ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
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USE OF FERROMAGNETIC AND FERROELECTRIC MATERIALS IN THE TUNING OF RF COMPONENTS

QUARTERLY PROGRESS REPORT NO. 8, TASK ORDER NO. EDG-4, PART I
Period Covering April 1, 1953 to June 30, 1953

Electronic Defense Group
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ABSTRACT

This report reviews the progress of Electronic Defense Group on Task Order No. EDG-4, Part I, for the quarter ending June 30, 1953. The results of a continuing survey of certain properties of titanate materials are reported, including the effects of temperature, frequency and electric field variations. A dielectrically tuned "broadcast" receiver is described.

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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 June 30, 1953.

Note: The progress on Task Order No. EDG-4, Parts II and III is classified and is described in a separate report.

2. PUBLICATIONS AND REPORTS

There were no publications during the quarter.

3. FACTUAL DATA

3.1 Magnetic Modulator (L. W. Orr)

Design equations for a magnetic modulator were derived, and the Mu surfaces for ferrite materials given in Technical Report No. 9 were employed to obtain optimum modulator design. A practical modulator has been constructed and is now being tested. It is expected that a technical report will be published on this in the near future.

3.2 Ferroelectrical Properties of Titanate Materials (H. Diamond)

3.2.1 Effect of Temperature on Dielectric Constant and Q. During the quarter the effect of temperature on dielectric constant and Q was determined for the Aerovox "Hi Q" body Nos. 40 and 41, as representative materials. Several other bodies were spot checked to be sure that the behavior was similar. The results obtained agreed well with previously published data.[1,2]

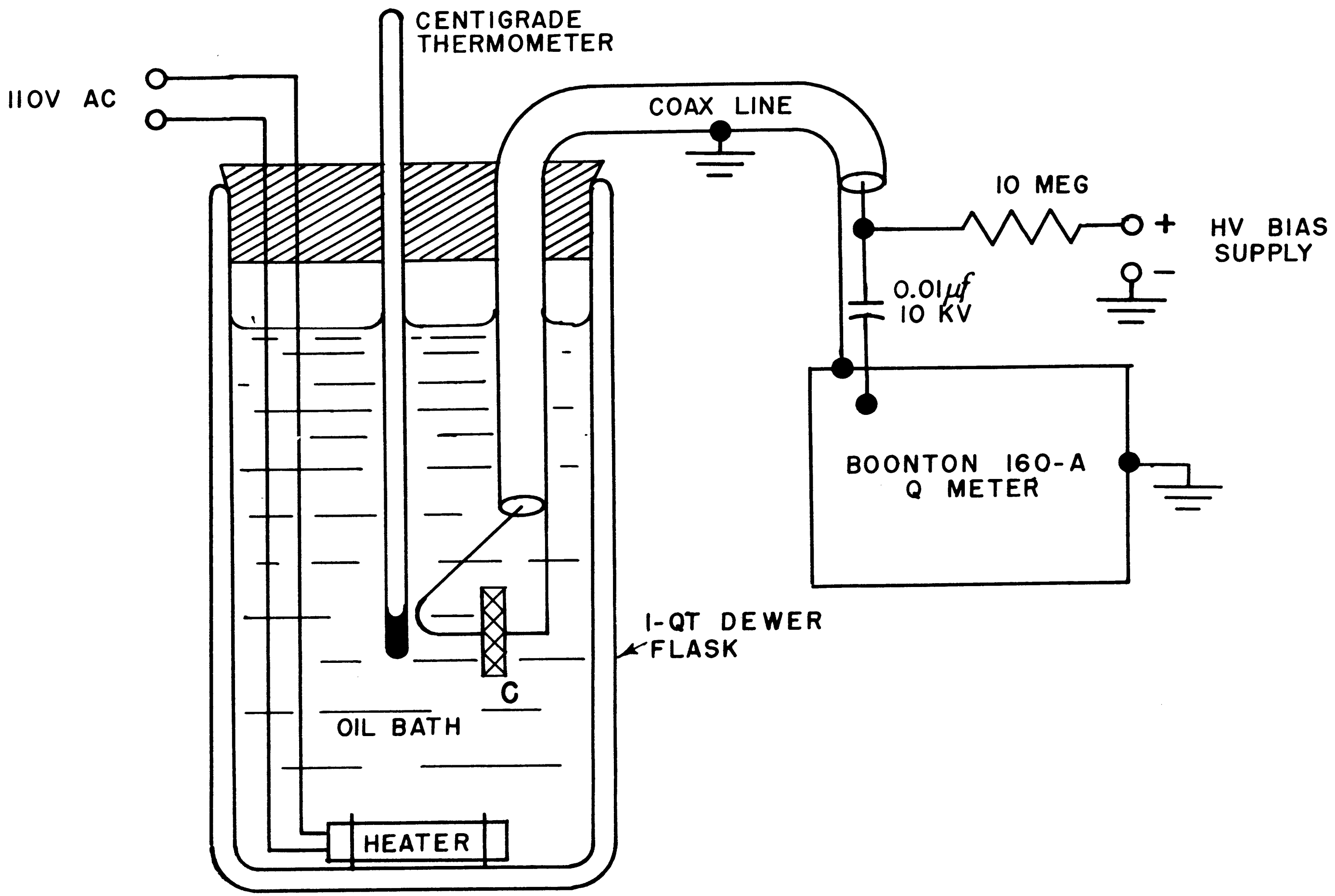
Figure 1 shows the equipment used for these measurements. The Boonton low-frequency Q meter, Model 160A was used. The transformer oil in the dewar flask is heated by a wire wound resistor providing a constant heating rate of one degree centigrade per minute. A Centigrade thermometer is placed .5 cm away from the sample. The measuring frequency was 275 kc.

The effect of temperature on dielectric constant and Q for the Aerovox Hi-Q body 41 is shown in Fig. 2. The temperature coefficient over the linear portion of the C vs. T curve is of the order of $5\mu\mu$f per degree centigrade. The curves shown in Fig. 2 are for an increasing temperature at a rate of one degree centigrade per minute. If the sample is allowed to cool, data points for the decreasing temperature, do not fall on the upgoing curves. This temperature hysteresis in capacity is shown in Fig. 3. The arrows indicate the direction of the temperature change. The rate of cooling the sample was of the order of 3 degrees centigrade per hour, this being much slower than the heating rate. The gross temperature hysteresis in capacity can be attributed primarily to the aging characteristic of the titanate bodies. Fig. 4 shows the aging effect for the Aerovox body 41 after heating to 100°C and quenching to 25°C in an oil bath.

It is observed in Fig. 2 that the point of maximum Q for this material lies at a significantly higher temperature than the point of maximum dielectric

