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ELECTRIC-TUNED CAPACITY-MODULATED VHF OSCILLATOR

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Electronic Defense Group
Department of Electrical Engineering

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This is not a final report. Further investigation may make it desirable to have this report revised, superseded or withdrawn.

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ABSTRACT

A method of utilizing the voltage tuning characteristics of ferroelectric capacitors in an electric tuned capacity modulated VHF oscillator is described. The oscillator employs titanate ceramic capacitors as both the tuning and modulating elements. The capacity of the tuning elements is varied by changing the electric field applied to the capacitors. The oscillator may be designed to work in the VHF and UHF regions where reactance-tubes and phase modulation methods are unwieldy.

This electric-tuned capacity-modulated VHF oscillator is the result of a development program designed to indicate the direction engineers can take in developing a voltage tunable frequency modulated oscillator suitable for operational use.

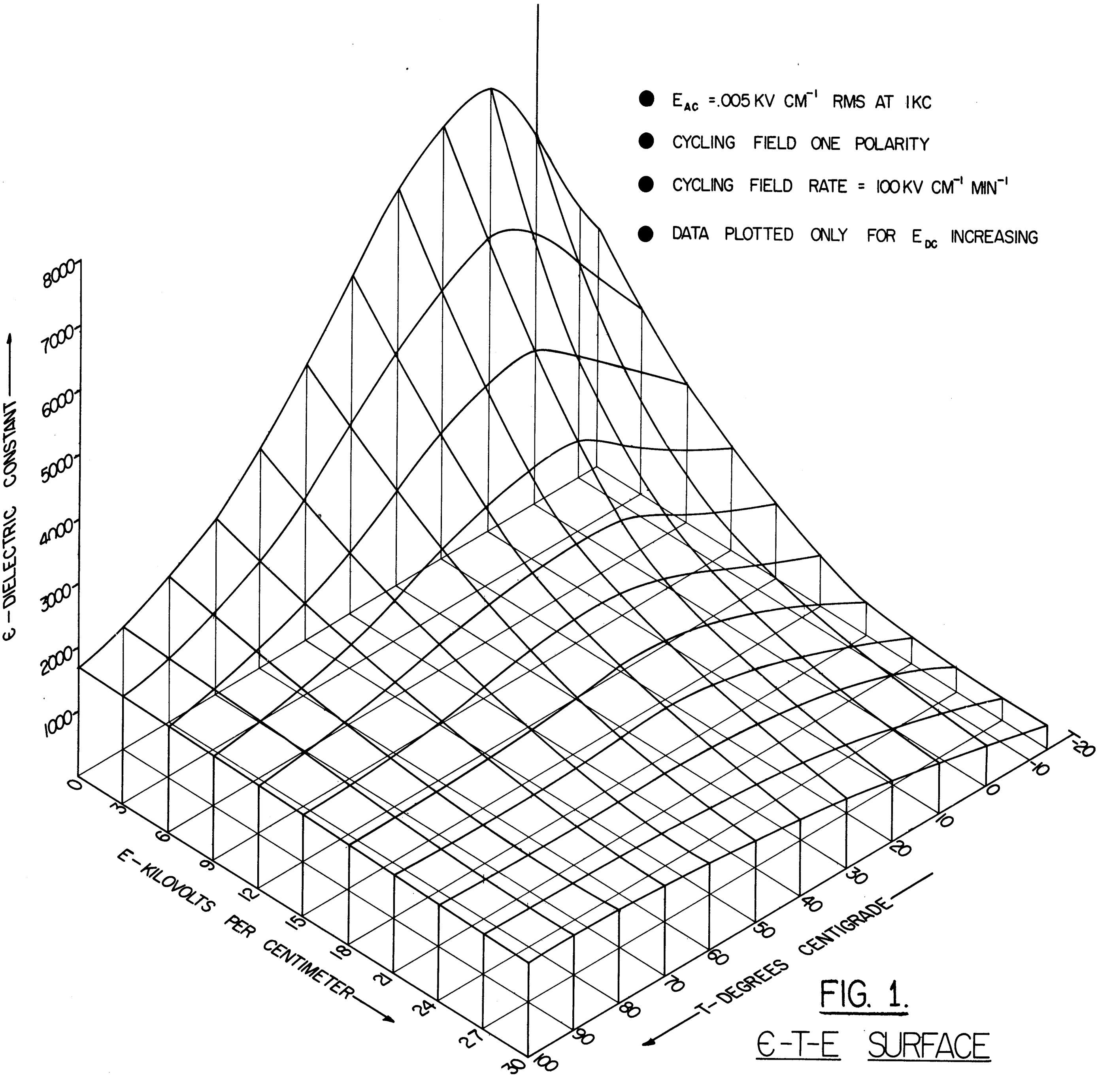
ELECTRIC-TUNED CAPACITY-MODULATED VHF OSCILLATOR

1. INTRODUCTION

It has been suggested by our laboratories and others[1] that the change in dielectric constant with applied field of certain ferroelectric materials be used as the basis for a voltage tunable frequency modulation system. The system would employ titanate ceramic capacitors as tunable elements of an oscillator tank circuit, their capacitance being changed by both a DC bias tuning voltage and a modulating voltage. A system such as this would be quite useful in the VHF- UHF region where conventional reactance-tubes and phase-modulation methods are unwieldy.

2. MATERIAL PROPERTIES OF THE TUNING ELEMENTS

Figure 1 shows the small signal dielectric constant (or permittivity) as a function of both temperature and biasing field for a typical commercially available ceramic material. The data are shown in three dimensions as a convenient means of presenting the temperature-field behavior. Note that the material is very temperature sensitive at low biasing fields and that the peak dielectric constant shifts to higher temperatures as a biasing field is applied. The curves shown are for a material constituted to have the peak ϵ occur near room temperature. Ceramics can also be made to have this peak occur either above or below room temperature. This particular material has been



- E_{AC} =.005 KV CM^{-1} RMS AT 1KC
- CYCLING FIELD ONE POLARITY
- CYCLING FIELD RATE = 100 KV CM^{-1} MIN^{-1}
- DATA PLOTTED ONLY FOR E_{DC} INCREASING

FIG. 1.

ε-T-E SURFACE

FOR AEROVOX "HQ"-91

applied to electrically-tunable devices operating at room temperatures without special thermostating arrangements, and the results have been surprisingly good. Compensating or thermostating techniques are required for applications where large temperature variations may be encountered.

Figure 2 shows the Q plotted as a function of both frequency and biasing field. Note that the Q, which is the inverse of the loss tangent, increases with an increasing biasing field at any selected frequency.

In a tuned tank circuit using voltage sensitive capacitors, the frequency increases with increasing bias field. Thus, the path traced on the QEF surface in such a case runs diagonally from the low frequency-low field region to the high frequency-high field region. In this manner, a reasonable Q is maintained over the selected frequency range.

3. THE TUNED RESONANT CIRCUIT

A capacitor tuning element consists of a pair of ferroelectric capacitors[2] in a series arrangement. When such an element is connected across an inductance, a voltage tunable resonant circuit is obtained. The resonant frequency of the tank circuit may be controlled by applying a variable DC bias voltage to the junction of the two capacitors with a ground return at one end of the coil. The DC bias voltage defines the operating point and center value of capacitance C_o. It is only necessary to superimpose an AC signal (e.g., modulation signal) which will vary the capacitance about the operating point. It should be noted that the two capacitors are in parallel with the bias and sweep voltages but in series with the RF voltage. This particular arrangement helps to obtain a low RF field across each ferroelectric capacitor and still have the required polarizing field held to reasonable values.

