THE UNIVERSITY OF MICHIGAN RESEARCH INSTITUTE
ANN ARBOR

DESIGN CONSIDERATIONS FOR A CAPACITANCE-MODULATED VFO

Technical Memorandum No. 60

Electronic Defense Group
Department of Electrical Engineering

By: T. W. Butler, Jr.

Approved by: C. B. Sharpe

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 Further investigation may make it desirable to have this report revised, superseded or withdrawn.

Project 2262

TASK ORDER NO. EDG-4
CONTRACT NO. DA-36-039 sc-63203
SIGNAL CORPS, DEPARTMENT OF THE ARMY
DEPARTMENT OF ARMY PROJECT NO. 3-99-04-042

September 1958

ACKNOWLEDGEMENT

The author wishes to acknowledge the assistance of Mr. Gordon A. Roberts in the design and testing of the capacity modulated VFO.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

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_1C_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:

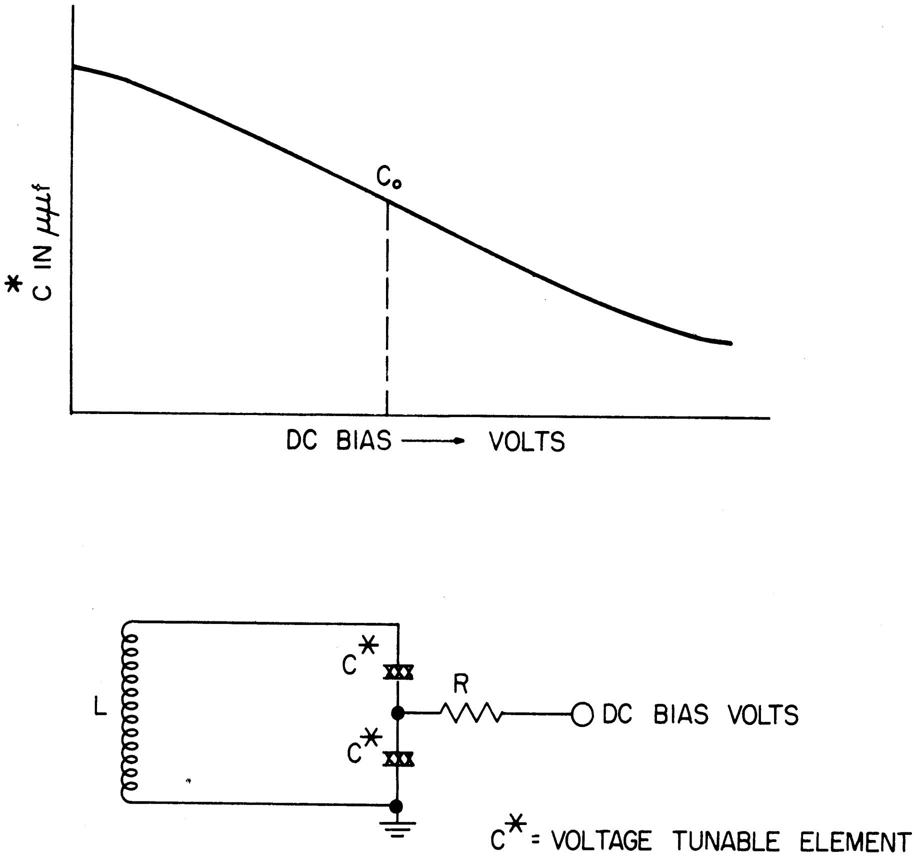


FIG. 1. BASIC WIDE RANGE TUNING CIRCUIT

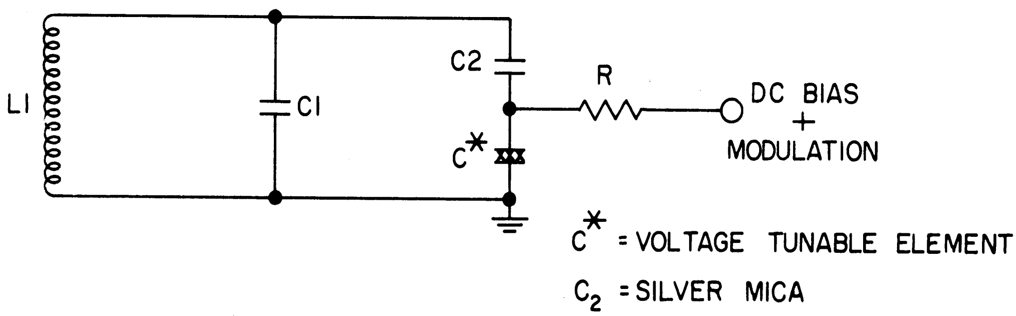


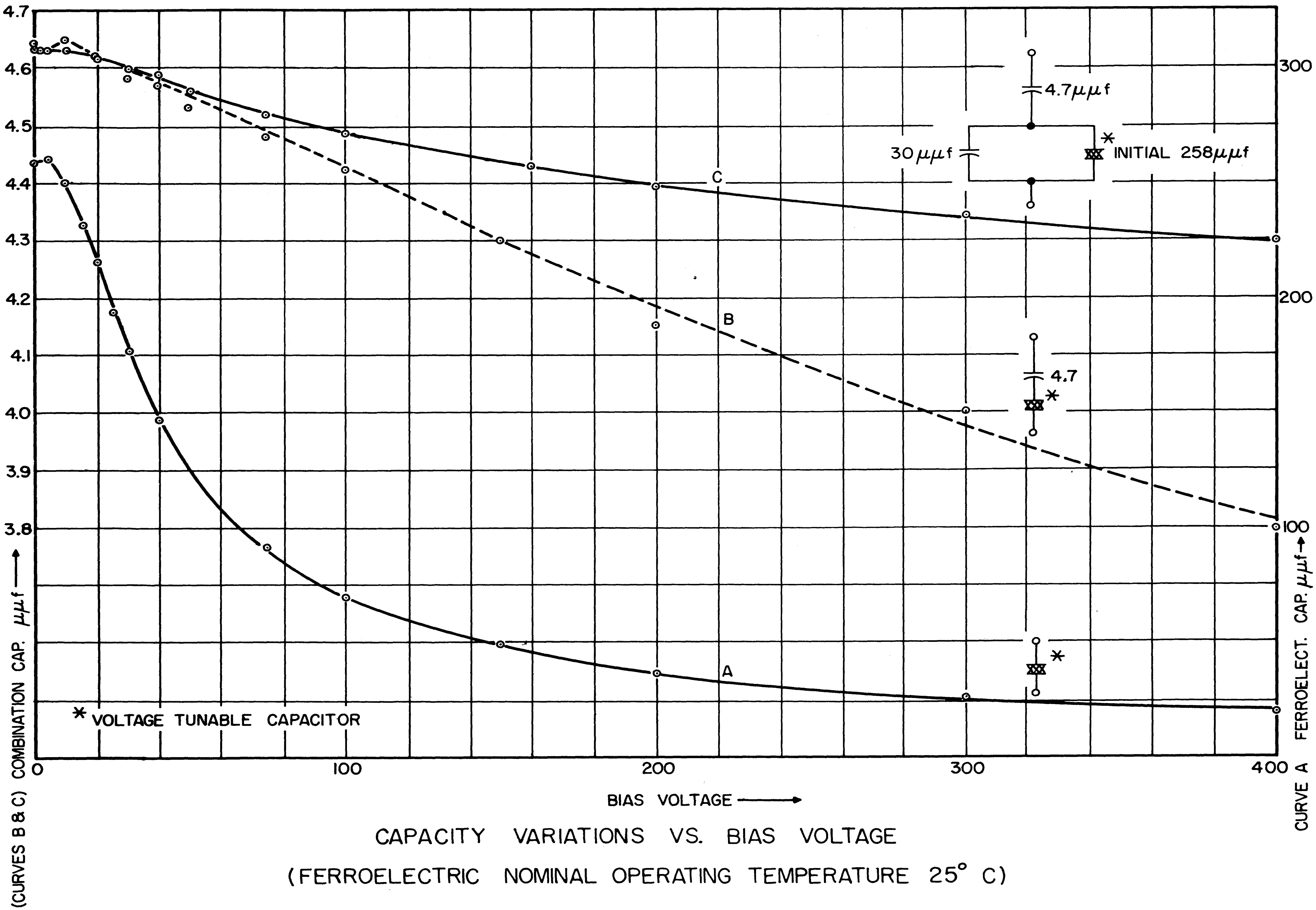
FIG. 2. BASIC FM CIRCUIT

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

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.

