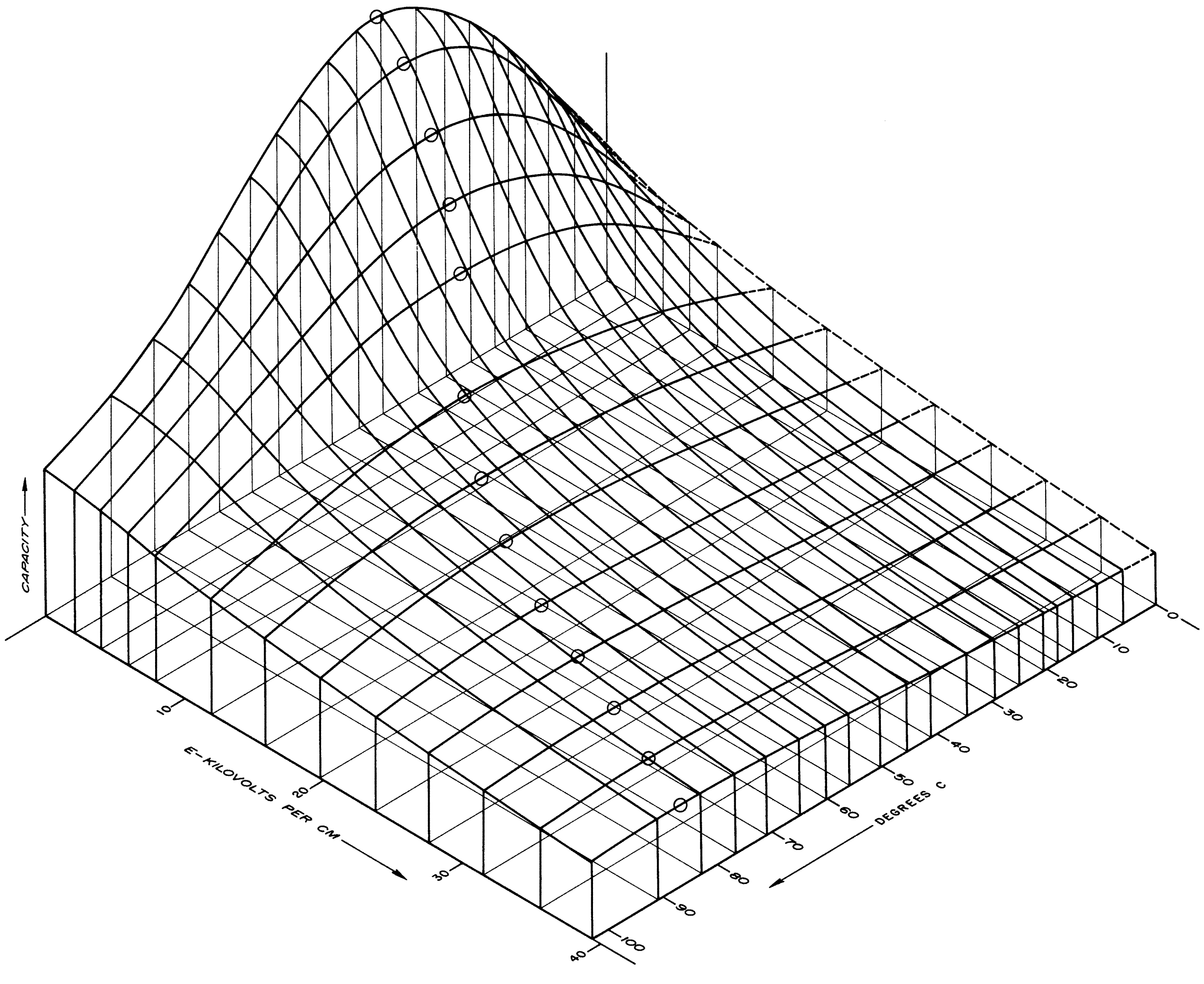

FIG. I

EPSILON-TEMPERATURE SURFACE
FOR AEROVOX HI-Q 41.

is shown on each such curve by a small circle. Thus, at zero field it is seen that ϵ_{max} occurs at about 43°C, while at a field of 2 kv/cm, ϵ_{max} occurs at about 67°C. This movement of ϵ_{max} to higher temperatures as the electric field is increased is further evidence of the Curie shift. (See Sect. 3.2.1)

The ϵ-T surface for a particular material is a clear presentation of tuning capabilities and severity of temperature coefficient for a particular combination of field and temperature. It is very useful in comparing various materials for specific applications such as electric tuning.

3.2.3 Ferroelectric Hysteresis. (L. W. Orr and H. Diamond) By means of the apparatus shown in Fig. 2, hysteresis loops of ferroelectric specimens at different temperatures may be displayed. The specimen is placed in a constant temperature bath of transformer oil and excited by a 60-cycle, 1000-volt power transformer. A voltage divider, R_1 and R_2, furnishes a suitable low voltage for the X input of the CRO which is proportional to the applied electric field. The polarizing current, i, which flows in the specimen, is integrated by capacitor C to give a voltage V proportional to the polarization P. This voltage is applied to the Y input of the oscilloscope. The display is thus a P-E loop for the specimen.