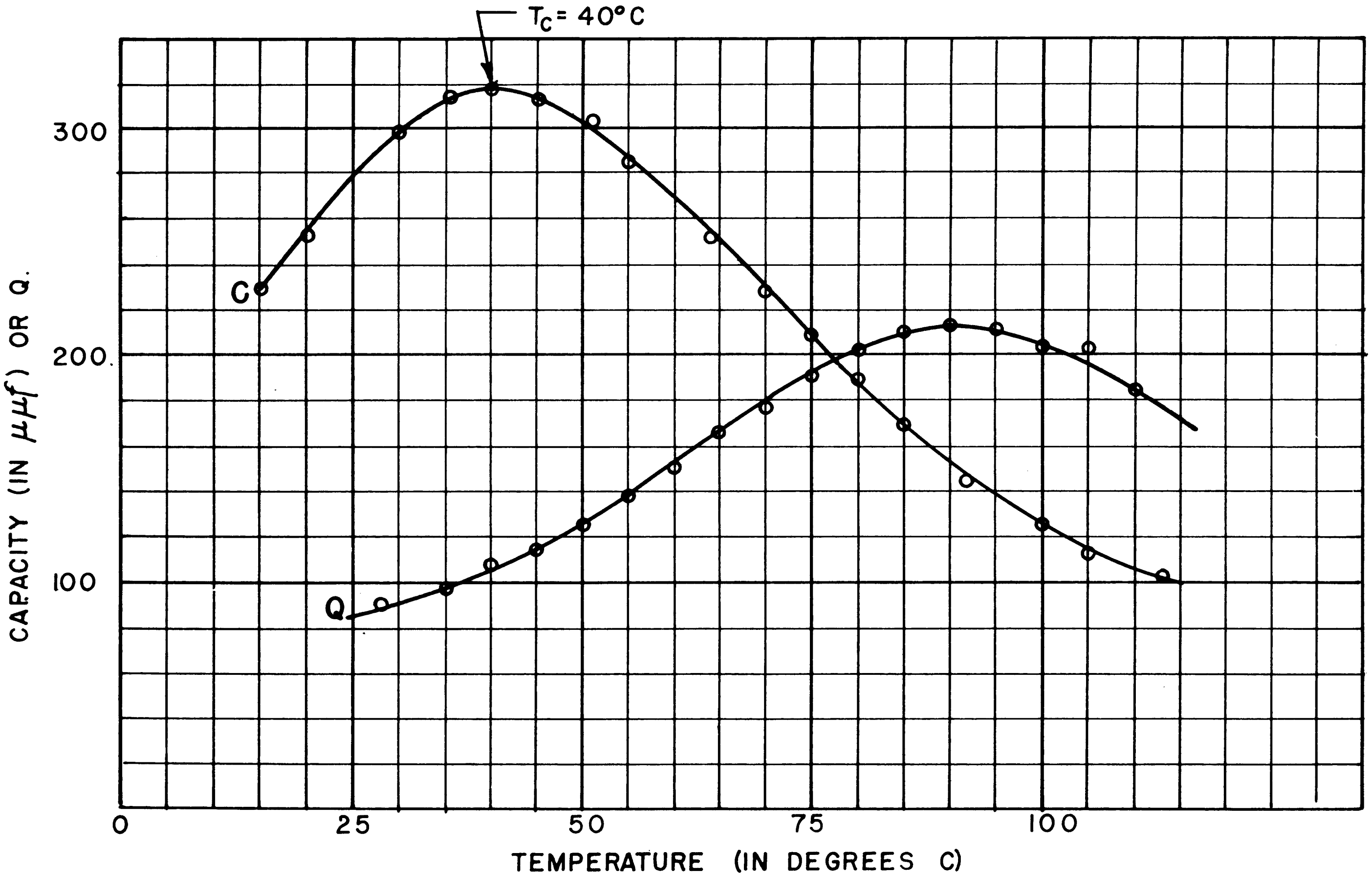
[1] Tele-Tech. May 1949.

[2] Aerovox Corporation, manufacturers data given in a private communication.