FIG. 2.

AEROVOX HI Q 91 CERAMIC
Q vs f AT GIVEN ELECTRICAL
FIELDS
AT ROOM TEMP 23°C

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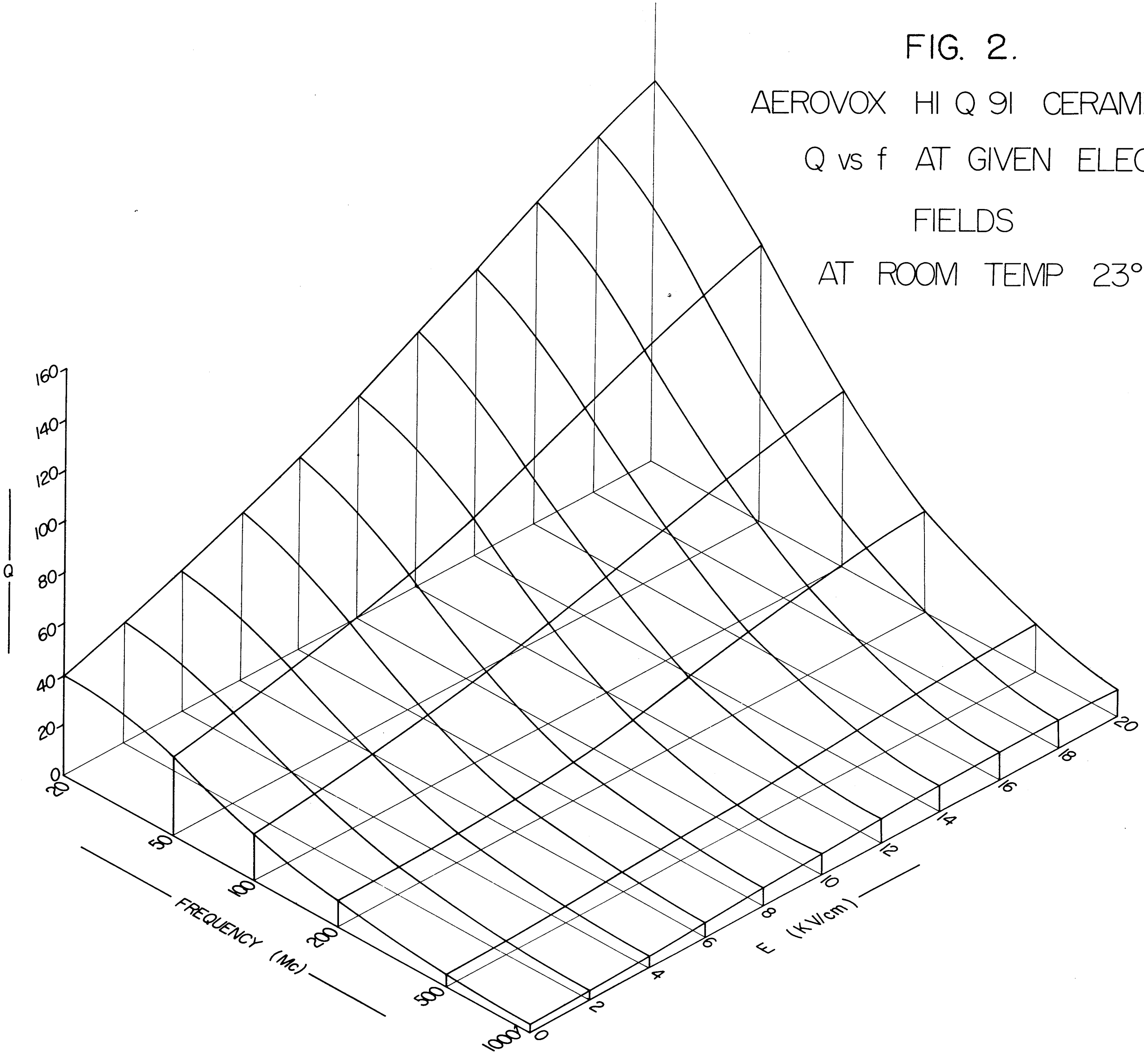

For electric tuned FM applications a ceramic having a large voltage sensitivity with a small temperature coefficient of capacitance is desired.

4. PRACTICAL CIRCUIT CONSIDERATIONS

In the initial stages of the design of the electric tuned capacity modulated oscillator, shown in Figure 3, the curve of capacity variation vs. voltage is selected at the desired operating temperature from the surface of Figure 1. A typical plot is shown in Figure 4. In the particular circuit to be tuned, the capacitance of the coil L, the associated tube, and wiring is lumped as C_s. This value is added to C and the capacity variation $C + C_s$ is then replotted. To determine the variation of frequency with voltage it is only necessary to plot $k(C + C_s)^{-1/2}$ vs. E as shown in Figure 5 where the constant k is equal to $\frac{1}{2\pi} L^{-1/2}$. The frequency range over which the oscillator is to work may now be selected. In this case a zero field value of 35 mc was chosen as the starting frequency. From the plot of Figure 6 (calculated curve) an idea of the linearity of the oscillator may easily be obtained. The oscillator appears to be quite linear over the frequency range 36 to 50 mc. The measured curve of oscillator frequency vs. applied tuning voltage shows an even greater range of linearity (36 to 56 mc). The theoretical curve and measured curve, however, appear to be in agreement over most of the tuning range. Determination of tank circuit Q may be obtained with the aid of the QEF surface of Figure 2.

It was possible with the aid of a spectrum analyzer to determine the dynamic measurements of deviation by observing the roots $Jn(M_f) = 0$ of the various Bessel function plots shown in Figures 7 through 11.

Figure 7 illustrates a series of plots for a 40 kc sine wave modulating frequency. In each case the modulation amplitude was varied until the indicated root was obtained. It was found that the dynamic measurements of