If P is the polarization in coulombs per sq cm, and A is the specimen area in sq cm, then we may write the current i in the form:

$$i = A \frac{dP}{dt}$$

so that

$$P = \frac{1}{A} \int i dt + \text{Const.} \qquad (1)$$

The voltage V on capacitor C is given by

$$V = \frac{1}{C} \int i dt + \text{Const.} \qquad (2)$$

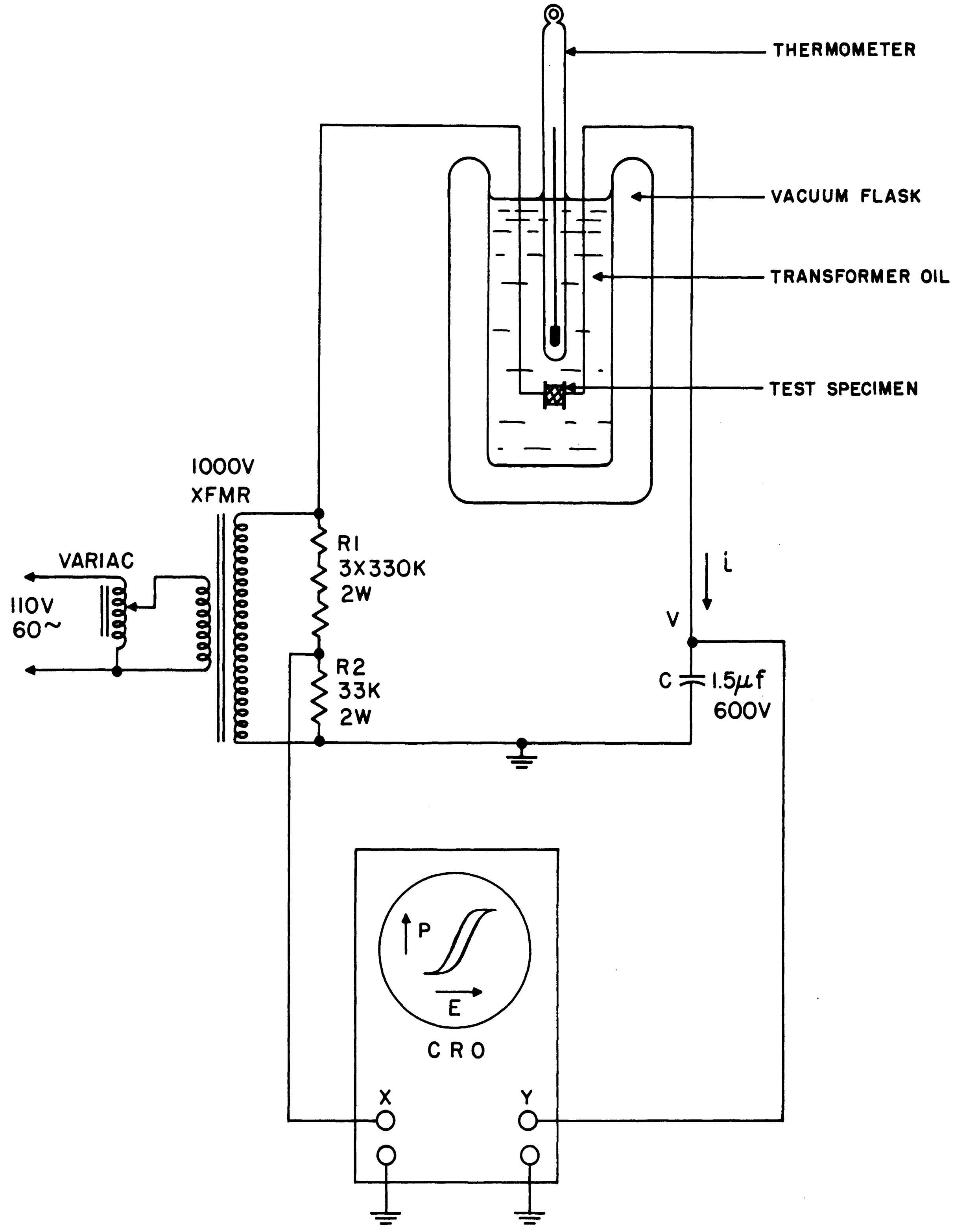

FIG. 2. P–E LOOP PLOTTER.