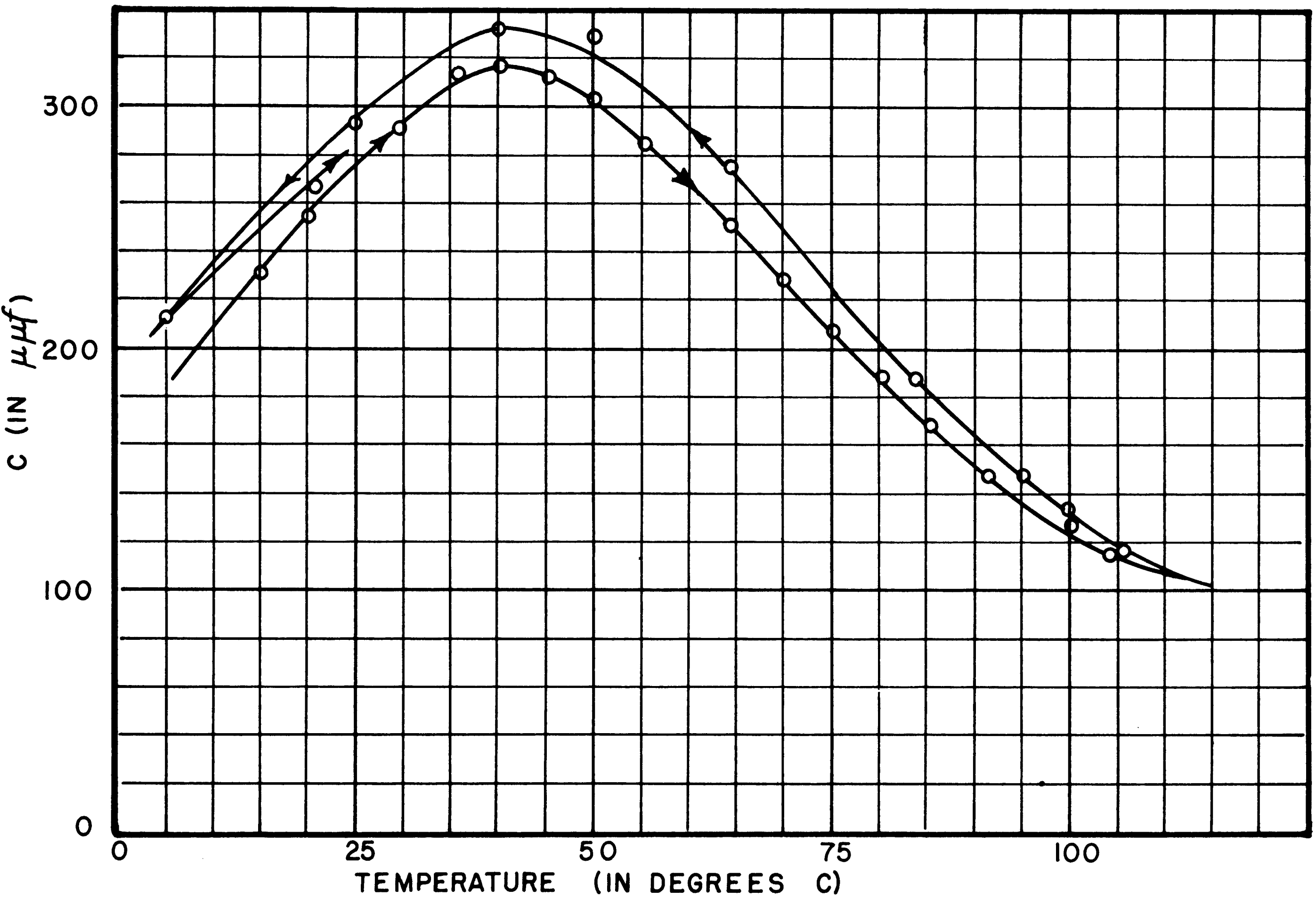
TEMPERATURE MEASURING APPARATUS
C IS THE UNIT BEING TESTED

FIGURE 1



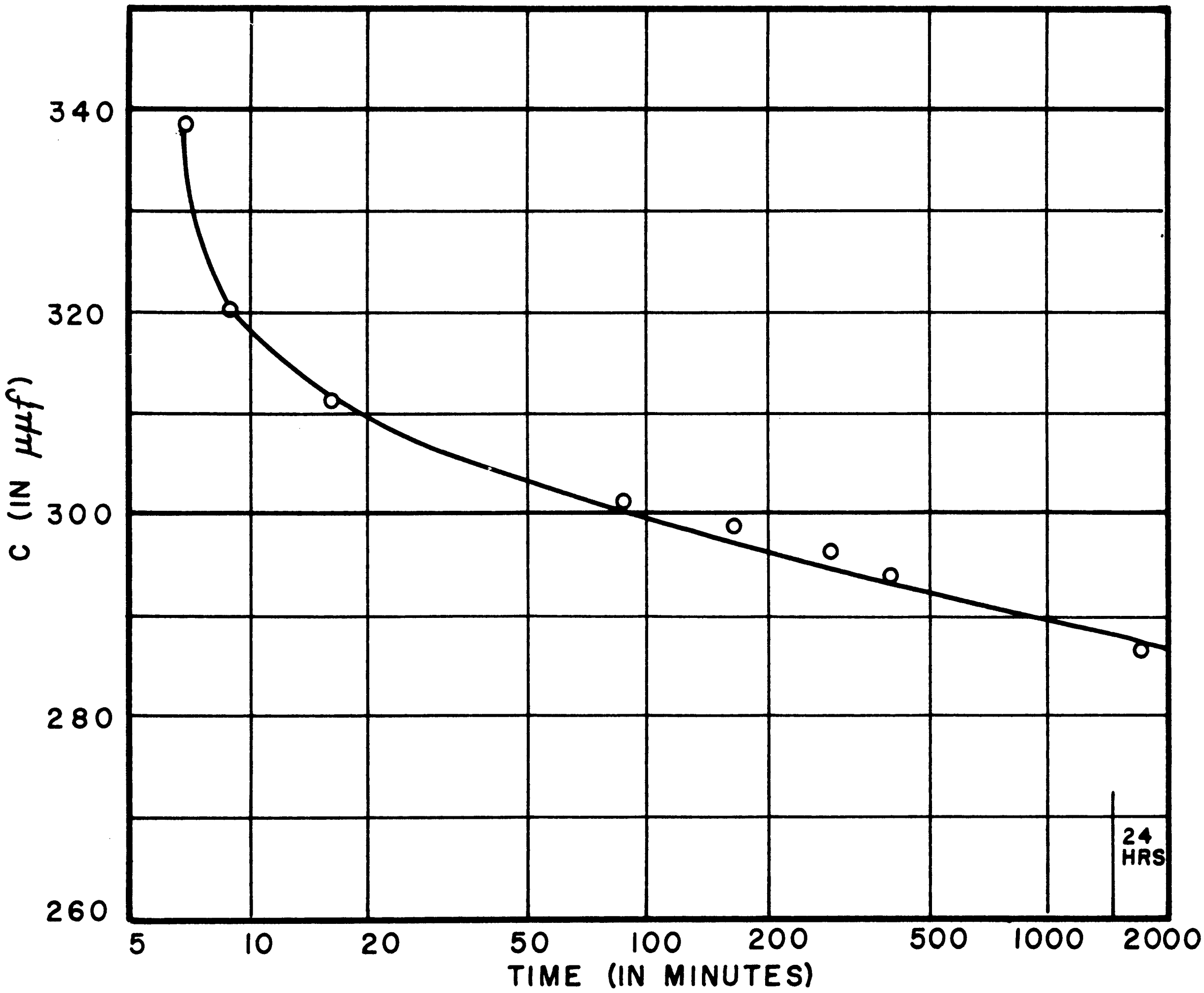
C & Q VS TEMPERATURE FOR ZERO FIELD
USING AEROVOX "HI Q" BODY NO 41

FIGURE 2



C VS TEMPERATURE. TEMPERATURE HYSTERESIS EFFECT, AEROVOX BODY NO. 41, FOR ZERO FIELD.

FIGURE 3



C VS TIME. AGING AFTER HEATING TO 100°C AND QUENCHING AT 25°C, AEROVOX "HI-Q" BODY NO 41.

FIGURE 4

constant. The peak of the Q curve seems to come close to the Curie temperature of pure barium titanate. (The sample tested contains 20% strontium titanate.)

3.2.2 The Effect of Frequency on Dielectric Constant and Q. On the basis of a report by Vincent[1] which described sharp peaks and dips in the dielectric constant vs. frequency, work was started to confirm this behavior. The measurements made, however, (after the data had been corrected for the effect of the instrument on the measurement) failed to show the reported peaks, but rather a very slightly decreasing dielectric constant. The decrease was about 4% from low frequencies to 100 mc. Figure 5 shows the effect of frequency on both Q and capacity for an Aerovox No. 40 body. Kittel[2] indicates that the dielectric constant of pure barium titanate decreases graudally with frequency until about 1000 mc, where there is a sharp decrease to about 10% of the low-frequency value.

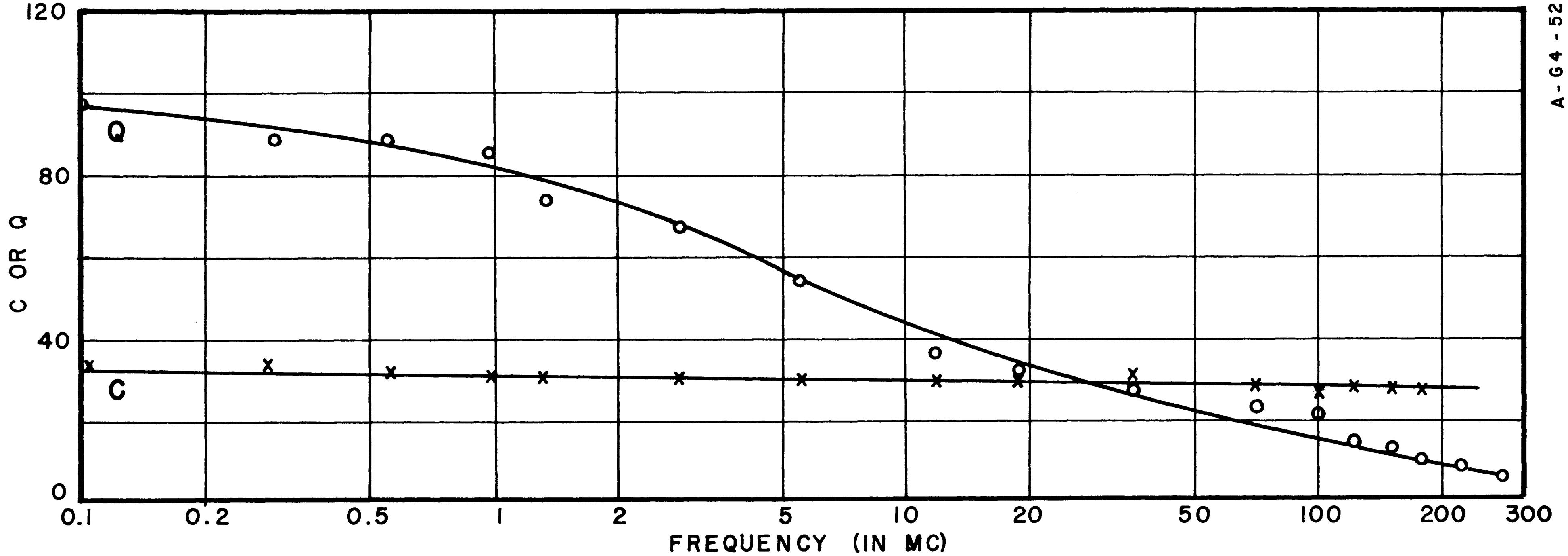
The high-frequency measurements were made with a Boonton 190A high-frequency Q meter. In order to minimize lead inductance effects, the samples were mounted as close as possible to the Q meter terminals, and also low-capacity units were used. The low-capacity units were constructed by fitting a small chip of the titanate body with leads and grinding the sides down to the desired capacity. Fig. 6 shows the construction of a typical capacitor used. These units were made with capacities ranging from 25 to 120$\mu\mu$f.

3.3 Applications of Ferroelectric Materials

3.3.1 The High-Frequency Swept-Oscillator. (H. Diamond) By employing the type of low-capacity unit used in the high-frequency measurements in the tank

[1] Vincent, A. M., "Dielectric Amplifier Fundamentals," Electronics, 24, p. 84 (Dec. 1951).

[2] Kittel, Charles, Introduction to Solid State Physics, John Wiley and Son, New York, 1953, Fig. 7-11, p. 130.



EFFECTIVE AC CAPACITY & Q VS FREQUENCY. AEROVOX "HI-Q" BODY NO 40 DIELECTRIC WITH SMALL AC FIELD UNDER CONDITIONS OF ZERO DC BIAS FIELD. BODY NO 41 IS SIMILAR.

FIGURE 5

A-G4-52 RFR 27 JUL 53

circuit of the high-frequency oscillator, Fig. 7, successful operation was obtained. The frequency of the oscillator, which employs a triode-connected 6AH6, could be varied from 50 to 100 mc by changing the applied biasing field by 1000 to 2000 v, depending upon other circuit parameters. The tank capacitors, C, were made from the Glenco K-3300 body. Each section of the tank capacitor was 120$\mu\mu$f. Frequencies were measured both on a communications receiver and with a grid dip meter using very loose coupling.