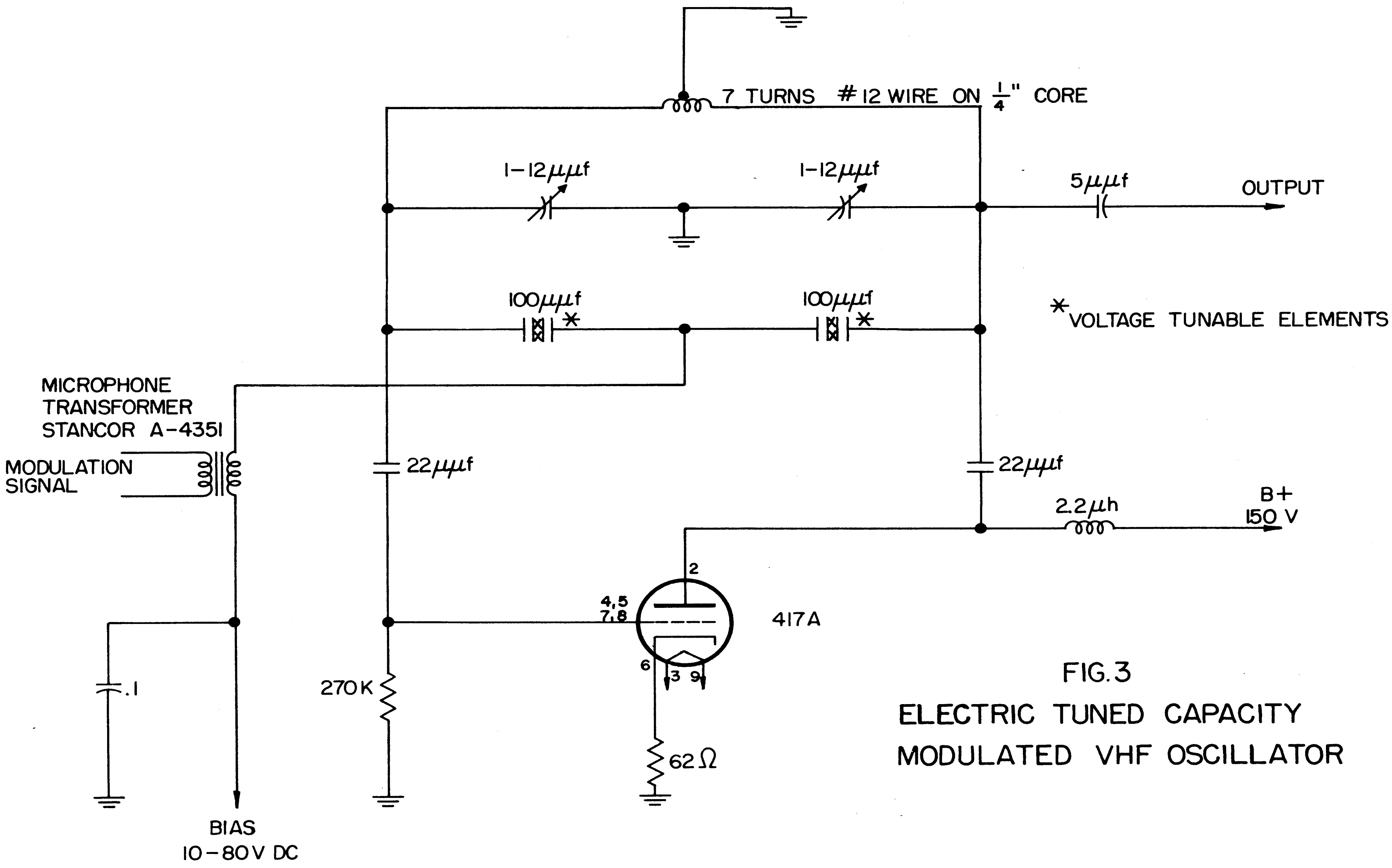

FIG. 3

ELECTRIC TUNED CAPACITY
MODULATED VHF OSCILLATOR

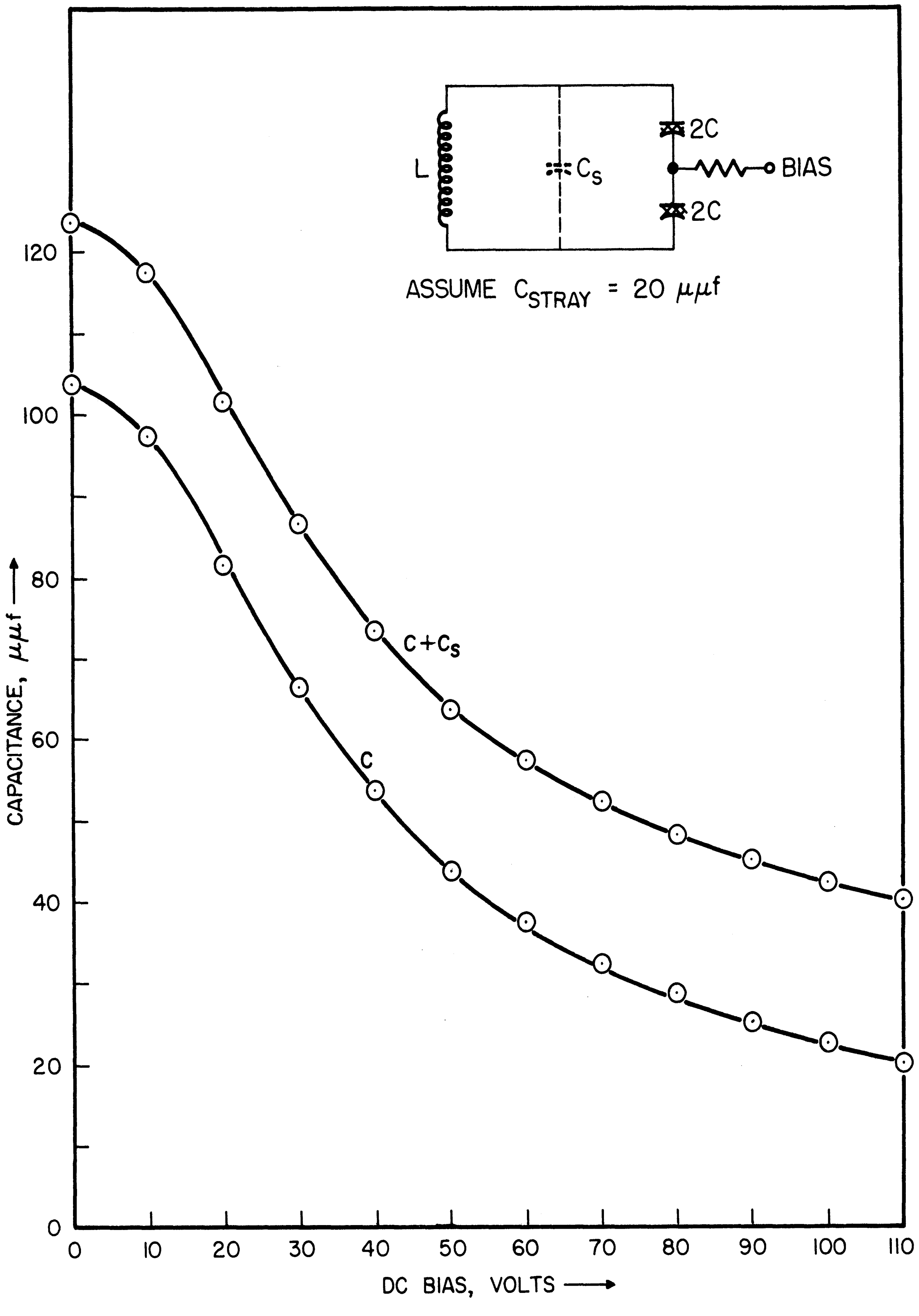

FIG. 4 CAPACITANCE VARIATION VS DC BIAS IN TYPICAL OSCILLATOR TANK CIRCUIT

