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DESIGN CONSIDERATIONS FOR A
CAPACITANCE-MODULATED VFO

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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 Further investigation may make it desirable to have this report revised, superseded or withdrawn.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

The use of ferroelectric capacitors in the design of a band switching capacity-modulated VFO which will meet FCC specifications regarding Narrow-Band frequency modulation (NFM) is presented. The chief advantage of NFM is that it reduces or eliminates certain types of interference to broadcast reception and is quite simple and inexpensive to construct using capacitance-modulation techniques.

DESIGN CONSIDERATIONS FOR A CAPACITANCE-MODULATED VFO

I. INTRODUCTION

The use of ferroelectric capacities in the design of an electric-tuned capacitance-modulated oscillator has been presented in previous reports.¹ The design of a band switching capacitance-modulated VFO which will meet F.C.C. specifications regarding narrow band frequency modulation (NFM) in the available Radio Amateur frequency bands is presented. Although the design was carried out with certain specific bands in mind the general design principles are flexible enough to allow their use in all VHF and UHF bands.

II. THEORETICAL CIRCUIT DESIGN CONSIDERATIONS

Since in the design of the capacitance-modulated VFO, electric tuning of the oscillator tank circuit is not a requirement (i.e., tuning over the range will be done by a variable air capacitor), and since it is desirable to maintain the overall frequency stability of the basic VFO without resorting to thermostating techniques and close regulation of the bias voltage, the basic wide range tuning circuit of Fig. 1 may be modified somewhat as shown in Fig. 2.² The tank circuit $L_1 C_1$ of Fig. 2 is shunted by the series arrangement of C_2 and C^* (voltage sensitive capacitor). Capacitor C_2 serves as a d-c blocking capacitor and also provides a means of multiplying the effective Q of the circuit. The Q of C_2 and C^* in series is approximated by:

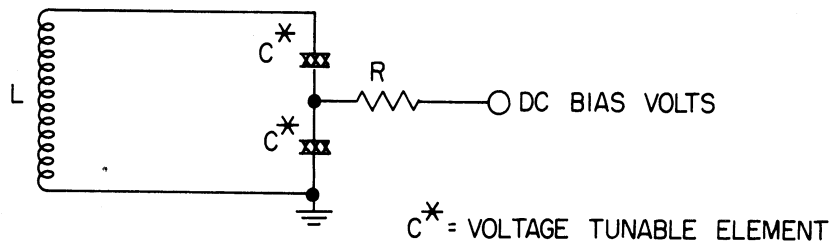
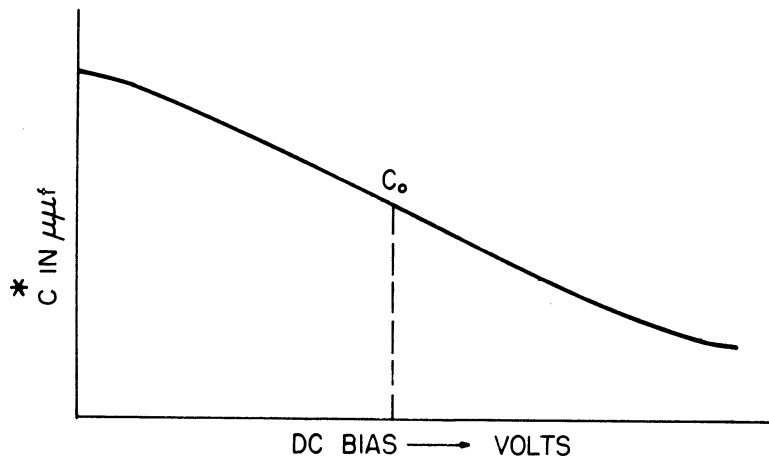