3.3.2 Dielectric Amplifiers. (M. Winsnes) In Section 3.1.2.3 of Progress Report No. 7 for the previous quarter, it was stated that the circuit shown in Fig. 4 of that report did not work satisfactorily, and that further work would be done on this circuit. This has now been done, and satisfactory results have been attained. The following values were used in this circuit:

$R_1 = R_2 = 10$ Meg

$R_3 = 10$k

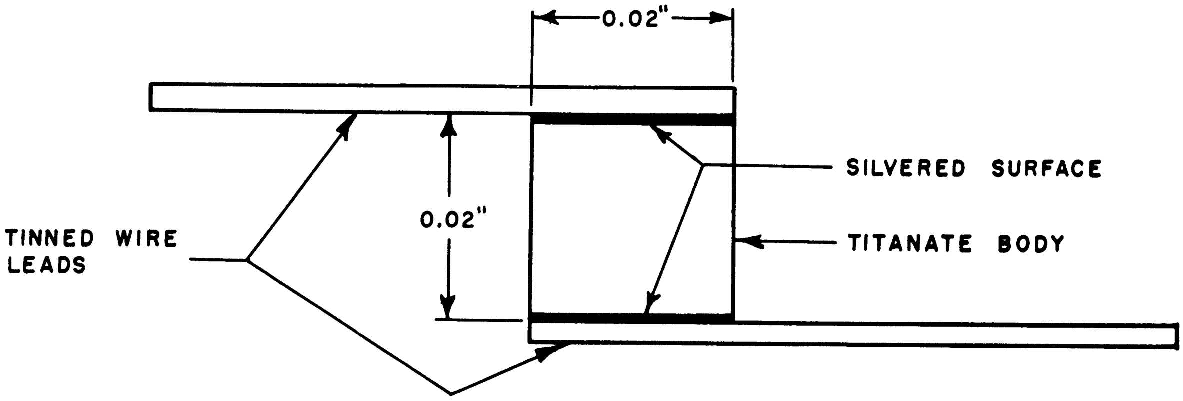
$L_1 = L_2 = 200\mu$hy

$C_1 = C_2 = C_3 = C_4$ = Glenco K 3300 capacitors 10 mils thick
400$\mu\mu$f at zero bias.

The diode was 1N34; the carrier frequency was 4.5 mc. A voltage gain of 1/2 was obtained under these conditions.

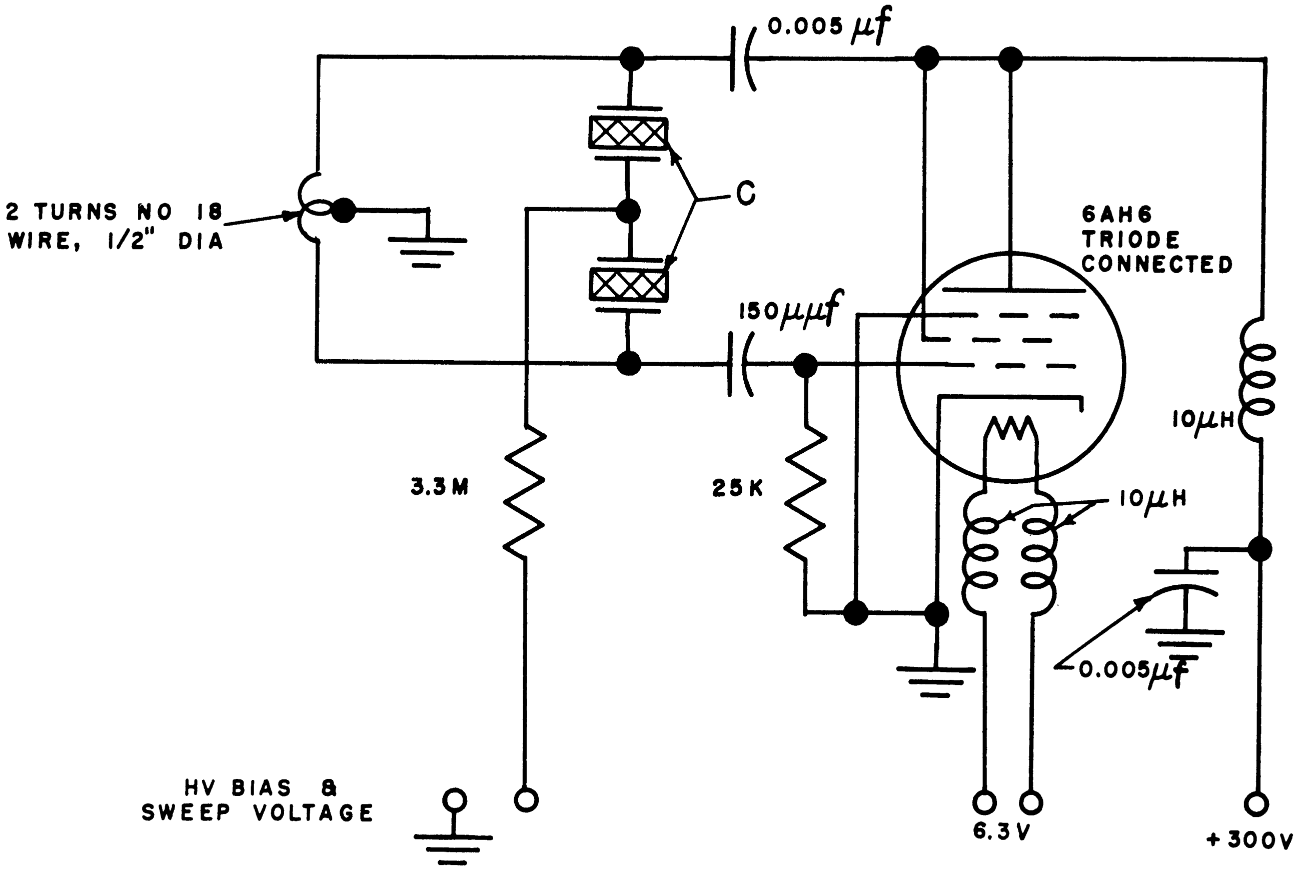
The current gain was 33 at 1000 cycles, and since the input is largely capacitive, it can be seen that the current gain will increase at lower frequencies. As a dc amplifier with R_1 and R_2 very large, a very large current gain may be obtained.

3.3.3 Ferroelectric Tuning of a Broadcast Receiver. (L. W. Orr and M. Winsnes) As reported earlier, an oscillator unit was built to investigate the tuning capabilities of titanate capacitors. The results were quite promising, so a dielectrically tuned broadcast receiver was designed and constructed.



CONSTRUCTION OF THE LOW VALUE TITANATE CAPACITORS

FIGURE 6



SWEPT OSCILLATOR CIRCUIT

FIGURE 7

3.3.3.1 Oscillator Unit. The oscillator-mixer stage was constructed first, and the circuit is shown in Fig. 8. The oscillator frequency could be varied by varying the dc bias applied to the titanate capacitors. Fig. 9 is a tuning curve showing the relationship between biasing voltage and frequency throughout one cycle of biasing voltage. It was found that the hysteresis, seen in the figure, increased with the cycling rate.

3.3.3.2 Polarization Lag. The increase in hysteresis with cycling rate is believed due to the polarization lagging behind the applied electric field. This time lag is considerable for a decreasing voltage, and somewhat shorter for an increasing voltage. To demonstrate the effect, Switch S, in Fig. 8, was switched from Position 1 to Position 2, and $\frac{f_t}{f_\infty}$ was plotted as a function of time t after the switching. f_t is the oscillator frequency at the time t, and f_∞ is the ultimate frequency. Frequencies were measured with a broadcast receiver. It was found that it made no noticeable difference in the data if the oscillator was on continuously or not.

Curve (1) of Fig. 10 shows the ratio $\frac{f_t}{f_\infty}$ for a Centralab K 3500 body 6 mils thick previously charged at 1000 volts for 10 minutes. Curve (2) is for the same unit charged at 1000 volts for 5 minutes and Curve (3) charged at 1000 volts for 1 minute. Curve (4) shows the ratio $\frac{f_t}{f_\infty}$ after the polarizing voltage was changed from 1000 volts to 500 volts. Curve (5) shows the response after 1000 volts polarizing voltage is suddenly applied.

Figure 11 shows the polarization lag for the Centralab K 7000, K 6000, and K 3500 bodies, and also the Glenco K 3300 body. The K 6000 body has a large temperature coefficient of frequency, and therefore the accuracy suffered. There also were variations from sample to sample. However, with the exception of two different samples of the K 6000 body, it was noted that the frequency ratio decayed approximately as a logarithmic function of time.