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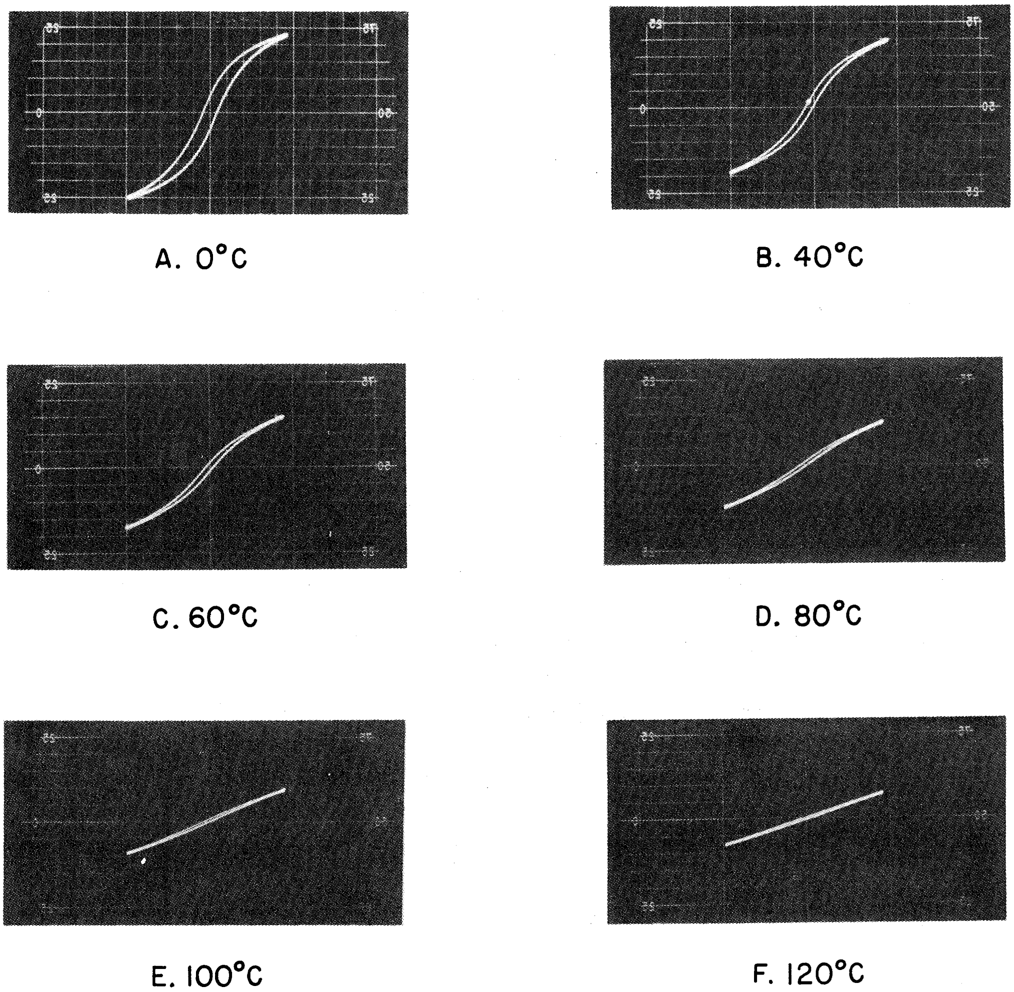
A. 0°C

B. 40°C

C. 60°C

D. 80°C

E. 100°C

F. 120°C

FIG. 3

P–E LOOPS
FOR AEROVOX HI–Q 41.

so that

$$P = \frac{1}{A} CV + \text{Const.} \qquad (3)$$

Using Eq 3, we may easily calibrate the vertical coordinate of the oscillogram.

Figure 3 shows a typical series of P-E loops at different temperatures. The series shown here is for a specimen of Aerovox Hi-Q 41. In each oscillogram the vertical calibration is one microcoulomb/cm^2 per small square, and the horizontal calibration 3.6 kv/cm per small square. These loops are for a peak field strength, or 18 kv/cm, representing the useful limit for the particular body and specimen thickness used (.020 inch). Similar specimens failed by voltage breakdown at field strengths slightly greater than 18 kv/cm.

It is possible to operate at considerably larger field strengths with very thin specimens, and an effort is being made to obtain certain materials in specimen thicknesses down to .001 inch. With very thin specimens, the high field region can be investigated.

The oscillograms in Fig. 3 show that as the temperature is raised the area of the hysteresis loop is reduced. The hysteresis is reduced most rapidly in the range of temperatures below the Curie (45°C). Above this temperature the hysteresis is reduced more gradually, and vanishes at about 120°C -- the Curie temperature of pure barium titanate. It is also seen that the average slope of the loop decreases above the Curie temperature, indicating a steadily decreasing dielectric constant.

Single crystals of pure barium titanate exhibit double hysteresis loops[1] when operated slightly above the Curie. This is due to the Curie shift mentioned previously, and is very pronounced in such crystals. We have not

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[1] See Merz "Double Hysteresis Loops in Barium Titanate" Phys. Rev., V. 91, p 513 (1953).

observed as yet any marked double loop in commercial multicrystal titanate-type ceramics.

3.2.4 Epsilon Surfaces and Butterfly Loops. If the equipment in Fig. 2 is modified so that combined ac and dc fields may be applied to a specimen, the variation in capacity may be measured as the ac measuring field and the dc field are both charged. Taking capacity measurements one obtains a set of data which may be presented as an "epsilon surface", the independent variables being E and ΔE. This is the exact analog of the mu surface[1] for magnetic specimens. There will be a different epsilon surface for each temperature. Fig. 4 shows a typical epsilon surface for a material operating below its Curie temperature.

It will also be possible to plot epsilon butterfly loops - here the dielectric constant is measured with a small high frequency ac component while the dc field is slowly cycled through positive and negative values. The analog to this in magnetic materials is the permeability butterfly loop.[2] It is expected that a fairly large butterfly hysteresis will be observed for specimens of titanate ceramics below their Curie temperature.