FIG. 1. BASIC WIDE RANGE TUNING CIRCUIT

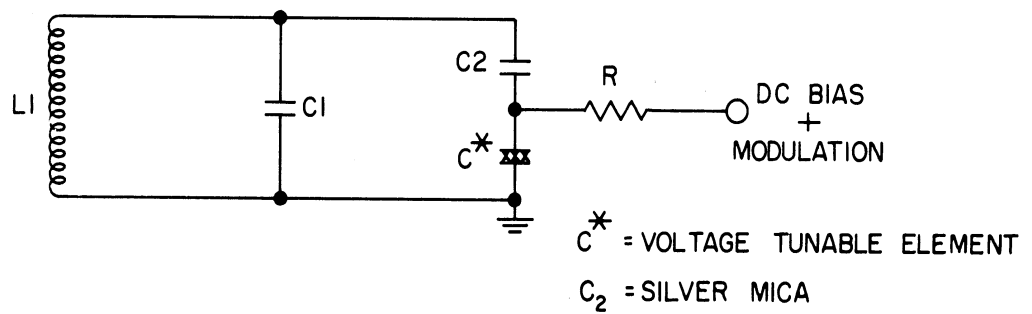


FIG. 2. BASIC FM CIRCUIT

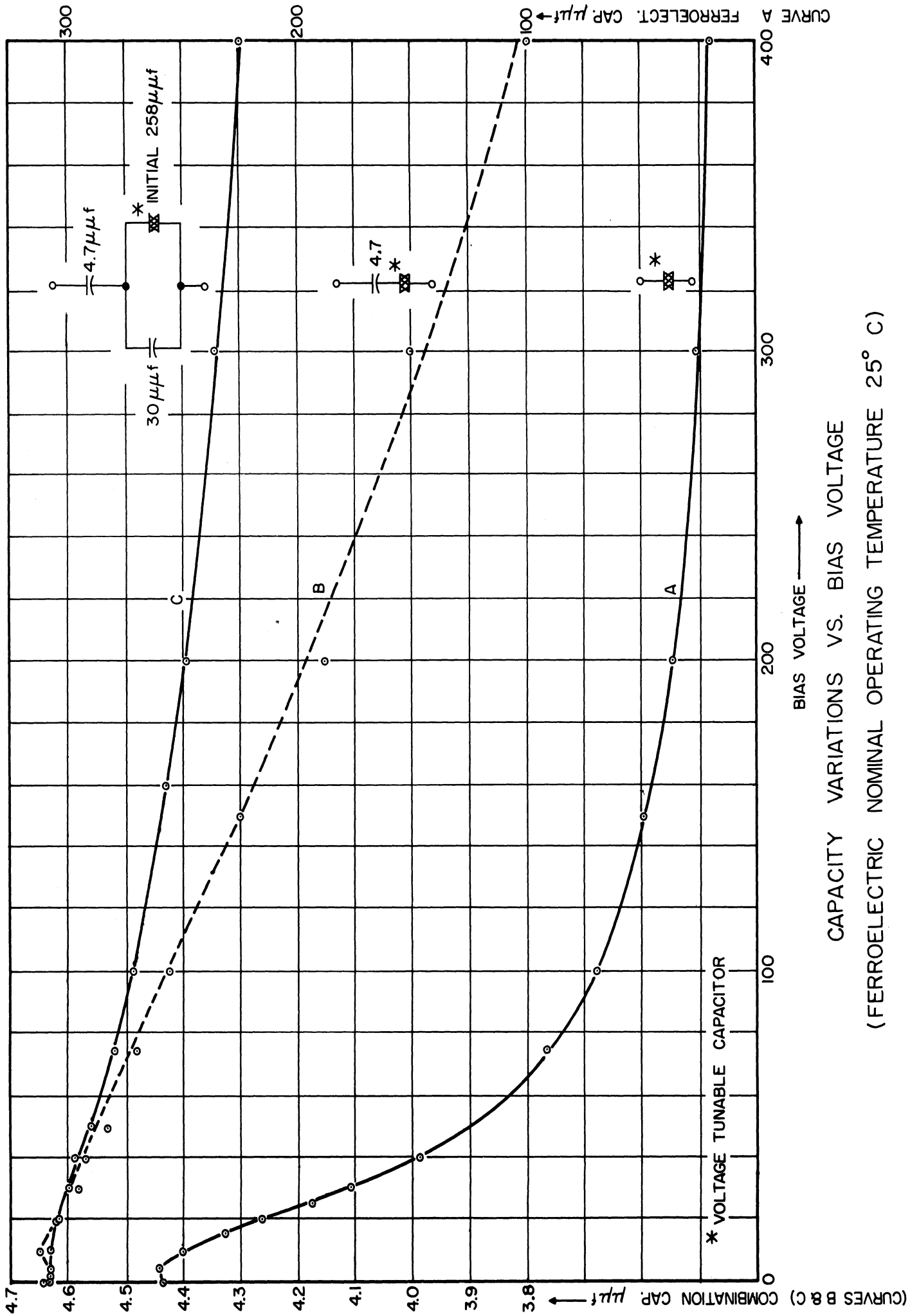
$$Q = Q_v \frac{C_2 + C^*}{C_2}$$

where Q_v is the Q of C^* .

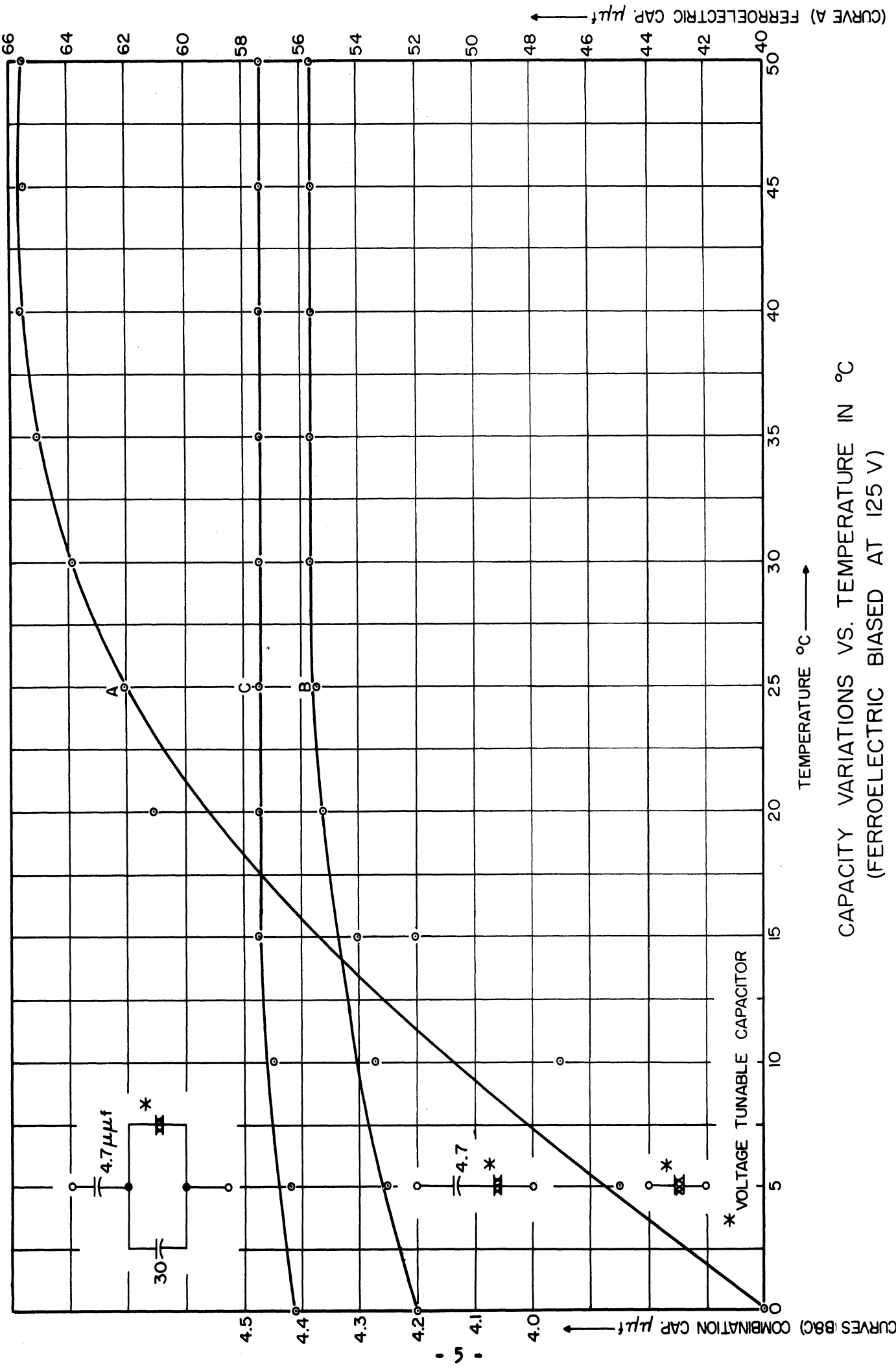
If C^* is very much larger than C_2 , as it is in the practical case, the effective Q of the circuit is greatly improved.