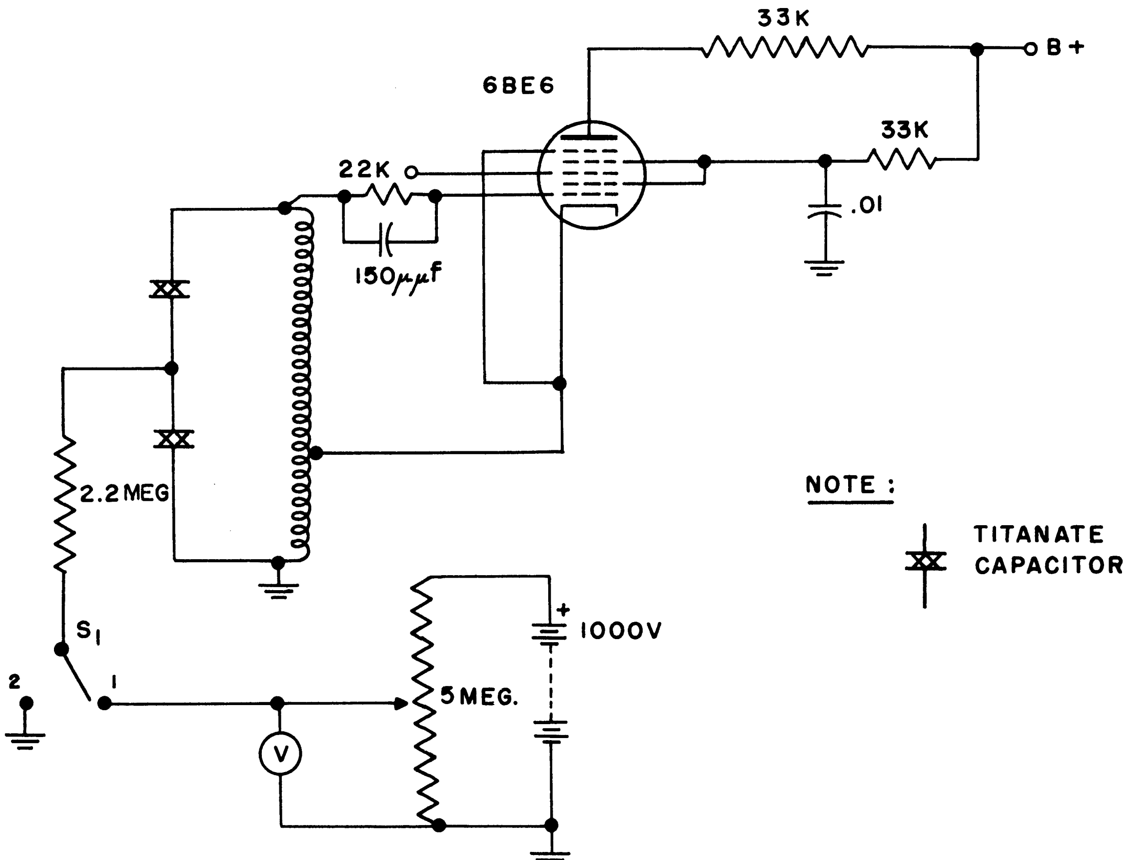


FIG. 8

MIXER – OSCILLATOR

M-970 A-G4-56 JEM 7-31-53

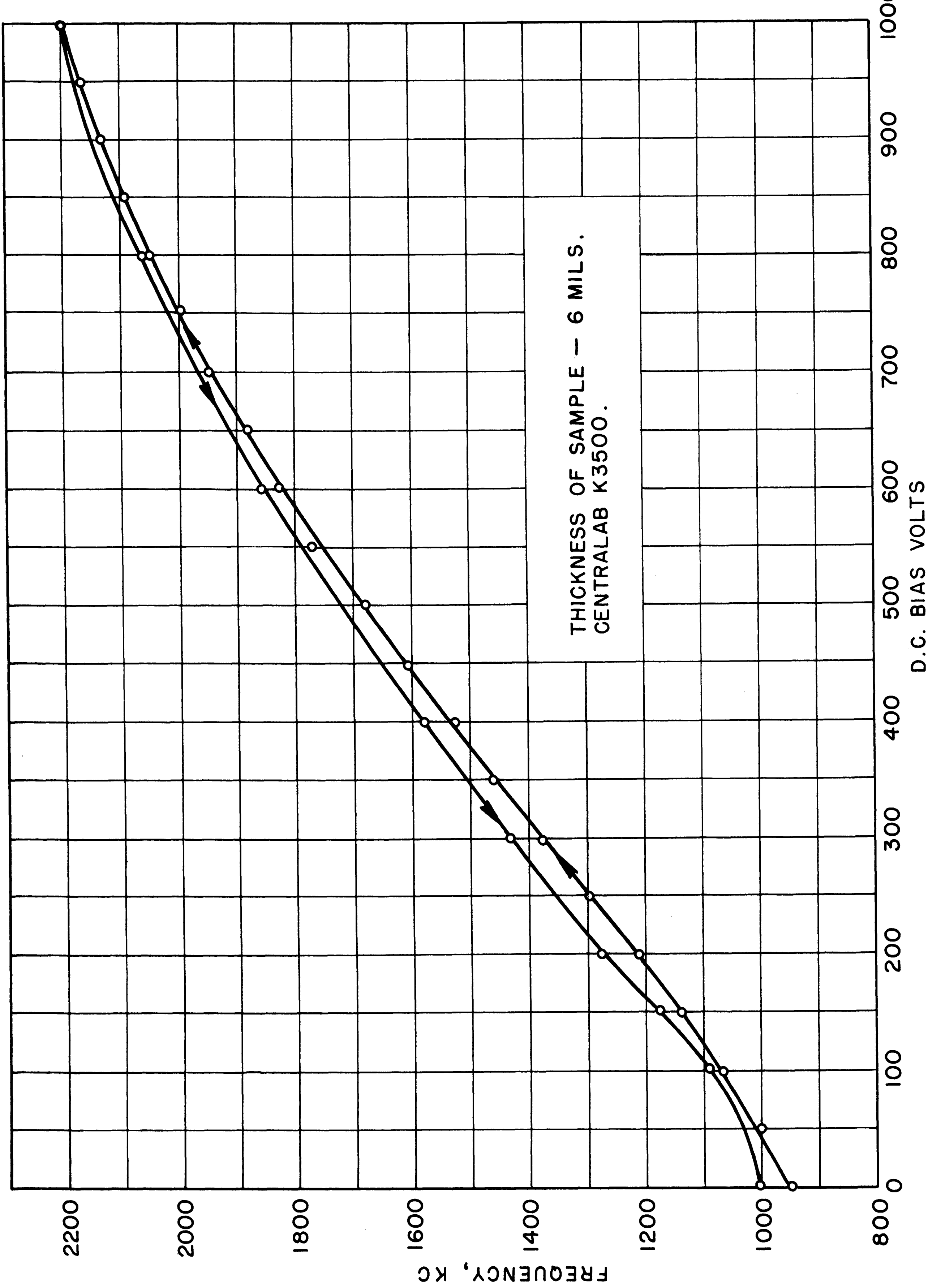


FIG. 9
OSCILLATOR TUNING CURVE.