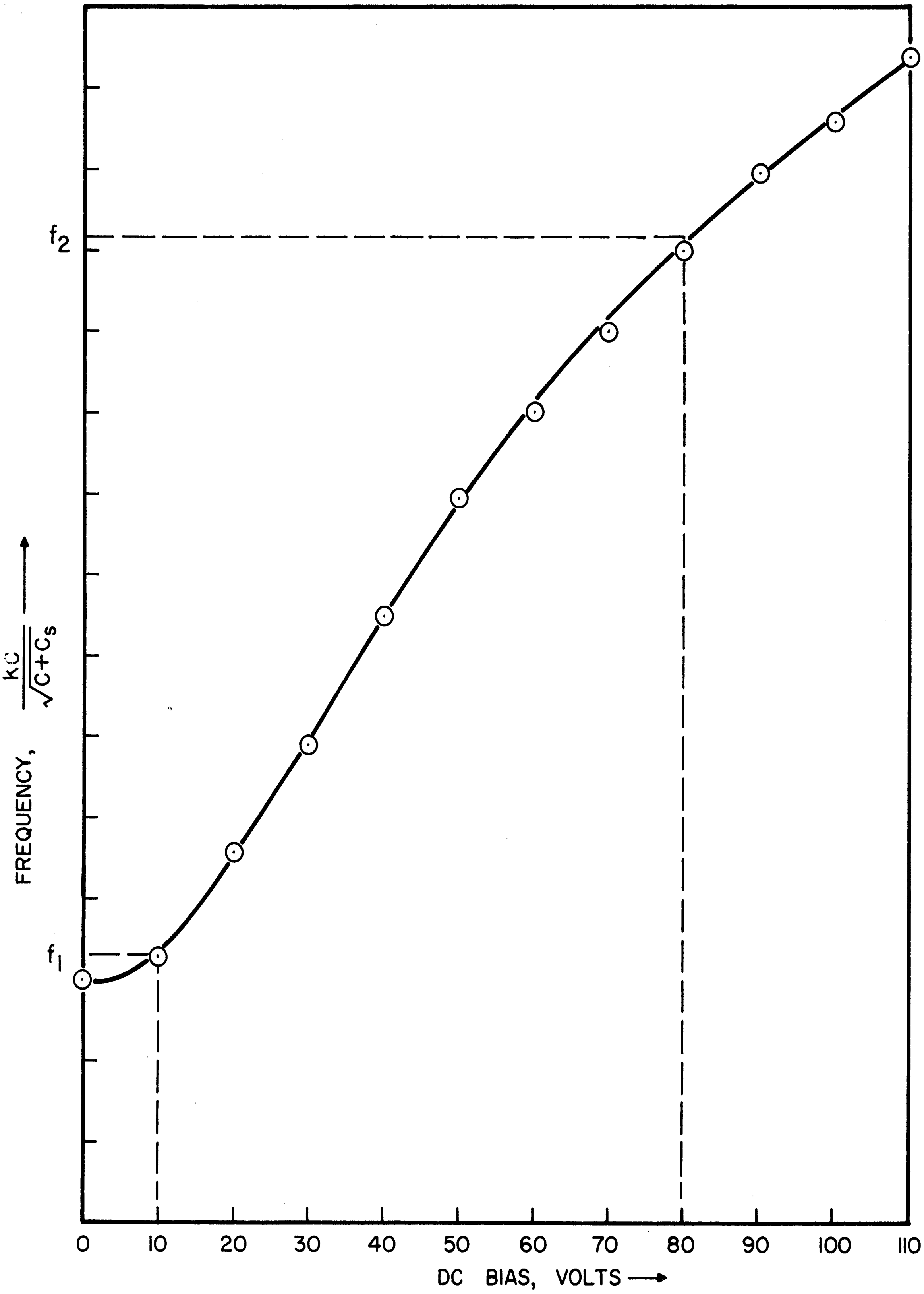

FIG.5 FREQUENCY VARIATION VS DC BIAS IN TYPICAL OSCILLATOR TANK CIRCUIT

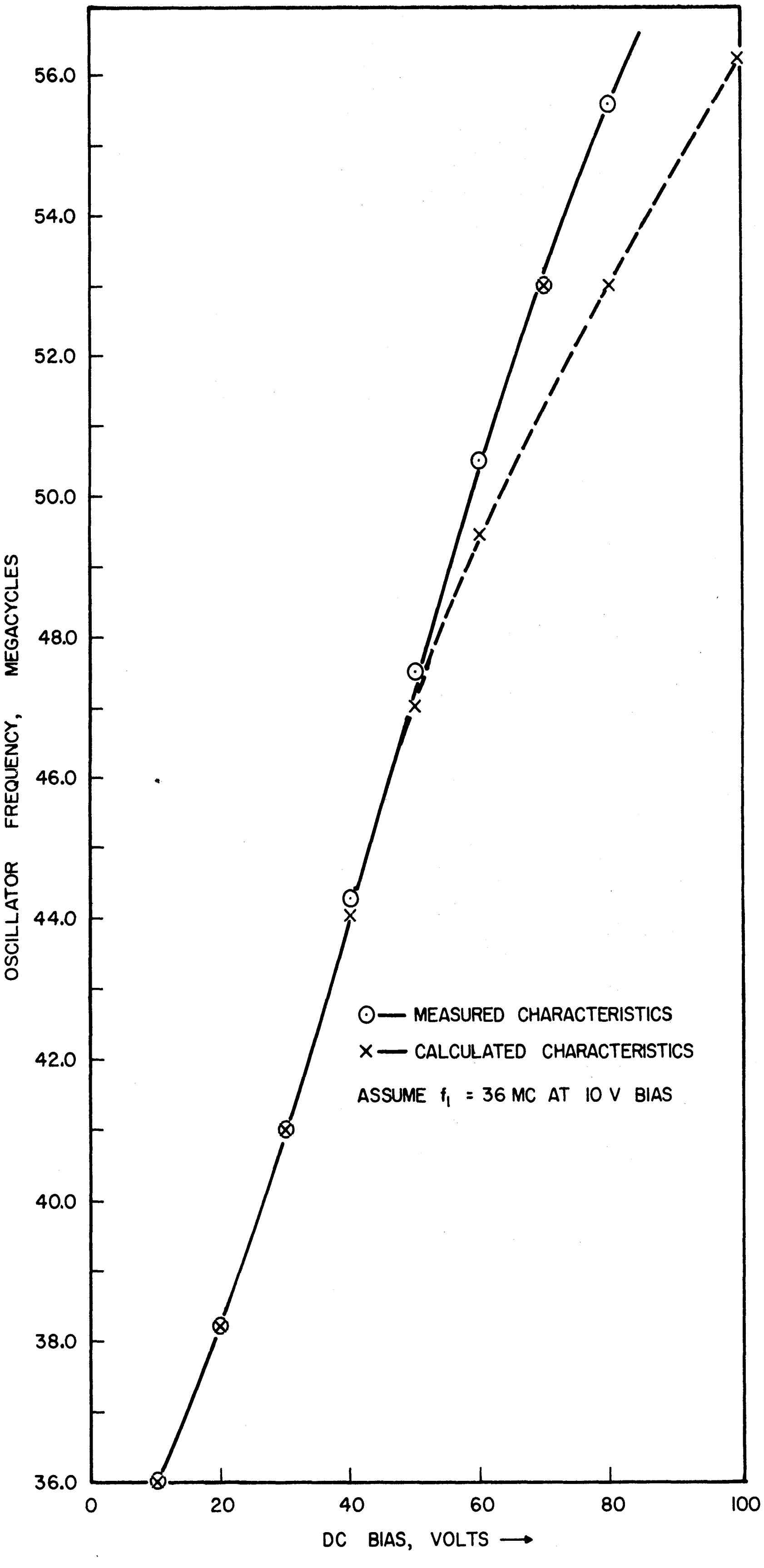

FIG. 6 STATIC CHARACTERISTICS

FREQUENCY DEVIATION VS DC BIAS