The actual curve of capacity variation vs voltage of the modulating element C^* is obtained from the ϵ -T-E surface² at the VFO nominal operating temperature (in this case 25°C) and replotted as shown in Fig. 3, curve a. Curve b of Fig. 3 is a plot of the series combination of C_2 and C^* , where C_2 has a constant value equal to 4.7 μf under all variations of voltage while C^* varies as shown. For the same voltage deviation (e.g., ± 40 volts either side of the 125 volt bias point) it is seen that the series combination changes only about .0025 $\mu\text{f}/\text{volt}$, while for the tunable element alone the change is about .3 $\mu\text{f}/\text{volt}$. To control the deviation even further, additional padding (e.g., 30 μf) can be shunted across C^* as shown by curve c, Fig. 3. For the given ± 40 volts deviation about the 125 volt bias level the series-parallel arrangement change is about .001 $\mu\text{f}/\text{volt}$.

The actual curve of capacity variation vs temperature of the modulating element (C^*) may also be obtained from the ϵ -T-E surface at the VFO bias voltage (in this case 125 volts) and replotted as shown in Fig. 4, curve a. Curve b of Fig. 4 is a plot of the series combination of C_2 and C^* , where C_2 remains constant with temperature at a value of 4.7 μf and C^* varies as shown. Curve c is a plot of the series-parallel arrangement where the 30 μf padder is also considered temperature insensitive. From the use of a series-parallel arrangement, it is seen that: (1) the linearity is improved; (2) the stability of the VFO is improved (i.e., changes in frequency due to temperature and bias variations are reduced); and (3) control of the



CAPACITY VARIATIONS VS. TEMPERATURE IN °C
(FERROELECTRIC BIASED AT 125 V)