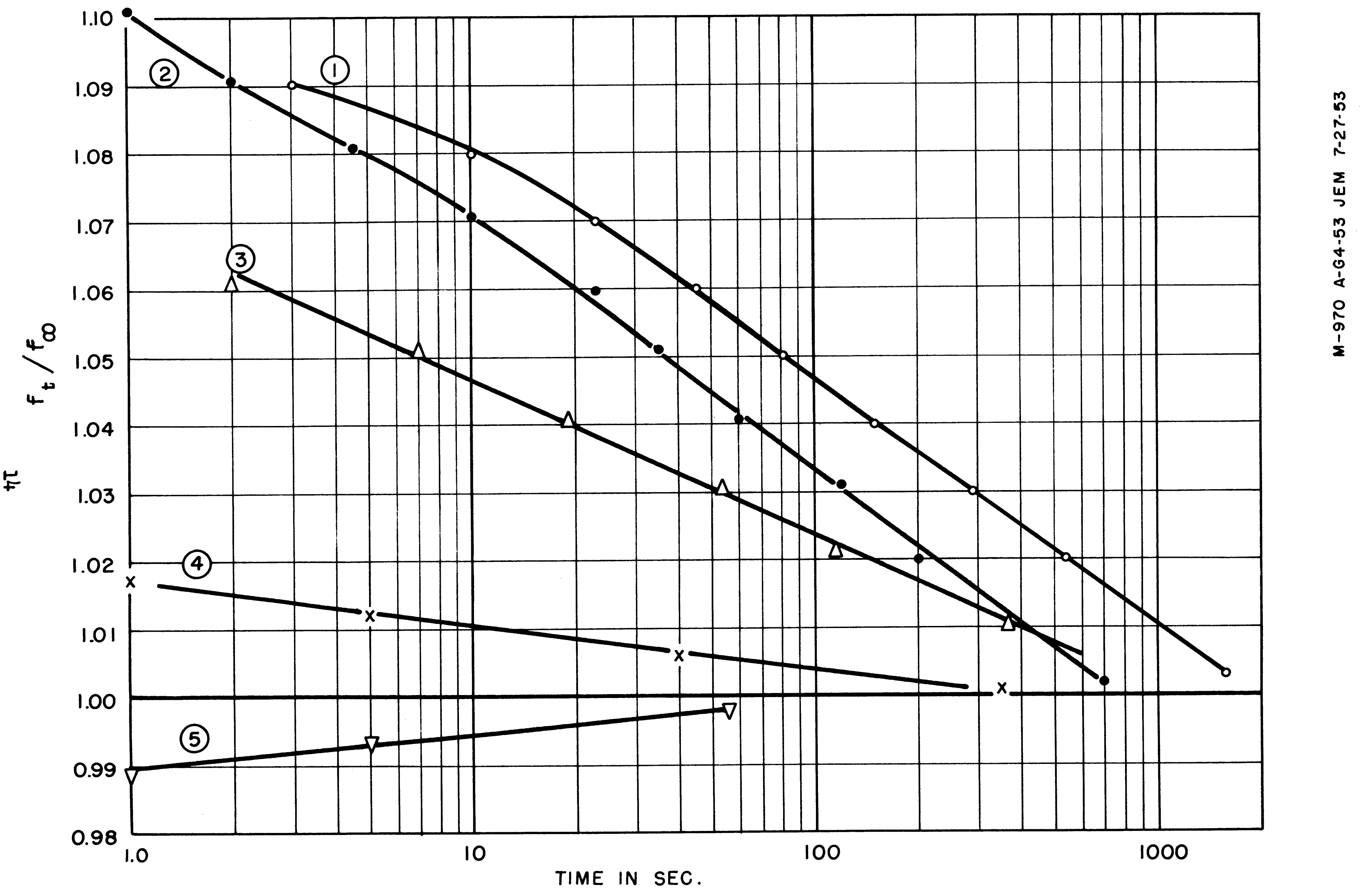


FIG. 10

POLARIZATION LAG FOR CENTRALAB K3500 BODY.

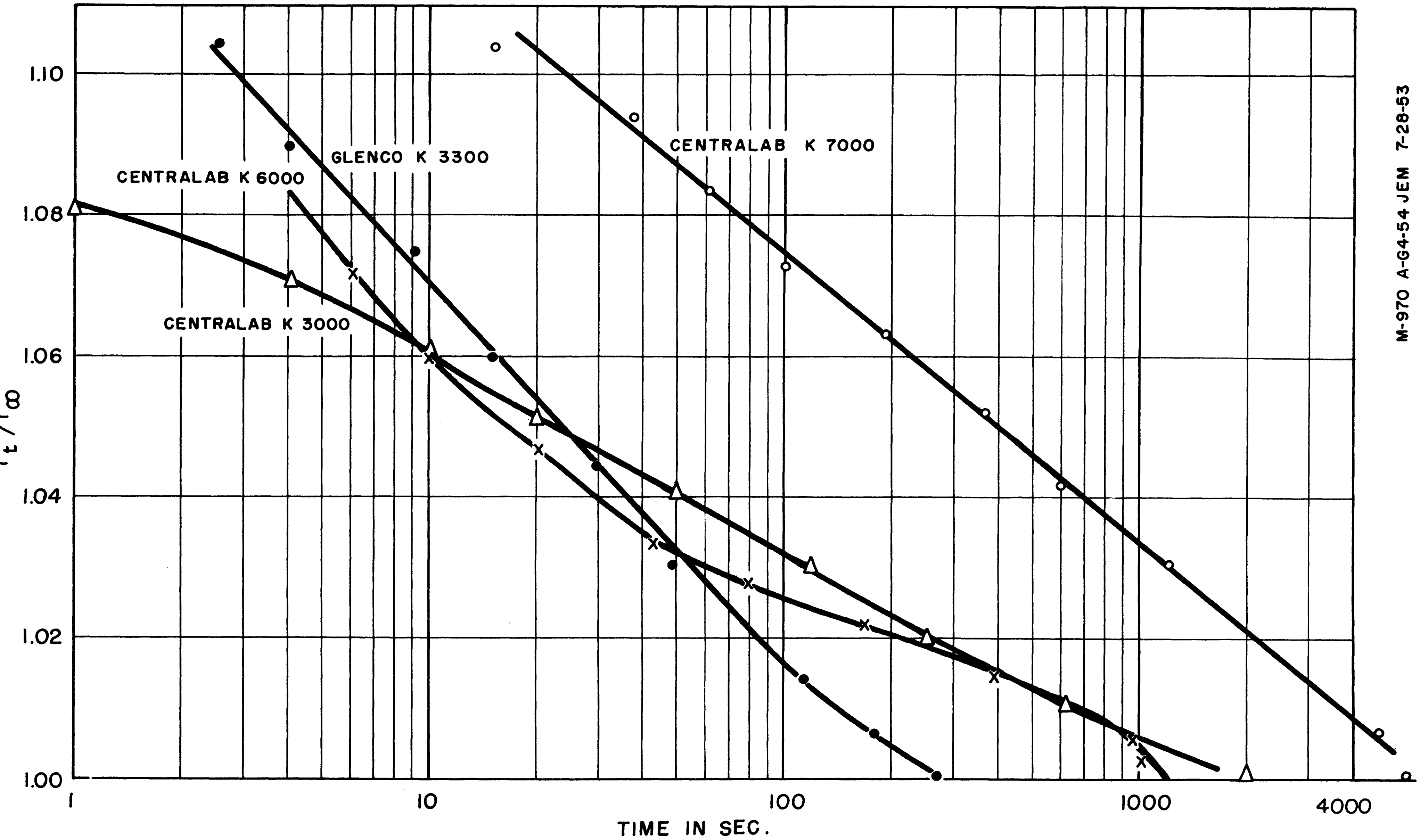


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FIG. 11.

POLARIZATION LAG FOR VARIOUS TITANATE BODIES.

SAMPLES CHARGED TO 100V/MIL FOR 10 MINUTES.

3.3.3.3 Temperature Effects. Figure 12 shows the effect of capacitor temperature on the frequency of the oscillator of Fig. 8. Using two tank capacitors made from a Centralab K 6000 body 10 mils thick, curves of frequency vs. polarizing voltage, with temperature as a parameter, are plotted. For dielectric tuning, materials of dielectric constant in the range 3000 - 4000 appear to be most desirable due to their higher temperature stability, and they also withstand a larger polarizing potential than the higher K bodies.

3.3.3.4 Complete Circuit of Broadcast Receiver. The circuit of the complete dielectrically-tuned broadcast receiver is shown in Fig. 13. It was found necessary to load the radio-frequency tanks to increase the bandwidth and hence improve the tracking. The resistor marked R* in the diagram was introduced to reduce the tracking error. The decoupling resistors in the polarizing circuit were reduced to 120 K ohms to reduce the time constant of the polarizing circuit.

3.3.3.5 Electronic Sweep Circuit. A sawtooth wave generator, Fig. 14, was built to impress a 1000 v sawtooth wave on the polarizing circuit of the receiver. The sawtooth has a fast rise time and then nearly linear decreasing voltage. This was employed because of the slower depolarizing described earlier. The sweep rate could be varied from about 10 cps to about 60 cps. The 1000-volt change swept the receiver from 1380 kc to 1010 kc using commercial 400$\mu\mu$f Glenco type K 3300 capacitors with .010 inch thick dielectric as the tunable elements.