3.2.5 Barkhausen Noise. (L. W. Orr and M. Winsnes) In low-level tuned circuits employing ferroelectric capacitors, the Barkhausen noise, caused by jumps in the domain walls, may introduce an undesirably large noise level. This applies to dielectric tuning of search receivers, fm dielectric modulators, and low-level dielectric amplifiers.

In order to study Barkhausen noise in various commercial capacitors at different temperatures, apparatus is being constructed which is shown in block

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[1] Orr: "Permeability Measurements in Magnetic Ferrites," Technical Report No. 9, pp. 22-26, Electronic Defense Group, Ann Arbor, Mich., Sept. 1952.

[2] Ibid. pp. 28, 32.

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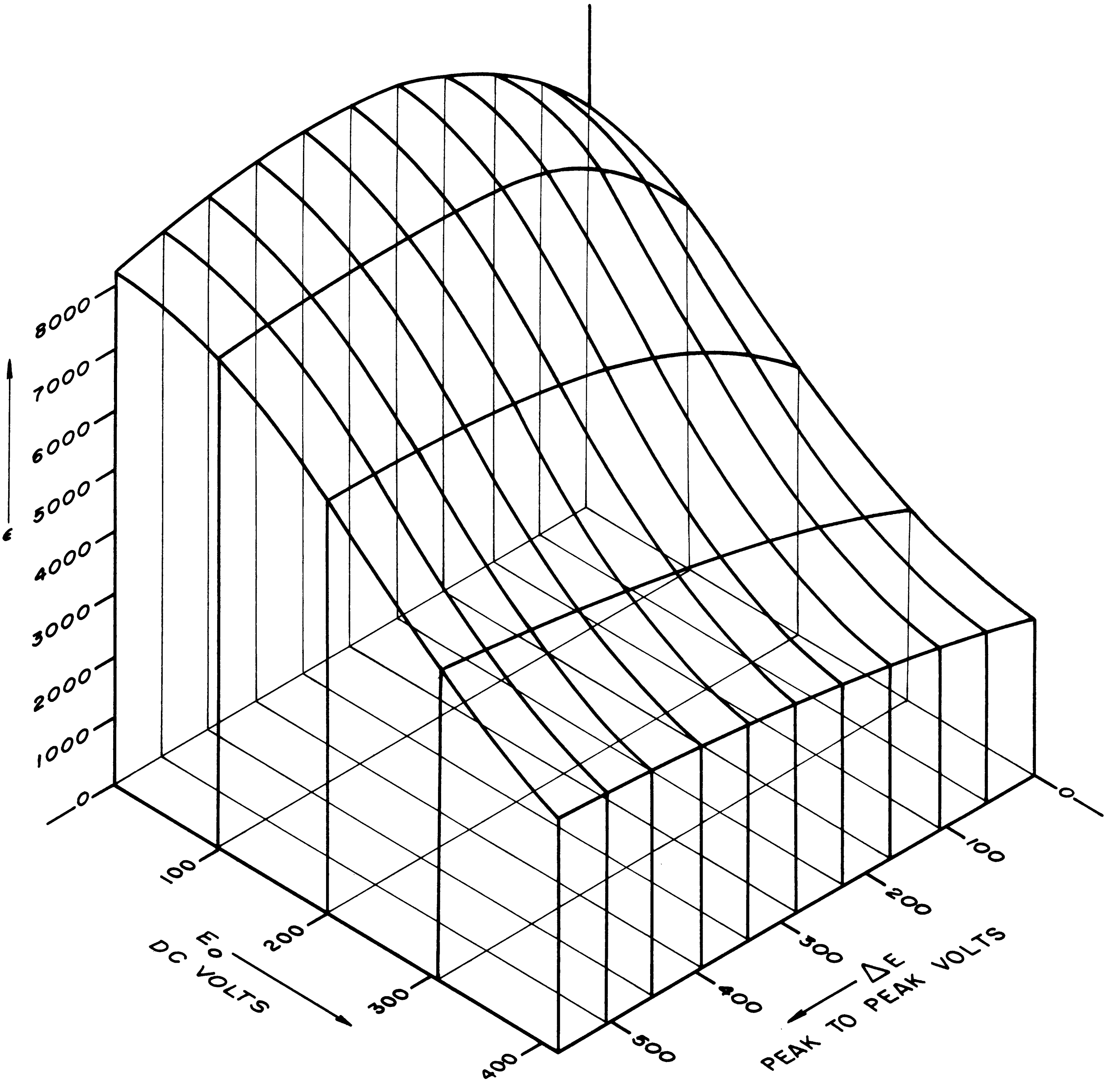

FIG. 4

EPSILON SURFACE FOR AEROVOX "HI-Q"
BODY 40 AT 26°C.

SPECIMEN THICKNESS = 0.02 INCH .

form in Fig. 5. The specimen is placed in a constant temperature oil bath, and cycled by applying to it a large 60-cycle sine voltage. A low-pass filter is used between the source of high voltage and the specimen, giving at least 70-db rejection of line transients, transformer noise, and other noise components above 5 kc which may enter through the high-voltage transformer. The noise generated in the specimen passes through a 4-section high-pass filter giving at least 70-db rejection of power frequency, harmonic components, and all other noise components below 10 kc. The noise from the output of the high-pass filter is amplified by a low-noise battery-operated preamplifier feeding a Tektronix Model 512 oscilloscope.