TEMPERATURE $^{\circ}\text{C}$ \longrightarrow

(CURVE A) FERROELECTRIC CAP. $\mu\mu\text{f}$ \longleftarrow

(CURVES B&C) COMBINATION CAP. $\mu\mu\text{f}$ \longleftarrow

* VOLTAGE TUNABLE CAPACITOR

4.7 $\mu\mu\text{f}$ *

30 $\mu\mu\text{f}$

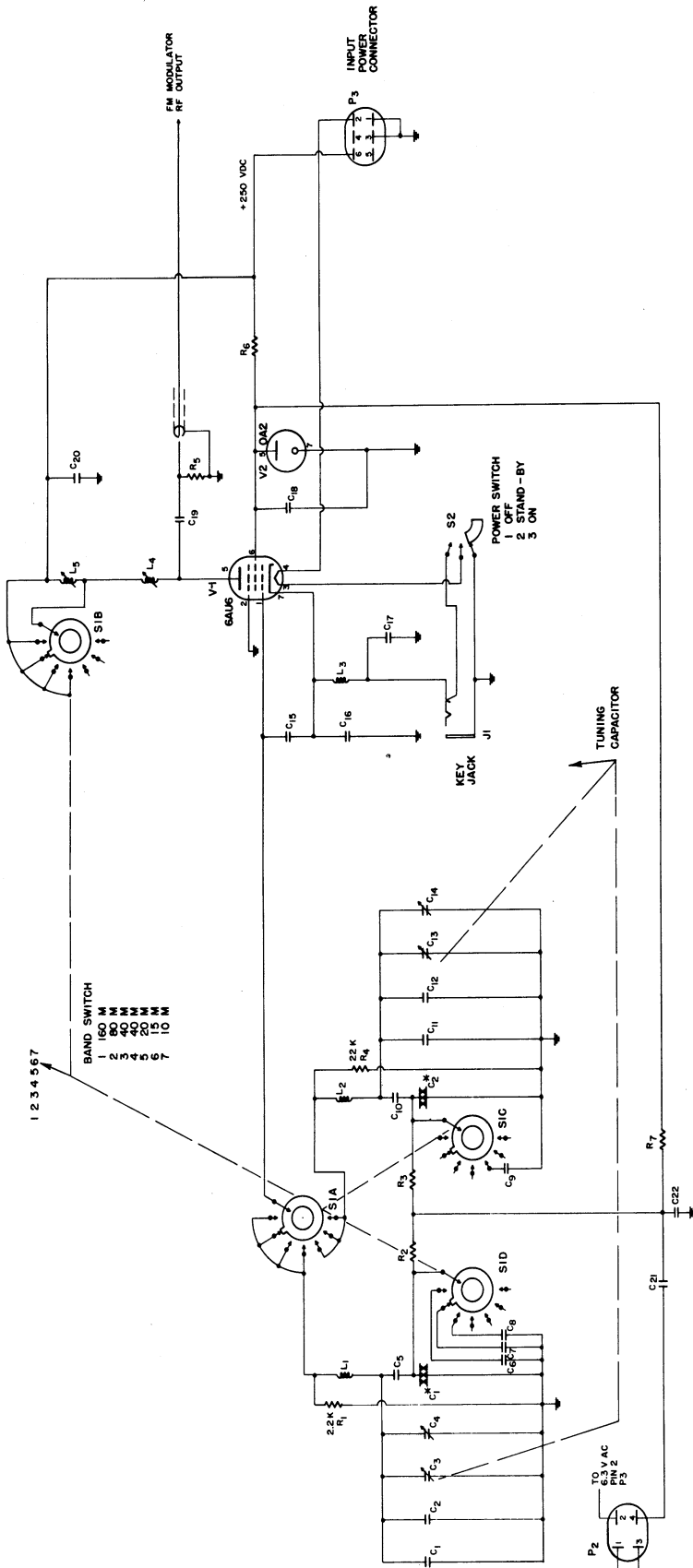
4.7 *

4.7 *

carrier frequency deviation due to the modulating signal is vastly facilitated, especially under band switching operation where a constant band to band modulation index is desired.

III. PRACTICAL CIRCUIT DESIGN CONSIDERATIONS

To demonstrate the feasibility of NFM, a typical commercially available all-band VFO was modified as shown in Fig. 5 and the photos of Figs. 6, 7 and 8. The basic circuit is the series-tuned Colpitts or "clapp" oscillator circuit. The tank circuit consists of two separate coils and two separate stator connections of a differential capacitor to develop the basic output frequencies. The basic output frequency in range 1 is 1.75 mc, doubling to 3.5 mc and quadrupling to 7 mc. The basic output frequency in range 2 is 7 mc, doubling to 14 mc, tripling to 21 mc and quadrupling to 28 mc. Padder capacitors are placed in parallel with the sections of the differential tuning capacitor for adjustment. A series arrangement, consisting of a 7.5 μf silver mica capacitor and a 200 μf ferroelectric capacitor are connected across range 1 of the tank circuit, while a second series arrangement, 3.7 μf silver mica capacitor and a 200 μf ferroelectric capacitor, is connected across range 2 of the tank circuit. According to FCC regulations for NFM, the channel width should not exceed twice the highest audio frequency in the modulating signal; therefore, based on an upper audio limit of 3 kc, the channel width should not exceed 6 kc. In band switching operation the modulation index is multiplied by the same factor that the carrier frequency is multiplied by; therefore, if the basic output frequency is 7 mc, for example, with a frequency deviation of 2 kc, then the output at 28 mc will have a deviation of 4×2 kc or 8 kc which is far too great.



PARTS LIST

Designation	Part Number	Quantity	Notes
C1	1.7 mfd	1	
C2	22	1	
C3	11 mfd MAX	1	
C4	4.5 - 50 mfd	1	
C5	3-7 mfd	1	
C6	56 mfd	1	
C7	47 mfd	1	
C8	20 mfd	1	
C9	10 mfd	1	
C10	10 mfd	1	
C11	33 mfd	1	
C12	35 mfd MAX	1	
C13	4.5 - 50 mfd	1	
C14	51.0 mfd	1	
C15	0.005 mfd	1	
C16	100 mfd	1	
C17	0.1 mfd	1	
C18	400 mfd	1	
C19	50 mfd	1	
C20	50 mfd	1	
C21	50 mfd	1	
C22	50 mfd	1	
C23	50 mfd	1	
C24	50 mfd	1	
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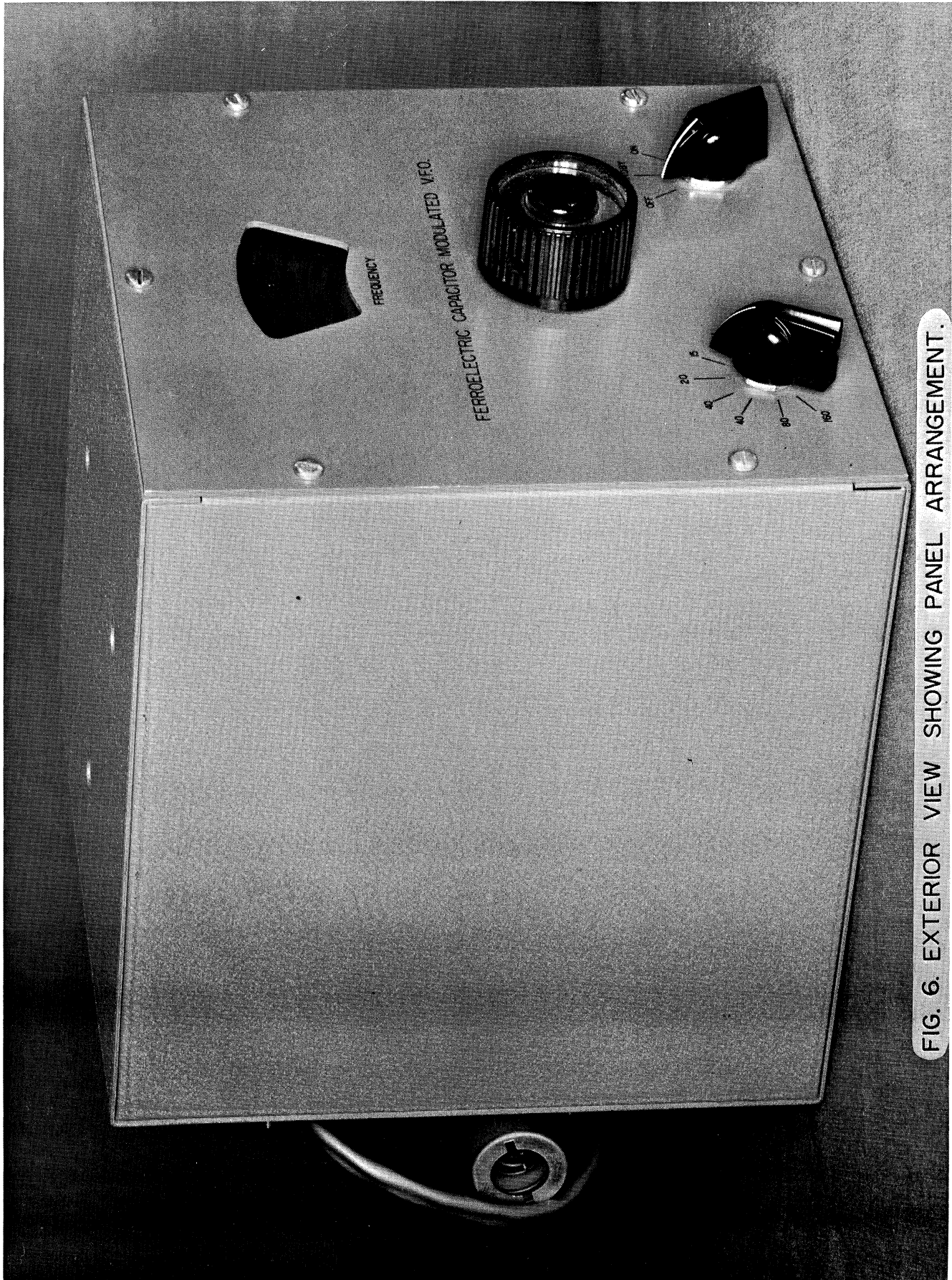