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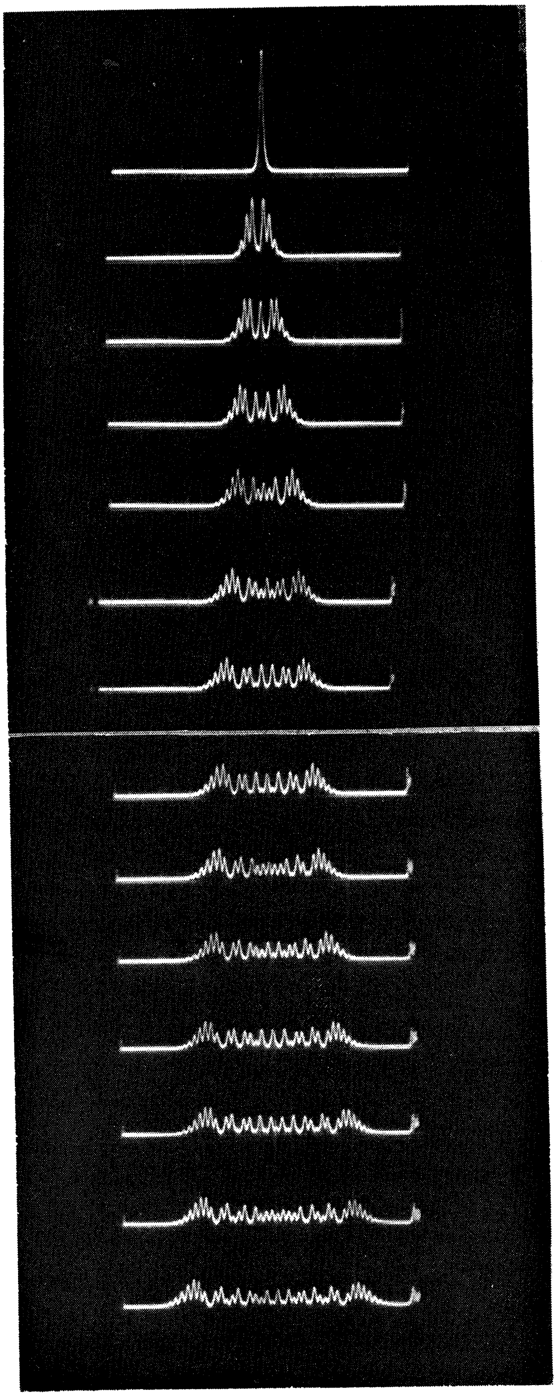


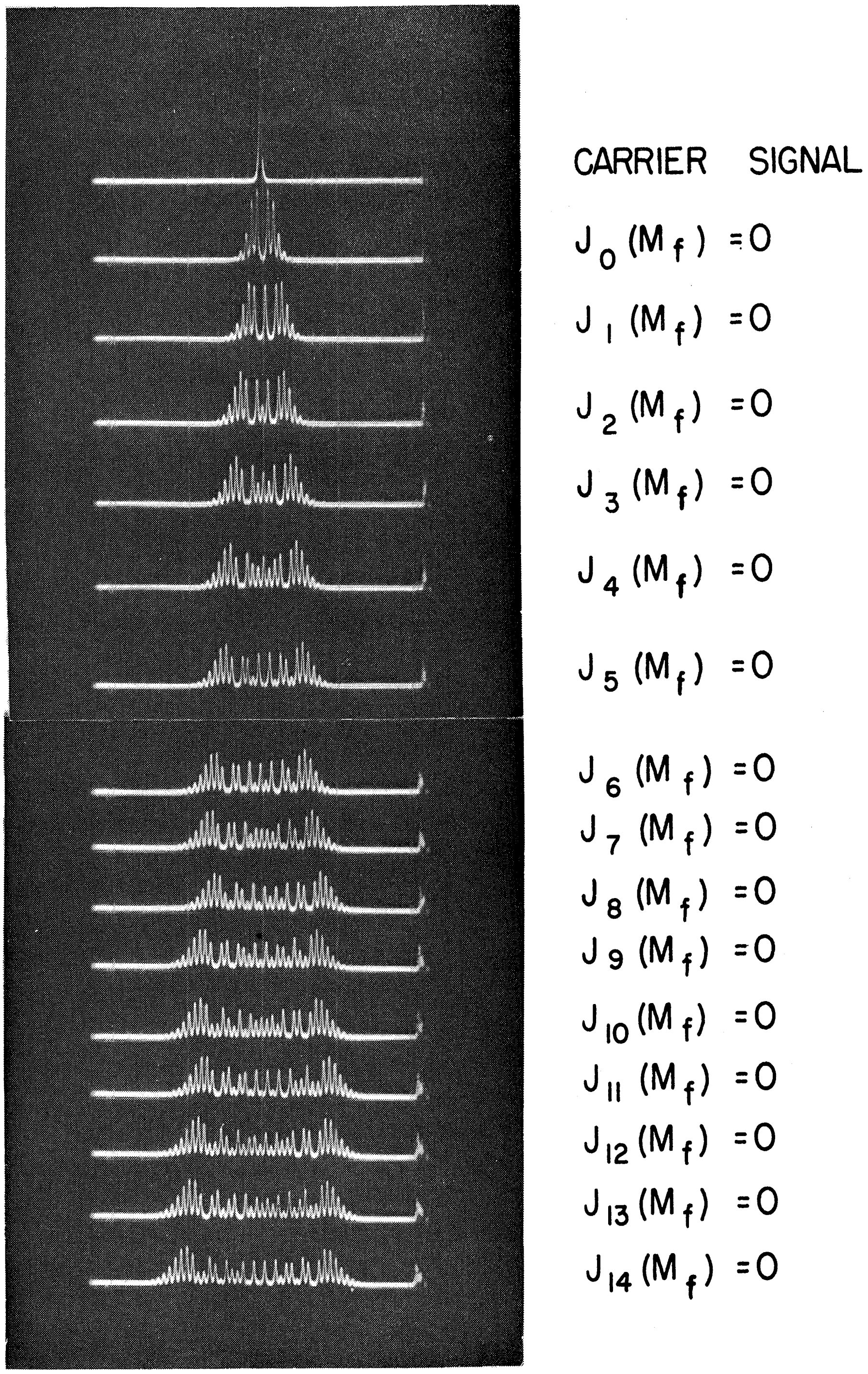
MODULATION SIGNAL— 40 Kc. SINE WAVE

CARRIER SIGNAL — 46 Mc.