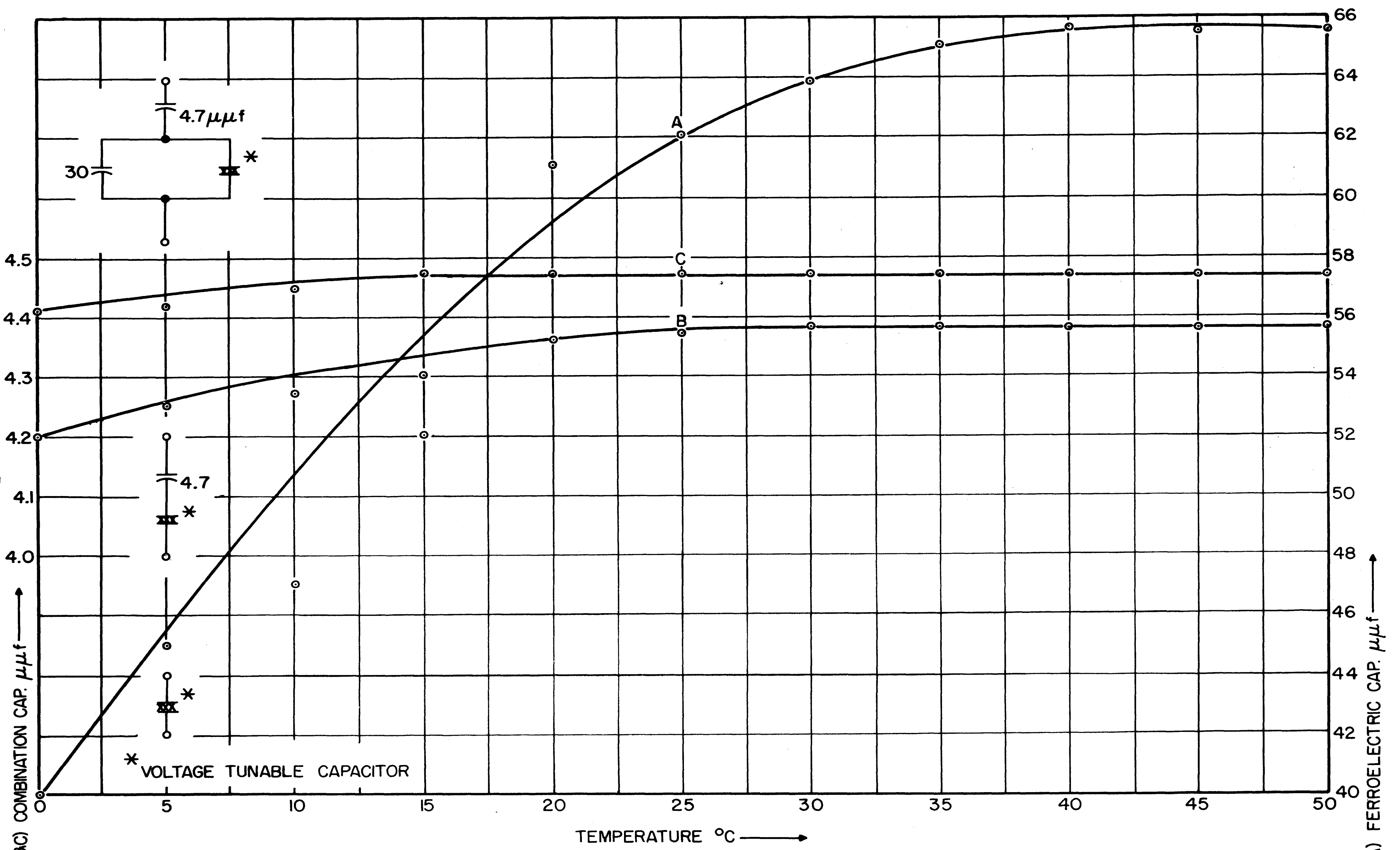
The actual curve of capacity variation vs voltage of the modulating element C* is obtained from the ε-T-E surface[2] at the VFO nominal operating temperature (in this case 25°C) and replotted as shown in Fig. 3, curve a. Curve b of Fig. 3 is a plot of the series combination of C_2 and C^*, where C_2 has a constant value equal to 4.7 μμf 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 μμf/volt, while for the tunable element alone the change is about .3 μμf/volt. To control the deviation even further, additional padding (e.g., 30 μμf) 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 μμf/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 μμf and C* varies as shown. Curve c is a plot of the series-parallel arrangement where the 30 μμf 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. BIAS VOLTAGE