FIG. 6. EXTERIOR VIEW SHOWING PANEL ARRANGEMENT.

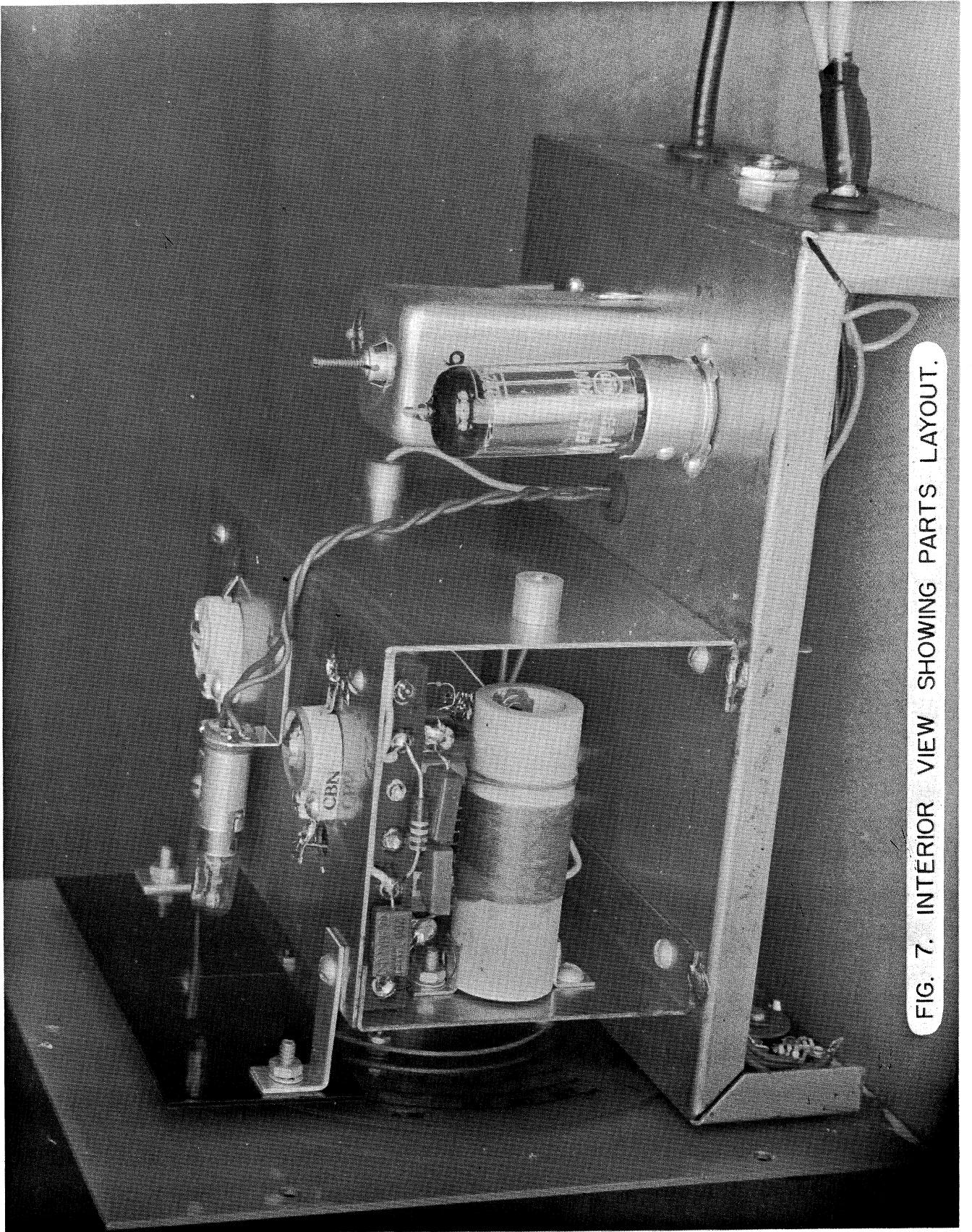


FIG. 7. INTERIOR VIEW SHOWING PARTS LAYOUT.