BIAS VOLTAGE — 50 VOLTS

FIG. 7

DEVIATION AS A FUNCTION OF MODULATION SIGNAL



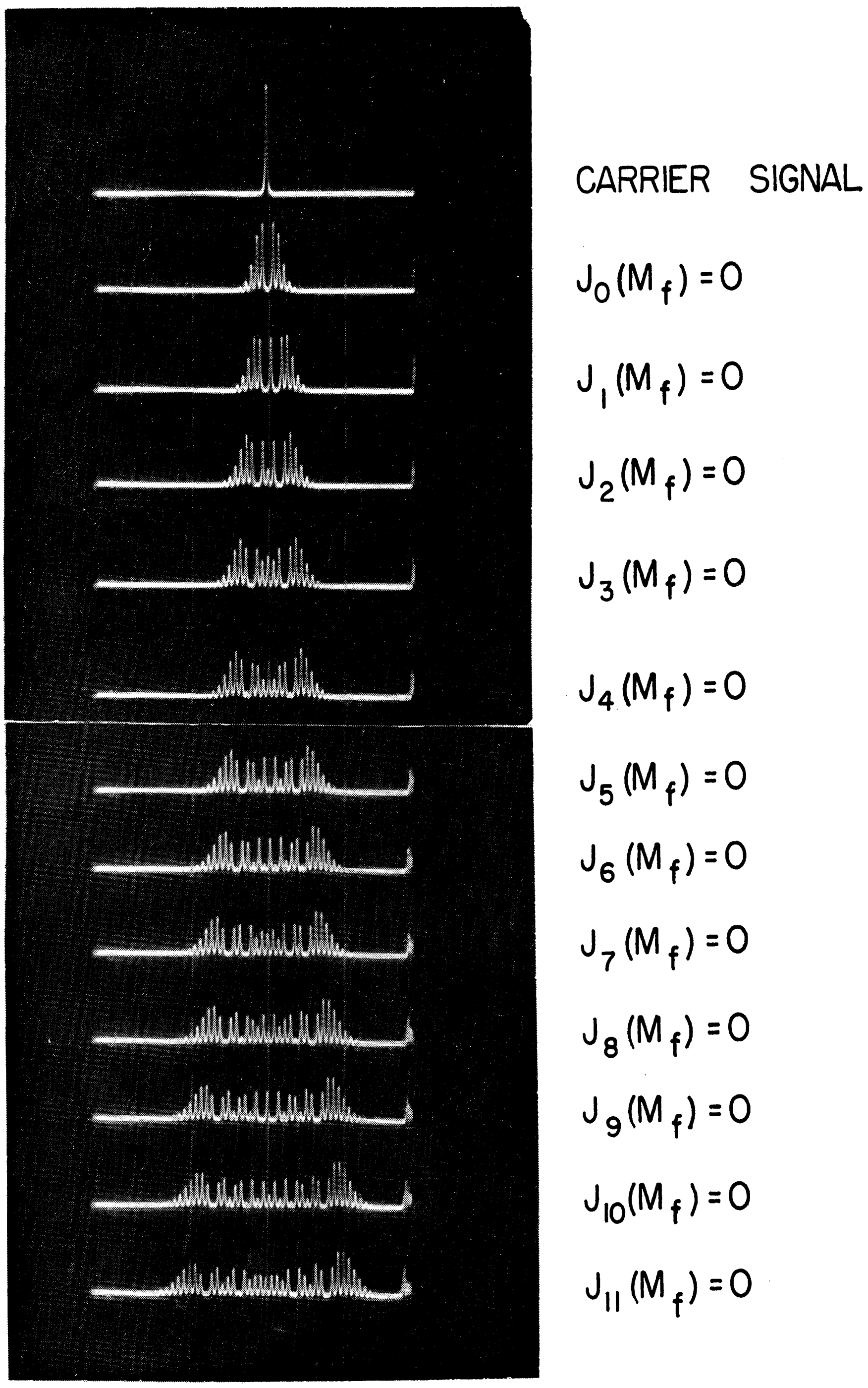
MODULATION SIGNAL — 75 Kc SINE WAVE

CARRIER SIGNAL — 46 Mc.

BIAS VOLTAGE — 50 VOLTS

FIG. 8

DEVIATION AS A FUNCTION OF MODULATING SIGNAL



MODULATION SIGNAL — 100 Kc SINE WAVE

CARRIER SIGNAL — 46 Mc

BIAS VOLTAGE — 50 VOLTS

FIG. 9

DEVIATION AS A FUNCTION OF MODULATING SIGNAL

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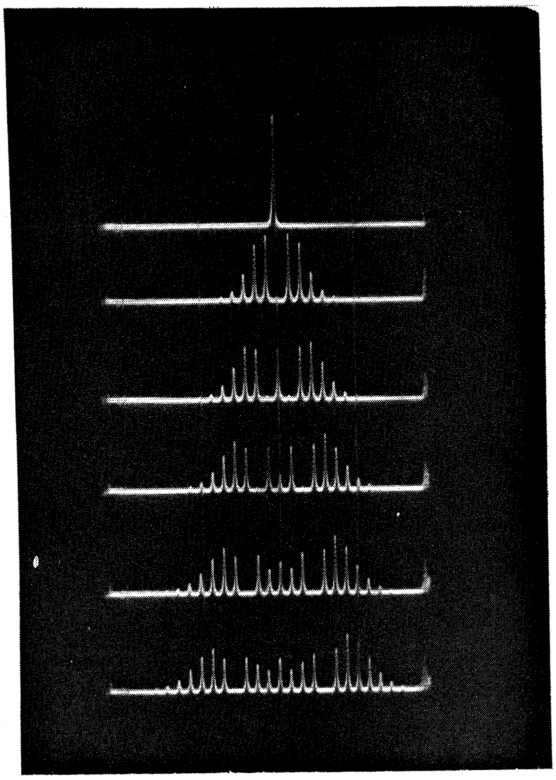

CARRIER SIGNAL

$J_0 (M_f) = 0$

$J_1 (M_f) = 0$

$J_2 (M_f) = 0$

$J_3 (M_f) = 0$

$J_4 (M_f) = 0$

MODULATION SIGNAL — 200 Kc SINE WAVE

CARRIER SIGNAL — 46 Mc.

BIAS VOLTAGE — 50 VOLTS

FIG. 10

DEVIATION AS A FUNCTION OF MODULATION SIGNAL

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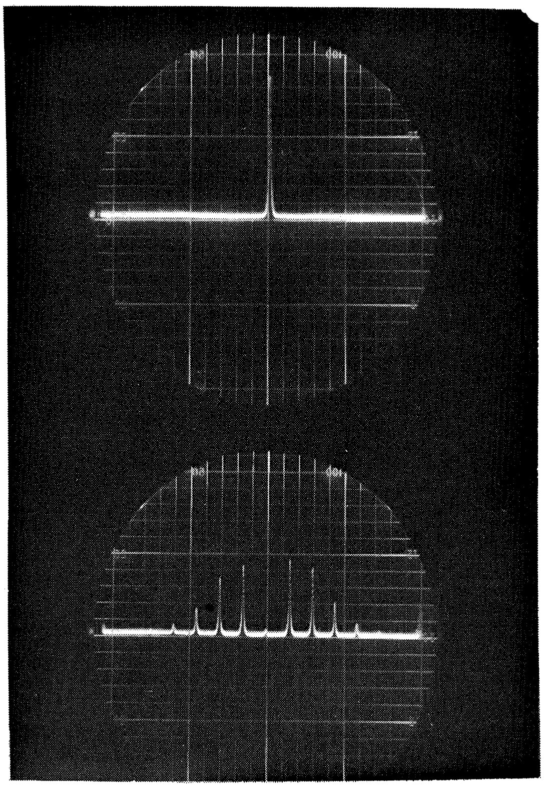

CARRIER SIGNAL

$J_0 (M_f) = 0$

MODULATION SIGNAL — 400 Kc. SINE WAVE

CARRIER SIGNAL — 46 Mc.

BIAS VOLTAGE — 50 VOLTS

FIG. 11

DEVIATION AS A FUNCTION OF MODULATION SIGNAL

deviation in modulation amplitude checked the static characteristics (Figure 6) quite closely. For example, a peak 40 kc sine wave modulating voltage of 1.8 volts was required to obtain the spectrum opposite J_5 $(M_f) = 0$. From the Bessel Function Tables the value of (M_f) at J_5 $(M_f) = 0$ is 8.78. Thus, the deviation of this spectrum is 8.78 x 40 kc = 350 kc. Going back to the static characteristics, it is found that at 46 mc, 2 volts are required to change the oscillator frequency 350 kc. As can be seen from the symmetry of the display, little incidental AM is in evidence. Figures 7, 8, 9, and 10 indicate the deviation of 75 kc, 100 kc, 200 kc and 400 kc sine wave modulating frequencies as functions of the amplitude of the respective modulating signals. The broad-band response is still quite good. In the VHF range deviations of $\pm$ 20% are readily obtainable. Under extreme conditions, the incidental amplitude modulation may become serious. For smaller deviations, however, the incidental amplitude modulation is negligible.