Figure 6 shows the noise (central trace) generated in a specimen of Aerovox Hi-Q 41 with an applied sinusoidal field (sine curve trace) of 5 kv/cm peak. This oscillogram indicates qualitatively a typical Barkhausen noise distribution with applied field below the Curie temperature. It is seen that the bulk of the Barkhausen noise is produced just after the field passes through zero. These regions correspond to the steep portions of the P-E loop (Fig. 3) where the number and size of Barkhausen jumps are both relatively large. As the temperature is raised slightly above the Curie, the noise maximum is shifted to high fields because of the Curie shift.

For quantitative noise measurement, some thought must be given to the method of measuring, since the noise is modulated at 120 cycles. A study will be made of various methods of noise measurement to determine the most suitable method for this application. At this writing a variable gating system is under consideration.

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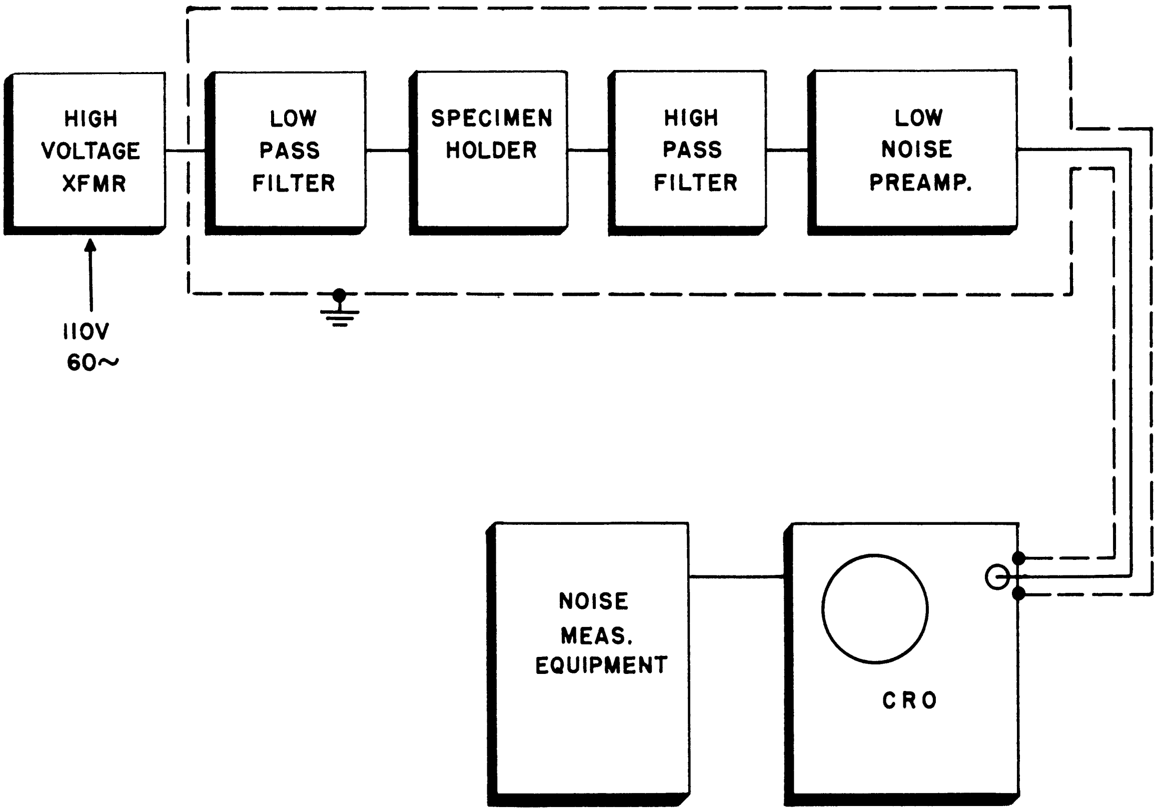

FIG. 5

BLOCK DIAGRAM
OF BARKHAUSEN NOISE ANALYSING EQUIPMENT.