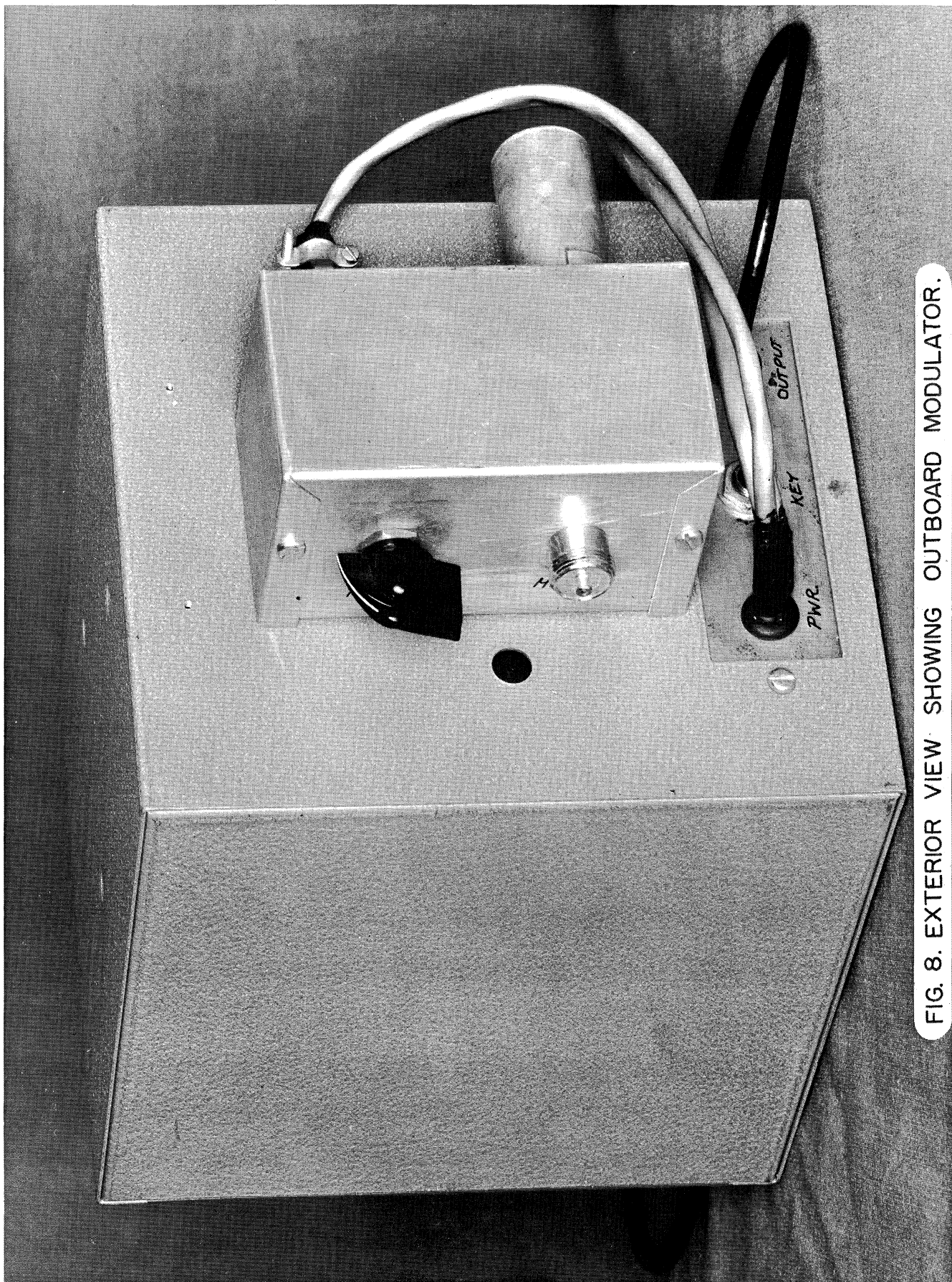


FIG. 8. EXTERIOR VIEW SHOWING OUTBOARD MODULATOR.

In order to maintain a constant deviation for a given modulation voltage, additional padding is shunted across the ferroelectric capacitor as the band is switched to higher frequencies. Since NFM is not allowed in the 1.75 mc band the basic frequency output was considered to be 3.5 mc and the deviation adjusted at this point to be ± 2 kc for a change in bias of ± 40 volts. For 7 mc operation a 30 μ f padder is switched across the ferroelectric capacitor as shown in the schematic. With this arrangement, deviation in the 1.75 mc band would be $1/2$ of the deviation obtained in the 3.5 mc band or ± 1 kc. The basic output frequency in range 2 is 7 mc, and the deviation is adjusted at this point to ± 2 kc for a change in bias of ± 40 volts. For operation at 14, 21, and 28 mc, additional padding capacitance is switched across the ferroelectric as shown.

The ferroelectric capacitor bias voltage is 150 volts and is taken from the plate of the OA2 regulator tube. The regulated voltage also represents the center of the linear portion of the voltage capacitance curve of the ferroelectric capacitor. Decoupling of the r-f from the bias is obtained by means of a one meg-ohm resistor, R7, connecting the plate of the regulator tube to the bias line and the 400 μ f capacitor C₂₂. The 330 K resistors, R₂ and R₃, and the 400 μ f capacitor C₂₂, serve as a filter to prevent r-f from getting back into the audio circuit. At the same time, the filter allows the audio variations at the plate of the audio amplifier to appear virtually unattenuated across the modulating capacitors.