5. TEMPERATURE EFFECTS

It was pointed out previously that it is desirable to use titanate materials which have a small temperature coefficient of dielectric constant over a wide temperature range. If the materials do not possess this quality, of if the oscillator is to be used over an extended temperature range (as it would be under field conditions), then methods of temperature compensation or thermostating techniques must be employed to maintain oscillator tuning range and stability. Temperature compensation may be obtained by using two capacitors in series which have their Curie points at different temperatures, i.e., one above and the other below the normal operating temperature. As shown in Figure 12, the Curie point of C_1 is 20°C while the Curie point of

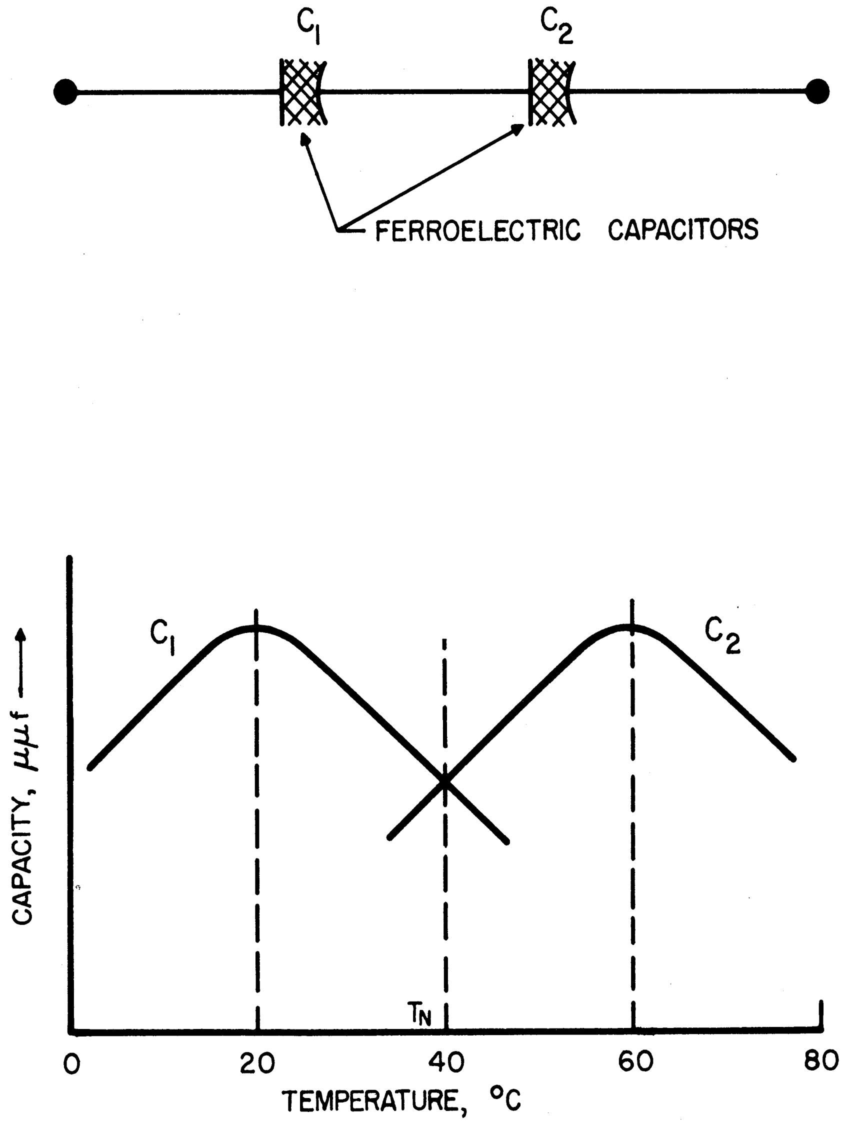

FIG. 12 METHOD OF TEMPERATURE COMPENSATION

C_2 is 60°C. The normal operating temperature T_n for the equipment is considered to be 40°C. Since at the normal operating temperature the function C_1 vs. T has a negative slope, while the function C_2 vs. T has a positive slope, any rise in temperature will cause C_1 to fall and C_2 to rise. If the rates of fall and rise are the same, compensation will be complete. The same reasoning holds true if the temperature falls below the normal operating temperature. This operation gives the effect of a broad Curie over the temperature range under consideration. Another method would be to build a broader Curie region into the material itself by use of a larger proportion of buffer material in the basic Barium Strontium mixture. Overtures in this direction have resulted in broader Curie regions, but tend to cause higher losses and less voltage sensitivity in the tuning elements. However, development work in this area is still proceeding. A third method of temperature compensation which has worked well is AFC, i.e., the error signal due to drift in the oscillator is picked off the output of a simple ratio detector and is then amplified and fed back to the tuning element. Thus, a change in frequency is reflected back as a change in the DC bias level of the tuning element which tends to restore the oscillator to its original state. Perhaps the simplest method of maintaining a constant temperature over a prescribed temperature range is by thermostating. To demonstrate the feasibility of using thermostating techniques, a small temperature controlled oven was rigged as shown in Figure 13. The temperature of the environment was varied from + 40°C down to - 5°C. The variations of capacitance with temperature were recorded. In both cases, the ratio of the value of capacity at various temperatures to that at 40°C was plotted as a function of temperature in degrees C. The results of this test are shown in Figure 14.