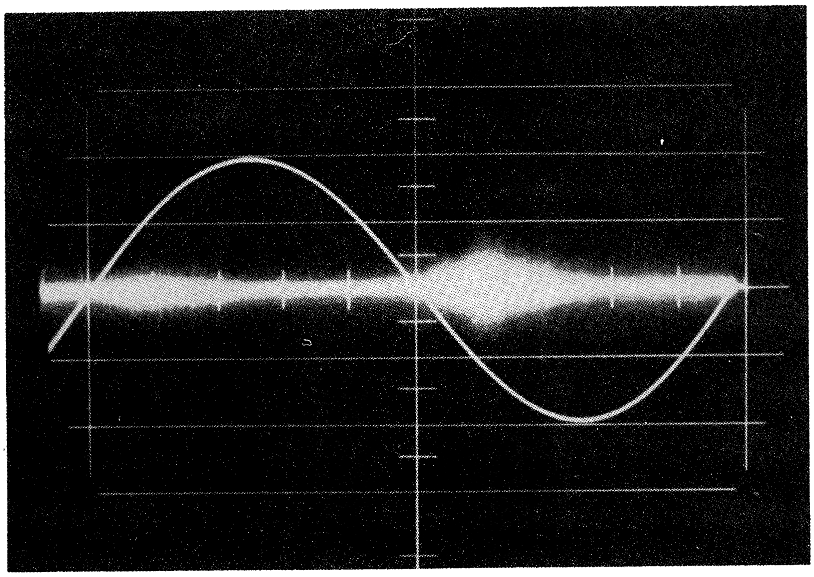

FIG. 6

BARKHAUSEN NOISE IN AEROVOX HI-Q 41
AT 27°C.

3.3 Applications of Ferroelectric Materials

3.3.1 High Frequency Swept Oscillator. (L. W. Orr and H. Diamond) An oscillator which can be electrically swept between 50 mc and 100 mc was previously reported.[1] Materials which are suitable for wide-range sweep have low Q's above 200 mc. But operation up to 200 mc is considered practicable by proper choice of materials. Above this frequency the Q is generally too low for a practical oscillator design. The reduction of Q in the region of 200-1000 mc is due to a molecular resonant loss, and this is a fundamental difficulty in the use of presently known ferroelectric materials in this frequency range.

3.3.2 FM Dielectric Amplifier. (L. W. Orr and M. Winsnes) The fm dielectric amplifier was not previously reported. It consists of a variable-frequency oscillator followed by a frequency discriminator. The circuit is shown in Fig. 7. The oscillator is a twin triode in push-pull. The oscillating tank, L, is tuned by a pair of ferroelectric ceramic capacitors, C_1 C_2, capable of capacity variation with applied dc field. The capacity variation produced by the audio input frequency modulates the oscillator. The fm output is discriminated by the high Q tuned circuits L_2 C_4, L_3 C_3. The upper circuit is tuned slightly above the carrier center frequency, and the lower, slightly below. The diodes demodulate to produce an audio output.

One model of this circuit was constructed using two pairs of Glenco Type SSM capacitors as C_1 and C_2. These are rated at 150 wvdc, and nominal capacity = 400 $\mu\mu$f each. They employ a 10 mil thick wafer of K 3300 ceramic. A photo of the amplifier is shown in Fig. 8. The four small Glenco capacitors are visible in the upper center of the photo mounted above the coil.

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[1] Quarterly Progress Report No. 8, Task EDG-4, Part I, July 1953.