The modulator section is a two stage audio amplifier utilizing a 12AX7 tube in a straightforward circuit. The control, R₁₂, at the input to the second audio section, serves as a deviation control. Since the amplitude variations at the plate of the audio amplifier determine the deviation of the oscillator, controlling the input signal to the audio amplifier also controls

the deviation of the oscillator. The optimum setting of this control will vary somewhat from band to band and is best determined by operational checks. The final setting should correspond to a deviation of somewhat less than 3 kc.

The modulator was constructed in a 2-1/4" x 2-1/4" x 4" mini-box and mounted outboard fashion on the rear of the VFO. Audio leads were brought into the VFO through shielded cables.

Since this particular VFO utilizes two tuned circuits in order to obtain greater bandspread, it was necessary to replace the existing band-switch with a four-section, 7-position, non-shorting type ceramic switch. In most VFO modifications, where the tank is a single-tuned circuit, band switch modifications will be much simpler. In any event, all modifications can be made by following the ideas presented in the foregoing sections.

Recalibration of the VFO should follow standard procedures as outlined in most Radio Handbooks³.

IV. PERFORMANCE CHARACTERISTICS

The oscillator frequency deviation on each band was measured by using a frequency counter in conjunction with a very stable frequency meter. The d-c bias on the ferroelectric capacitor was varied 40 volts either side of the 150 volt bias level and the deviation was noted. Two sample curves are shown in Fig. 9. Curve A (Fig. 9) shows the deviation in the fundamental frequency range (i.e., 7.2 mc) and curve B shows the deviation at the 4th harmonic (28.8 mc). Note that the modulation index in the two ranges is almost identical and that the modulator is linear over the entire range.

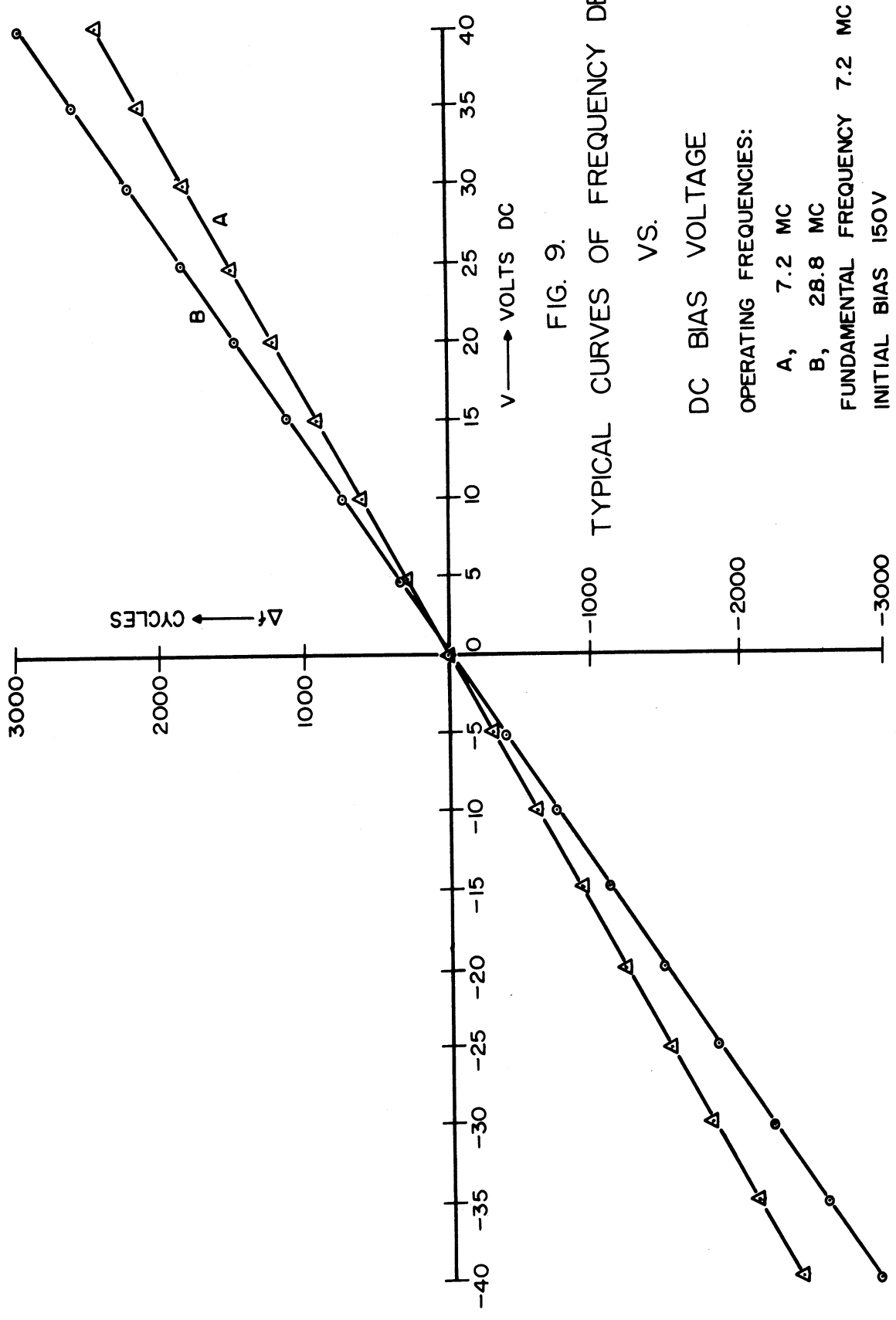


FIG. 9. TYPICAL CURVES OF FREQUENCY DEVIATION VS.