(FERROELECTRIC NOMINAL OPERATING TEMPERATURE 25° C)

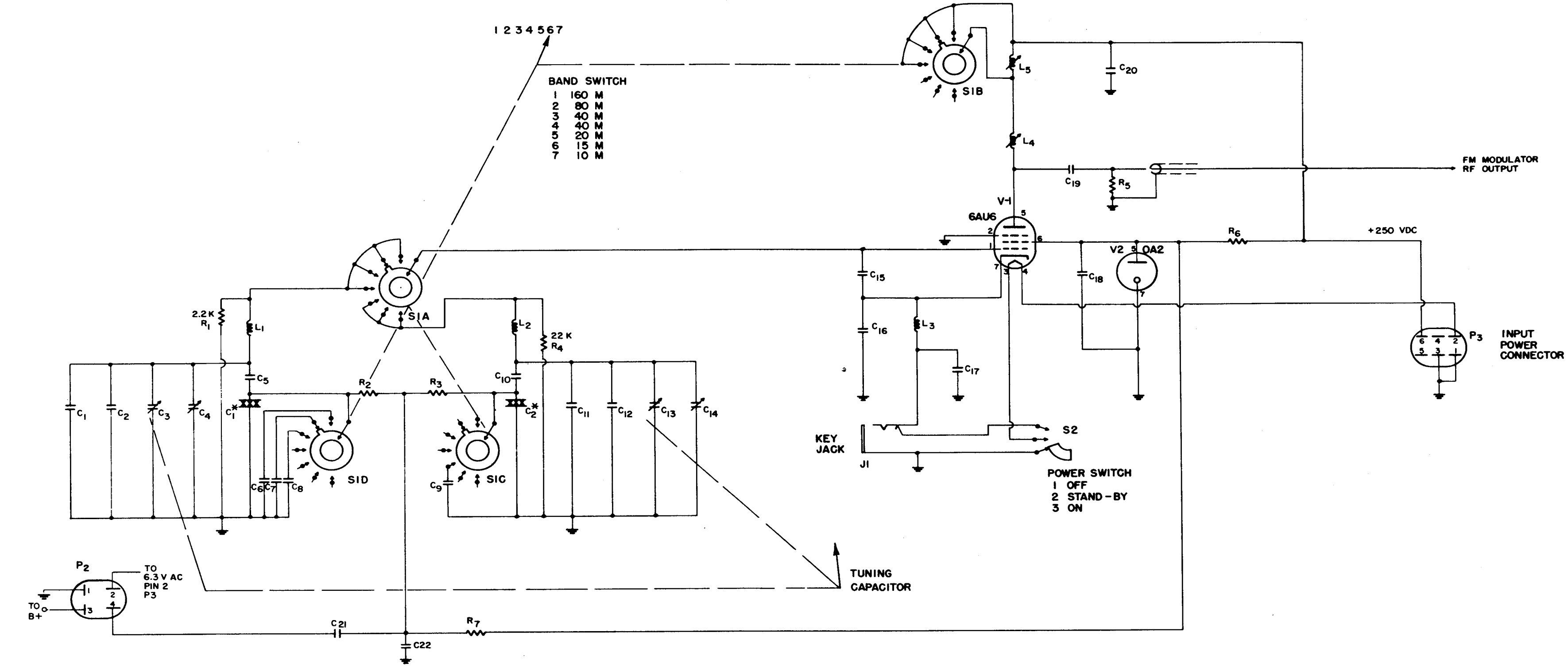


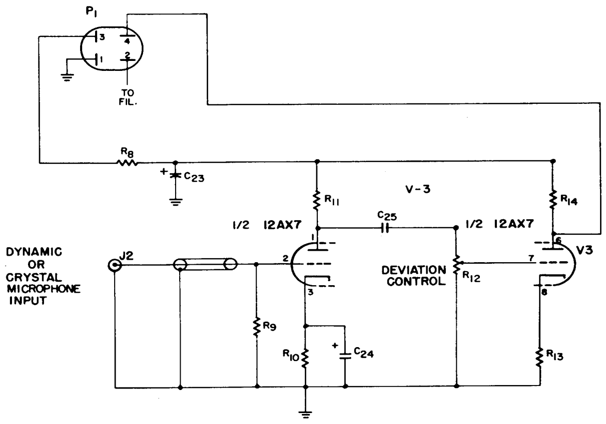
CAPACITY VARIATIONS VS. TEMPERATURE IN °C
(FERROELECTRIC BIASED AT 125 V)

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 μμf silver mica capacitor and a 200 μμf ferroelectric capacitor are connected across range 1 of the tank circuit, while a second series arrangement, 3.7 μμf silver mica capacitor and a 200 μμf 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 x 2 kc or 8 kc which is far too great.





MODULATOR AMPLIFIER

PARTS LIST

Capacitors

C_1	4.7 µµfd	CERAMIC N750
C_2	22 µµfd	SILVER MICA
C_3	11 µµfd MAX	TUNING CAPACITOR
C_4	4.5 - 25 µµfd	CERAMIC TRIMMER NPO
C_5	3.7 µµfd	CERAMIC NPO (1.5 µµfd and 2.2 µµfd in parallel)
C_6	56 µµfd	SILVER MICA
C_7	47 µµfd	SILVER MICA
C_8, C_9	30 µµfd	SILVER MICA
C_{10}	7.5 µµfd	SILVER MICA (2-15's IN SERIES)
C_{11}	10 µµfd	CERAMIC N750
C_{12}	33 µµfd	SILVER MICA