M-970 A-CT-63 JEM 10-5-53

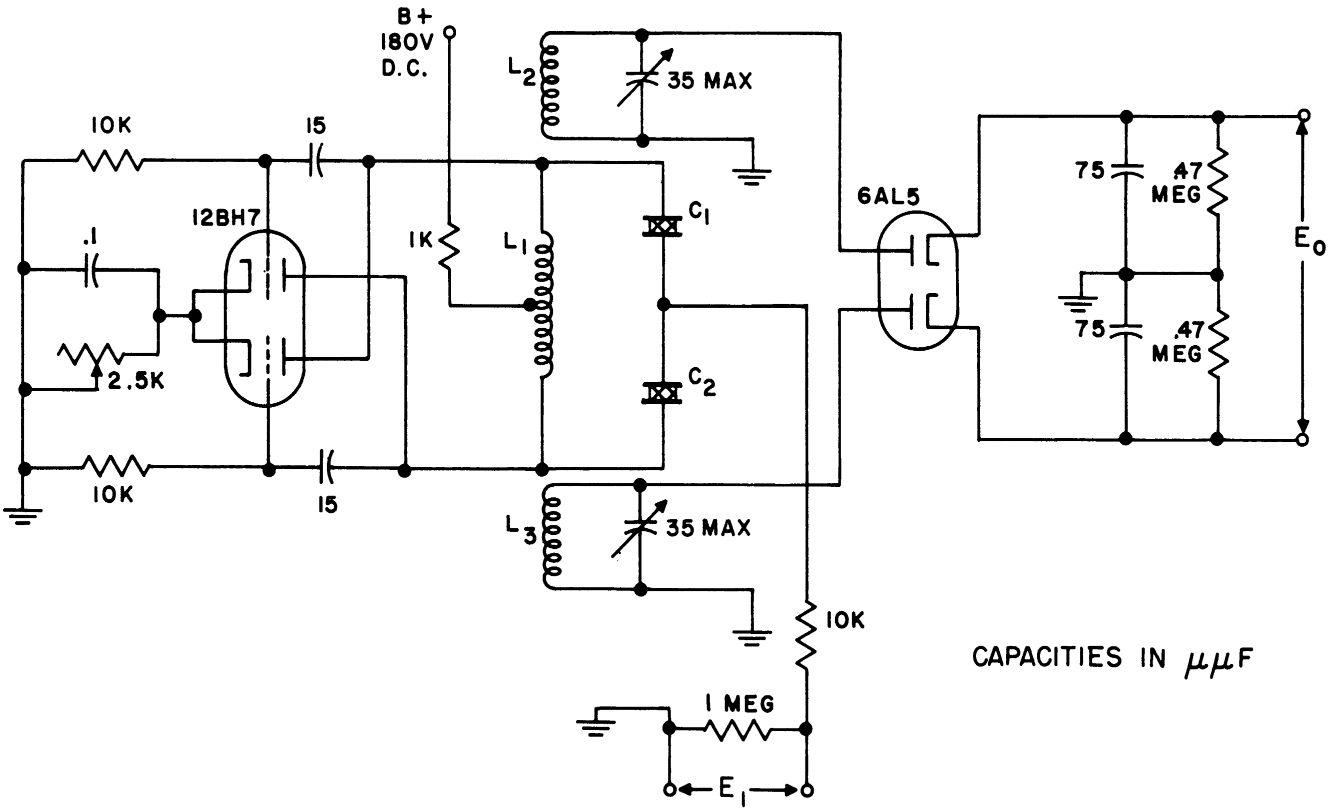

FIG. 7

FM DIELECTRIC AMPLIFIER CIRCUIT.

M-970 A-P4-12 JEM 10-2-53

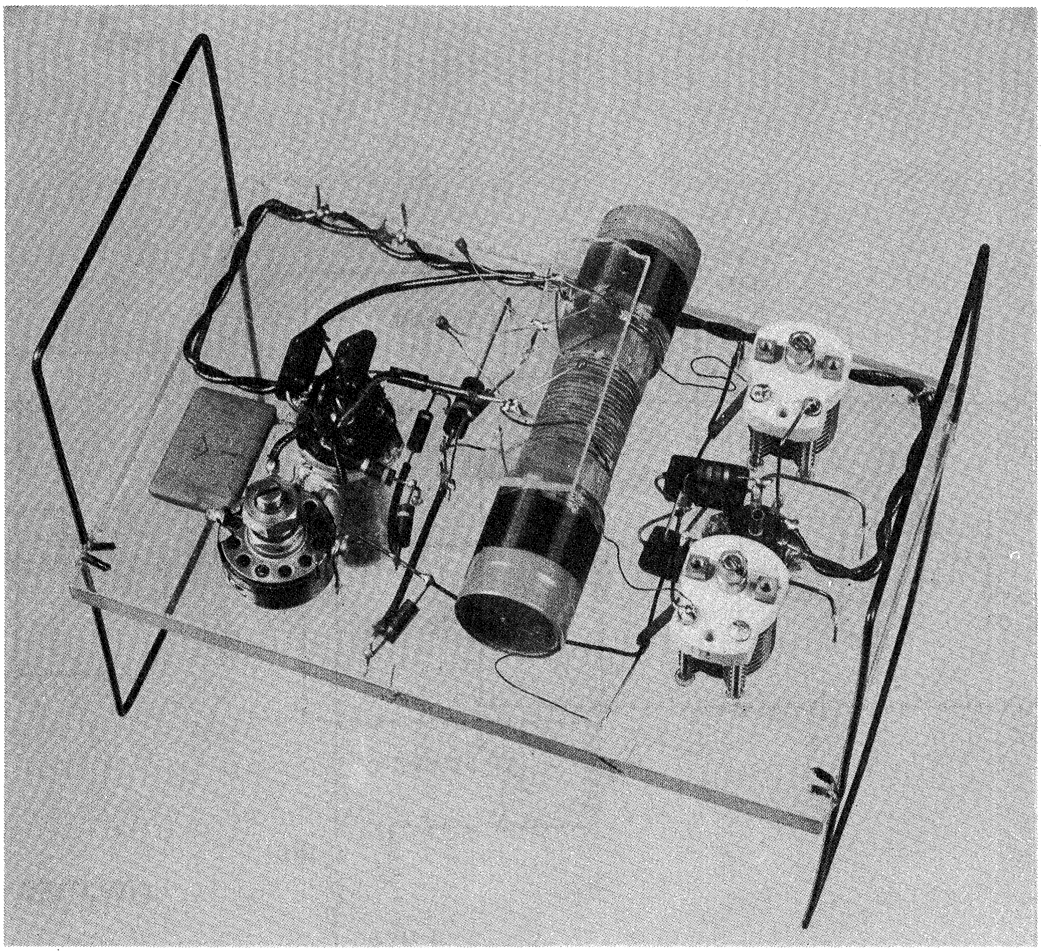

FIG. 8

F-M DIELECTRIC AMPLIFIER SHOWING LUCITE BREADBOARD CONSTRUCTION.