Figure 15 shows the local radio spectrum when the polarizing voltage is impressed on the horizontal axis and the detector output on the vertical axis of the display scope. The strong station at the left is WPAG (1050 kc). Frequency markers (lower trace) were obtained by multiple exposure and an enternal signal

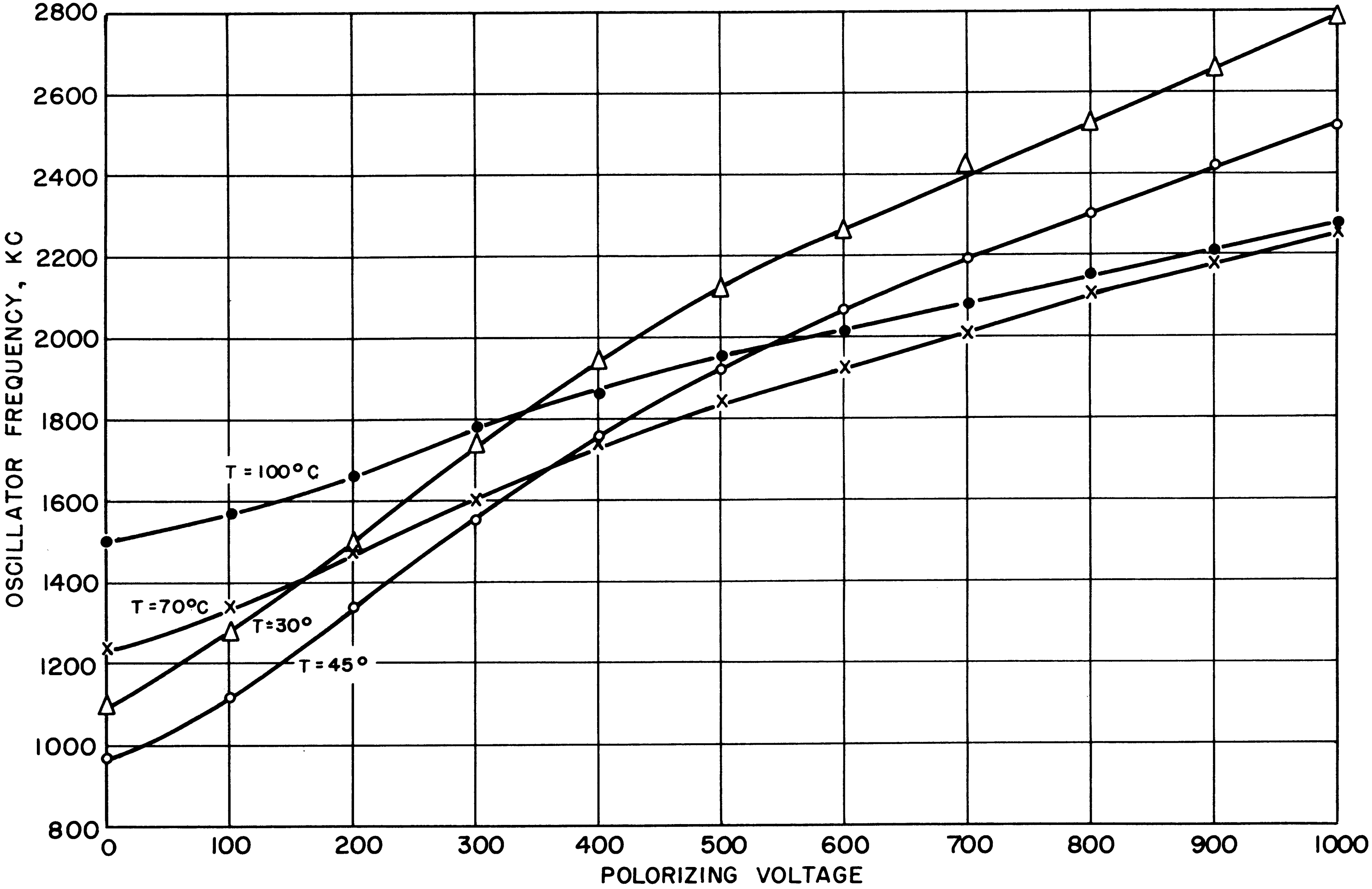


FIG. 12

TEMPERATURE EFFECT ON TUNING.

CENTRALAB K6000. THICKNESS OF SAMPLE = 6 MILS.

M-970 A-G4-55 JEM 7-31-53

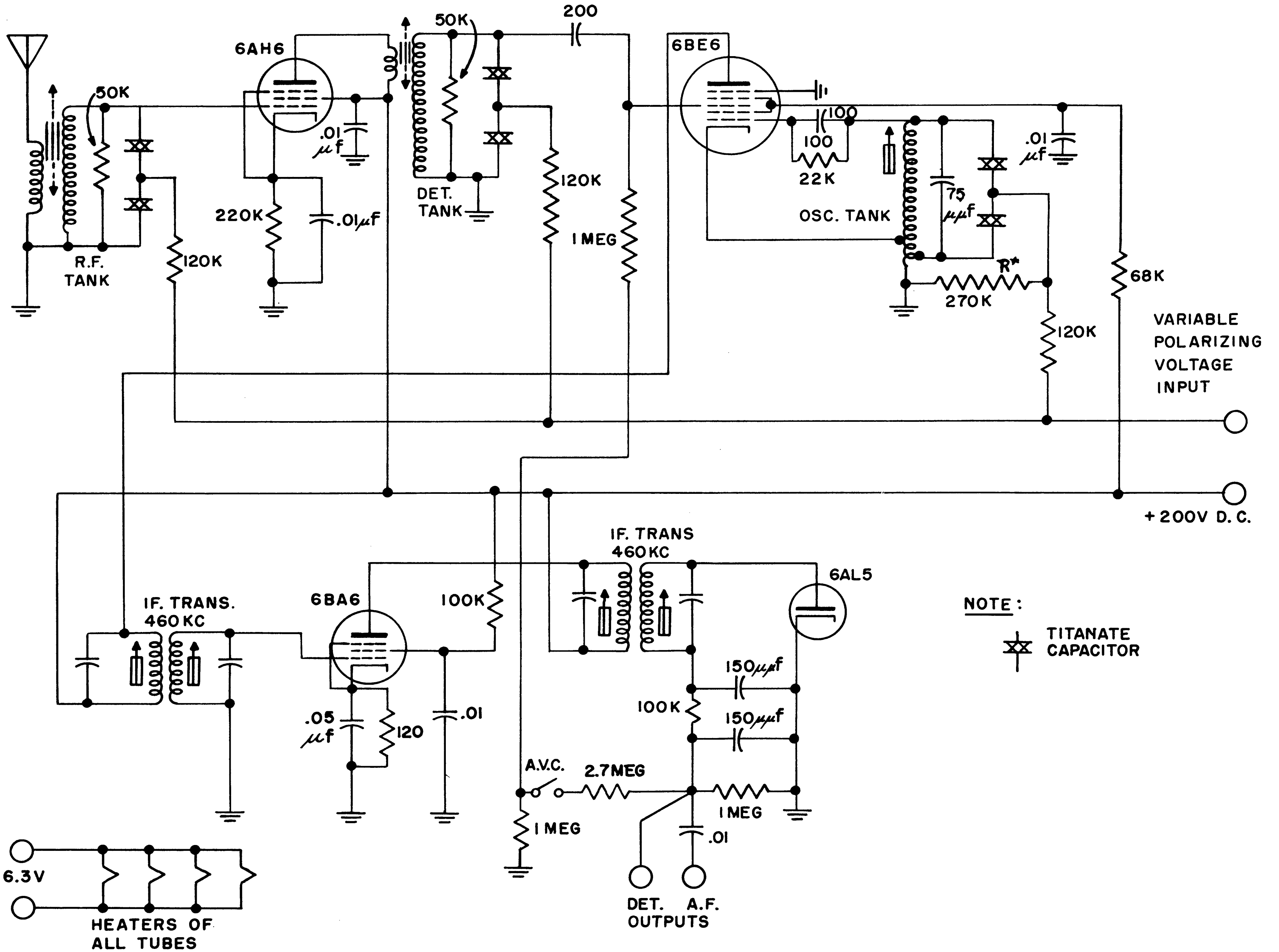
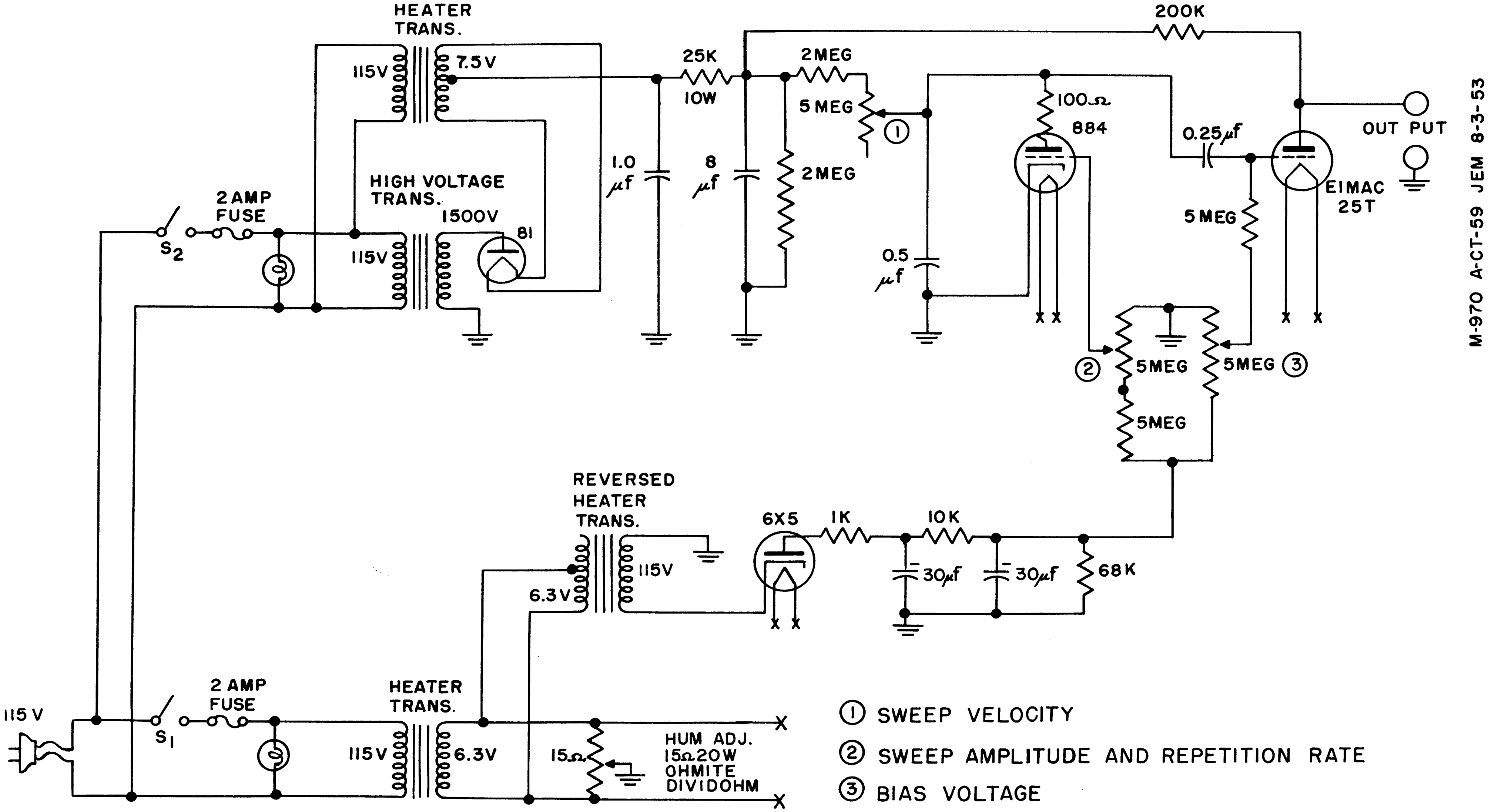