C_{13}	35 µµfd MAX	TUNING CAPACITOR
C_{14}	4.5 - 25 µµfd	CERAMIC TRIMMER NPO
C_{15}, C_{16}	510 µµfd	SILVER MICA
C_{17}, C_{18}, C_{20}	0.005 µfd	GENERAL PURPOSE CERAMIC
C_{19}	100 µµfd	SILVER MICA
C_{21}	0.1 µfd	METALIZED PAPER 400 VOC
C_{22}	400 µµfd	SILVER MICA
C_{23}	20 µfd	450 VDC ELECTROLYTIC
C_{24}	50 µfd	25 VDC ELECTROLYTIC
C_{25}	0.05 µfd	METALIZED PAPER 400 VDC
C_1*, C_2*	250 µµfd	UOF M FERROELECTRIC MODULATING CAPACITOR

Resistors

R_1	2.2 k	1/2 w
R_2, R_3	330 k	1/2 w
R_4	22 k	1/2 w
R_5, R_8	47 k	1/2 w
R_6	15 k	10 w
R_7, R_9	1 MEG	1/2 w
R_{10}, R_{13}	2.2 k	1/2 w
R_{11}, R_{14}	100 k	1/2 w
R_{12}	0.5 MEG	POT.

Inductors

L_1	9.3 µh	HIGH STABILITY INDUCTORS IN THE TUNED CIRCUIT.
L_2	115 µh	
L_3	1 mh	
L_4	5 - 15 µh	
L_5	50 - 150 µh	

Miscellaneous

V_1	6AU6
V_2	OA2 - WA
V_3	12AX7
S_1	4 POLE 7 POSITION NON SHORTING SWITCH CENTRALAB PA-2013
S_2	SPECIAL 3 POSITION SWITCH
J_1	MALLORY TYPE 2A JACK
J_2	AMPHENOL 75-CL-PCIM
P_1	JONES P-304-FP
P_2	JONES S-304-CCT
P_3	JONES P-306-CCT