M-970 A-P4-13 JEM 10-2-53

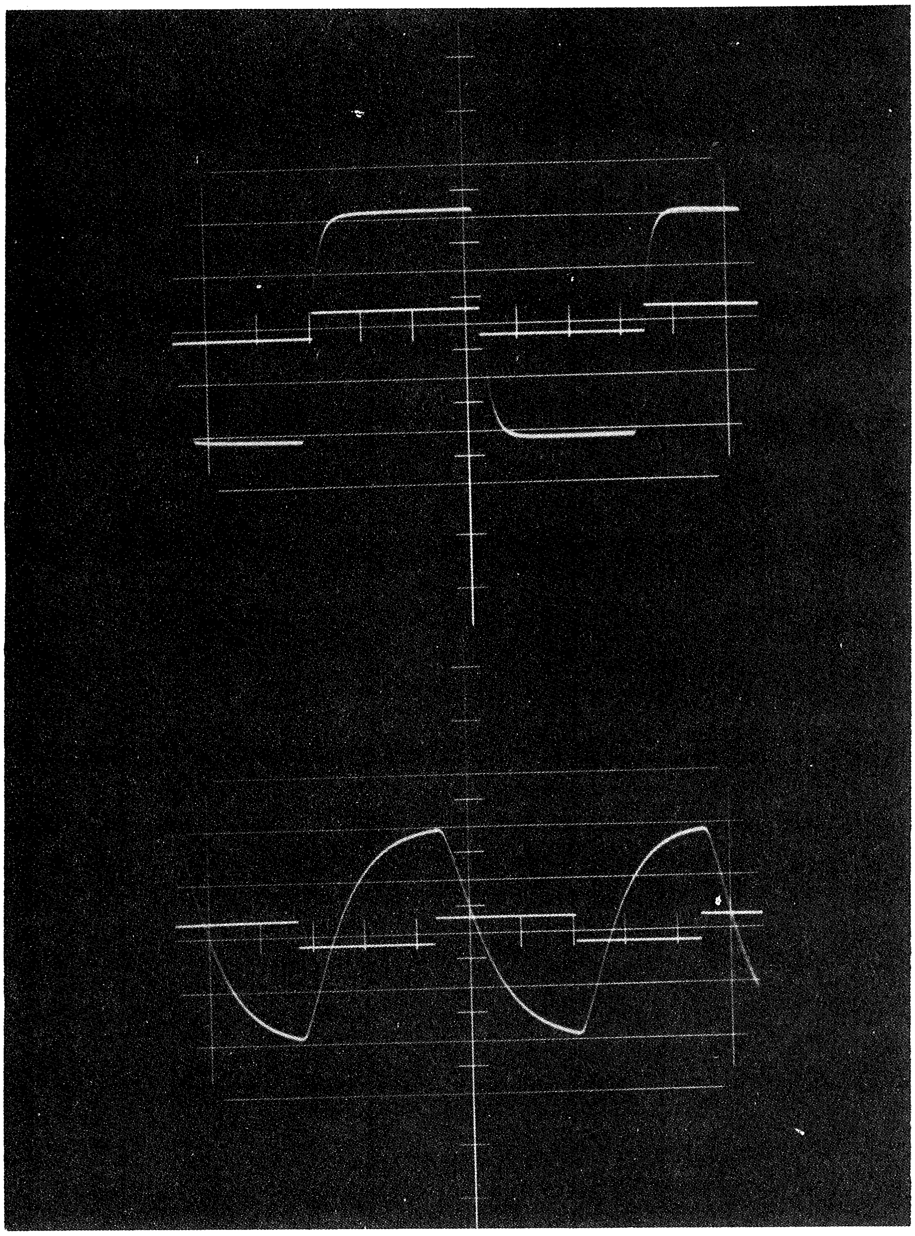

FIG. 9

TRANSIENT RESPONSE
F–M DIELECTRIC AMPLIFIER.

SQUARE WAVE INPUT FREQUENCIES:
A = 1KC
B = 5KC

The figure also illustrates the lucite breadboard construction found to be quick, clean, and easily modified. No bolts, rivets, or cement is required in construction, yet components are rigidly held in place by heating with a soldering iron and impaling the heated end into the lucite. End frames of heavy wire make the structure self-supporting in any position.

The amplifier operates at a center (carrier) frequency of 5 mc, and gives a voltage gain of 9.0 ± 1 db up to about 7 kc. An audio output voltage of 40-volts peak can be obtained with less than 5% harmonic distortion. The transient response for square-wave inputs of 1 kc and 5 kc are shown in Figs. 9A and 9B, respectively. Input and output voltage waves are shown on each oscillogram with the same vertical calibration (10 volts per division).

The amplifier requires a voltage-regulated power supply for stable operation, since the polarizing bias for C_1 and C_2 is obtained from B+. A voltage gain of 50 is possible by replacing the dielectric capacitors with others using 2-mil dielectric wafers.[1]

4. PROGRAM FOR NEXT INTERVAL

Evaluation of ferrite cores for magnetic tuning units will be made on cores produced on Task 6. A standard procedure will be instituted as soon as the equipment now being designed has been built up.

The Barkhausen noise study of ferroelectric materials will proceed, and as soon as adequate measuring equipment is designed and constructed, quantitative data will be taken. Noise in dielectric-tuned receivers will also be studied, and results compared with the Barkhausen noise measurements made on individual specimens.

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[1] Wafers of these ceramics are now being produced by Glenco Corp. down to one mil.

Some delay is anticipated in activity during the next quarter due to the moving of all Electronic Defense Group projects to the new building on the North Campus.

5. CONCLUSIONS

Results obtained on ferroelectric specimens correspond nicely to data obtained by other workers in this field. The measurement of Barkhausen noise should assist greatly in evaluating ferroelectric materials in tuning rf components. The present activity is proceeding satisfactorily.

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