FIG. 13. DIELECTRICALLY TUNED RECEIVER.

M-970 A-CT-60 JEM 8-4-53



(1) SWEEP VELOCITY

(2) SWEEP AMPLITUDE AND REPETITION RATE

(3) BIAS VOLTAGE

S_1-HEATER POWER, AND BIAS SWITCH

S_2-HIGH VOLTAGE POWER SWITCH

FIG. 14

SAWTOOTH GENERATOR.

M-970 A-P4-8 JEM 8-4-53

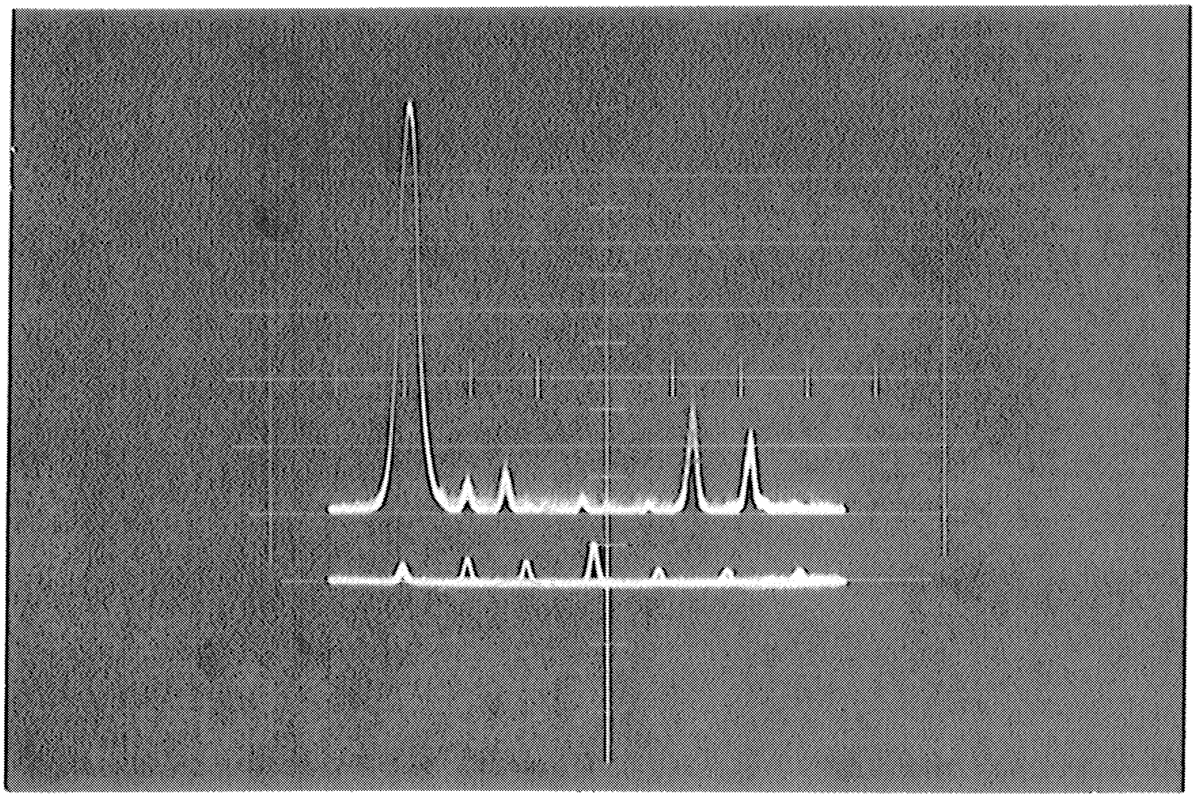


FIG. 15

PANORAMIC DISPLAY OF
RECEIVER OUTPUT.

SWEEP WIDTH = 370 KC
CENTER FREQUENCY = 1200 KC
MARKER SPACING = 50 KC

generator. The markers are separated 50 kc, the central one being 1200 kc. These show the frequency sweep to be fairly linear with sweep voltage.

4. PROGRAM FOR NEXT INTERVAL

A technical report on magnetic modulator design using mu-surfaces will be written, and laboratory test data will be obtained for inclusion in the report. The study of properties of ferroelectric materials and applications will be reviewed. Further work is being planned to study ferroelectric fm modulation above 100 mc. The problems in construction of very thin low capacity units will be examined.

5. CONCLUSIONS

The present activity is proceeding satisfactorily, and the findings to date indicate that a more basic study of ferroelectric phenomena would greatly assist the design of components.

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