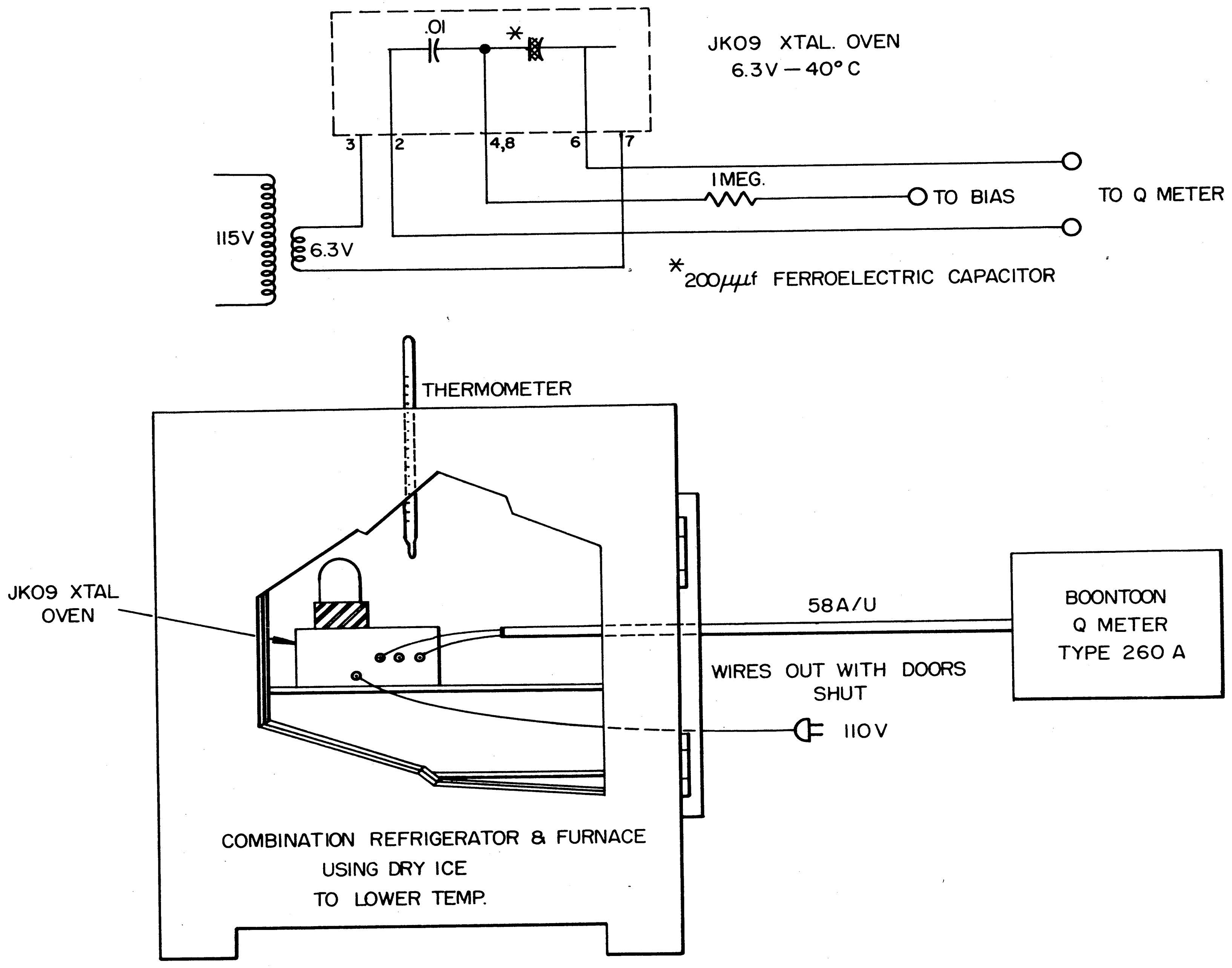

FIG. 13 METHOD FOR CHECKING THERMOSTATING ARRANGEMENT

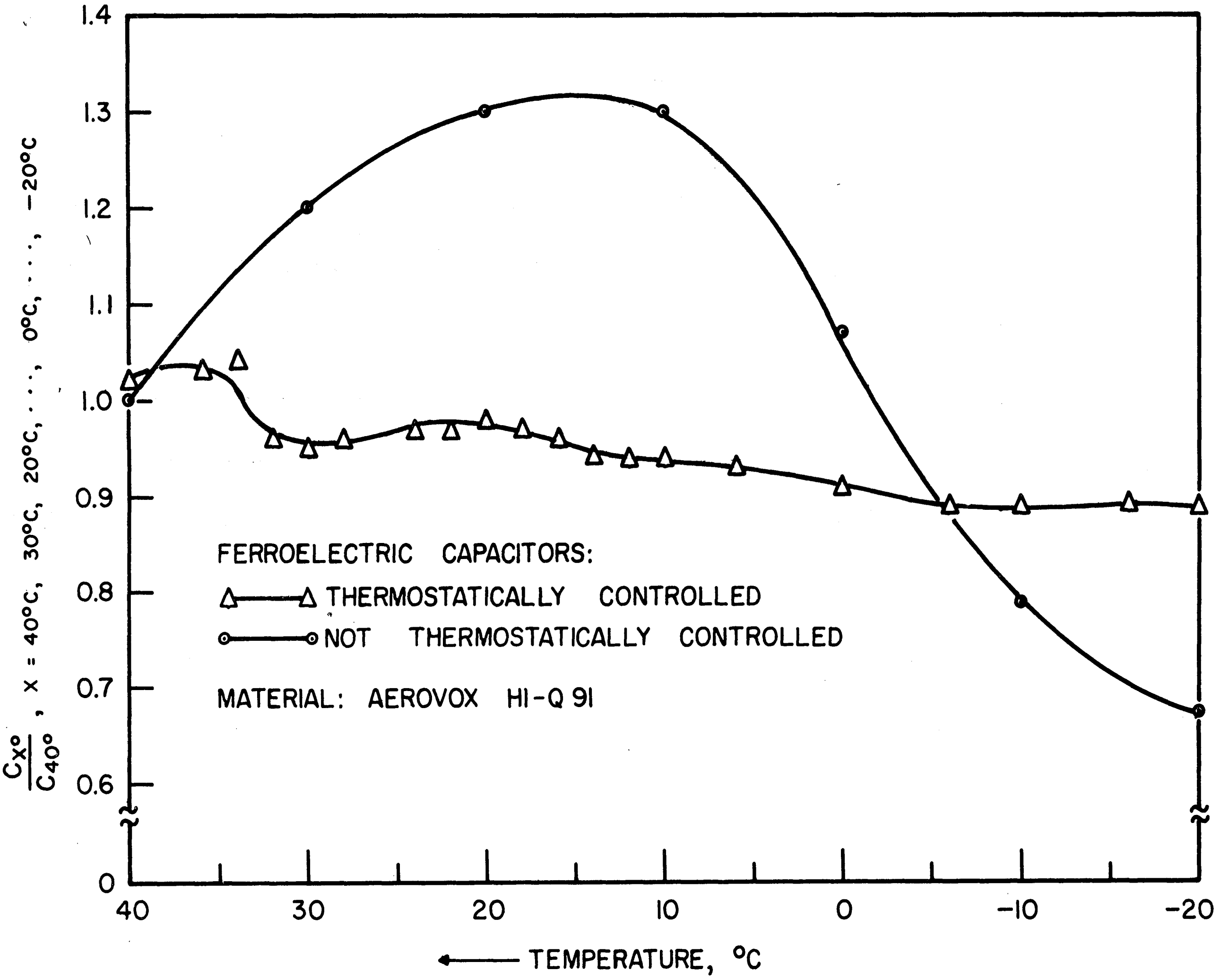

FIG. 14. RATIO OF CAPACITANCE, $\frac{C_{X°}}{C_{40°}}$, VS. TEMPERATURE IN DEGREES CENTIGRADE

6. CONCLUSIONS

The electric-tuned Capacity-Modulated Oscillator Systems should find application in any equipment which has the requirement of

1) Broad frequency response

2) Wide frequency deviation

3) Very small package

In particular the above system has been successfully used in the design of a VHF transistorized FM oscillator and a narrow-band Capacity-Modulated "VFO".

Sweep rates in excess of 500 kc can be easily obtained for small frequency deviations. The major difficulty at present is obtaining a large tuning ratio while maintaining a small temperature coefficient. However, this difficulty is gradually being reduced through the development of new materials and manufacturing techniques.

ERRATA

Page 5, line 11: $\frac{1}{2}\pi L^{-1/2}$ should read $\frac{1}{2\pi}L^{-1/2}$

Page 8, ordinate: $\frac{KC}{\sqrt{C+C_s}}$ should read $\frac{K}{\sqrt{C+C_s}}$

Page 17, line 21: -5°C should read -20°C

REFERENCES

1. M. Apstein and H. H. Wieder, "Capacitor-Modulated Wide Range FM System," Electronics, vol. 26, p 190; Oct., 1953.

2. T. W. Bulter, Jr., H. Diamond, L. W. Orr, "Sub-miniature Non-linear Capacitors for Application to VHF Wide-range Tuning Devices," Proceedings of the National Electronics Conference, vol. XI, 1955.

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