DC BIAS VOLTAGE

OPERATING FREQUENCIES:

A, 7.2 MC

B, 28.8 MC

FUNDAMENTAL FREQUENCY 7.2 MC

INITIAL BIAS 150V

The deviation is within allowable limits on all bands 3.5 through 30 mc.

As shown in Figure 10, the frequency stability of the VFO vs temperature, with and without the ferroelectrics in the circuit, is compared. The degradation of the VFO close to its normal operating temperature (39°C) is not serious. It should be noted that neither thermostating techniques nor additional compensating capacitors were used in this modification. If increased temperature stability is a requirement either of the above ideas could easily be incorporated.

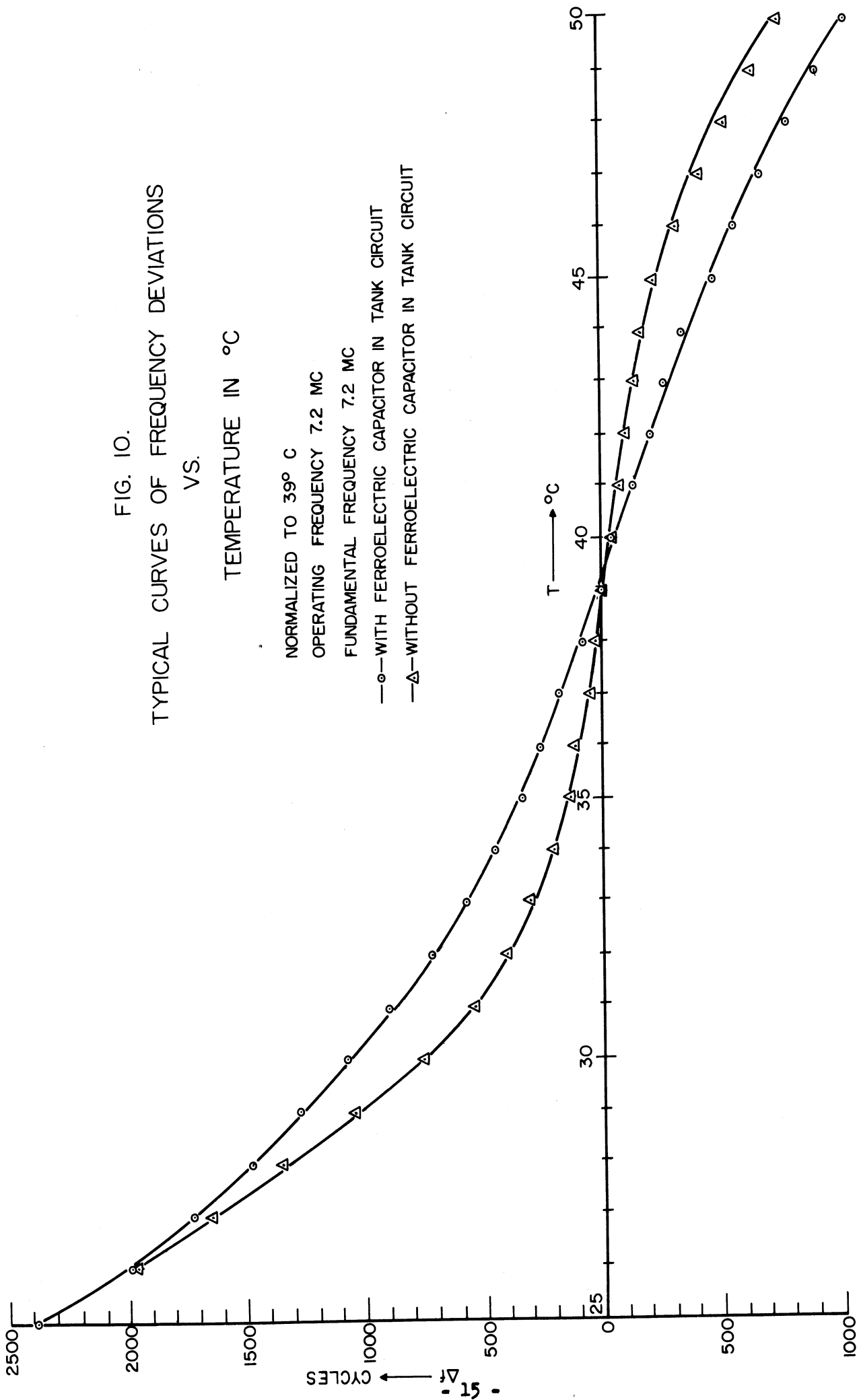
V. CONCLUSIONS

The use of ferroelectric capacitors as the modulating elements in a narrow-band FM system have proved to be quite useful in the VHF-UHF region where conventional reactance tube and phase-modulation methods are unwieldy. The chief advantage of narrow-band FM is that it reduces or eliminates certain types of interference to broadcast reception and is quite simple and inexpensive to construct using capacitance-modulation techniques. Detection of NFM on a typical AM receiver is quite easily accomplished by means of slope detection, i.e., moving off frequency slightly.

Use of this type of VFO in portable and mobile operation, where equipment must be restricted in size, should prove very helpful.

FIG. 10.
TYPICAL CURVES OF FREQUENCY DEVIATIONS
VS.
TEMPERATURE IN °C

NORMALIZED TO 39° C
OPERATING FREQUENCY 7.2 MC
FUNDAMENTAL FREQUENCY 7.2 MC
—○— WITH FERROELECTRIC CAPACITOR IN TANK CIRCUIT
—△— WITHOUT FERROELECTRIC CAPACITOR IN TANK CIRCUIT



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