FIG. 5. FM CAPACITY MODULATED VFO

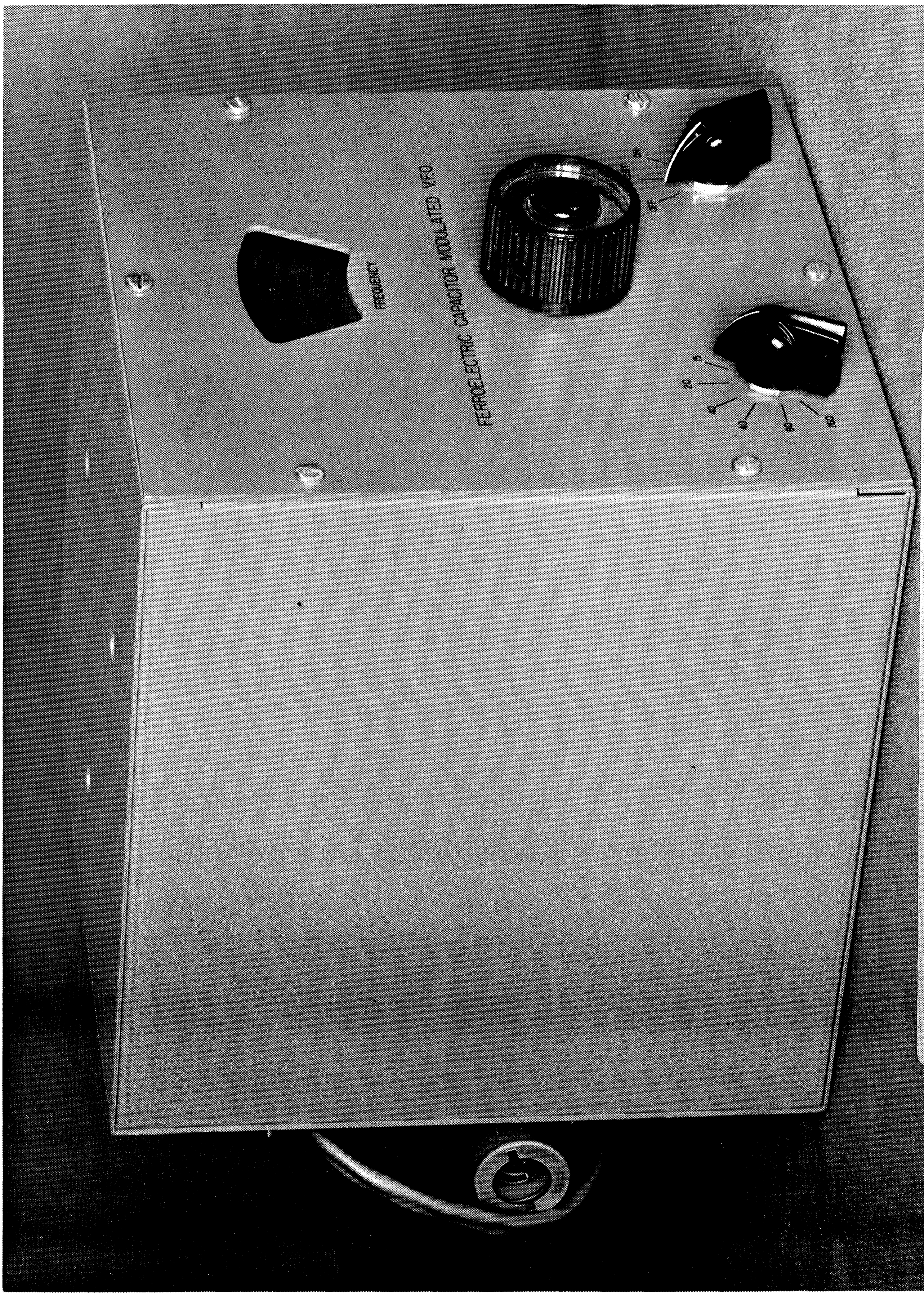


FIG. 6. EXTERIOR VIEW SHOWING PANEL ARRANGEMENT.

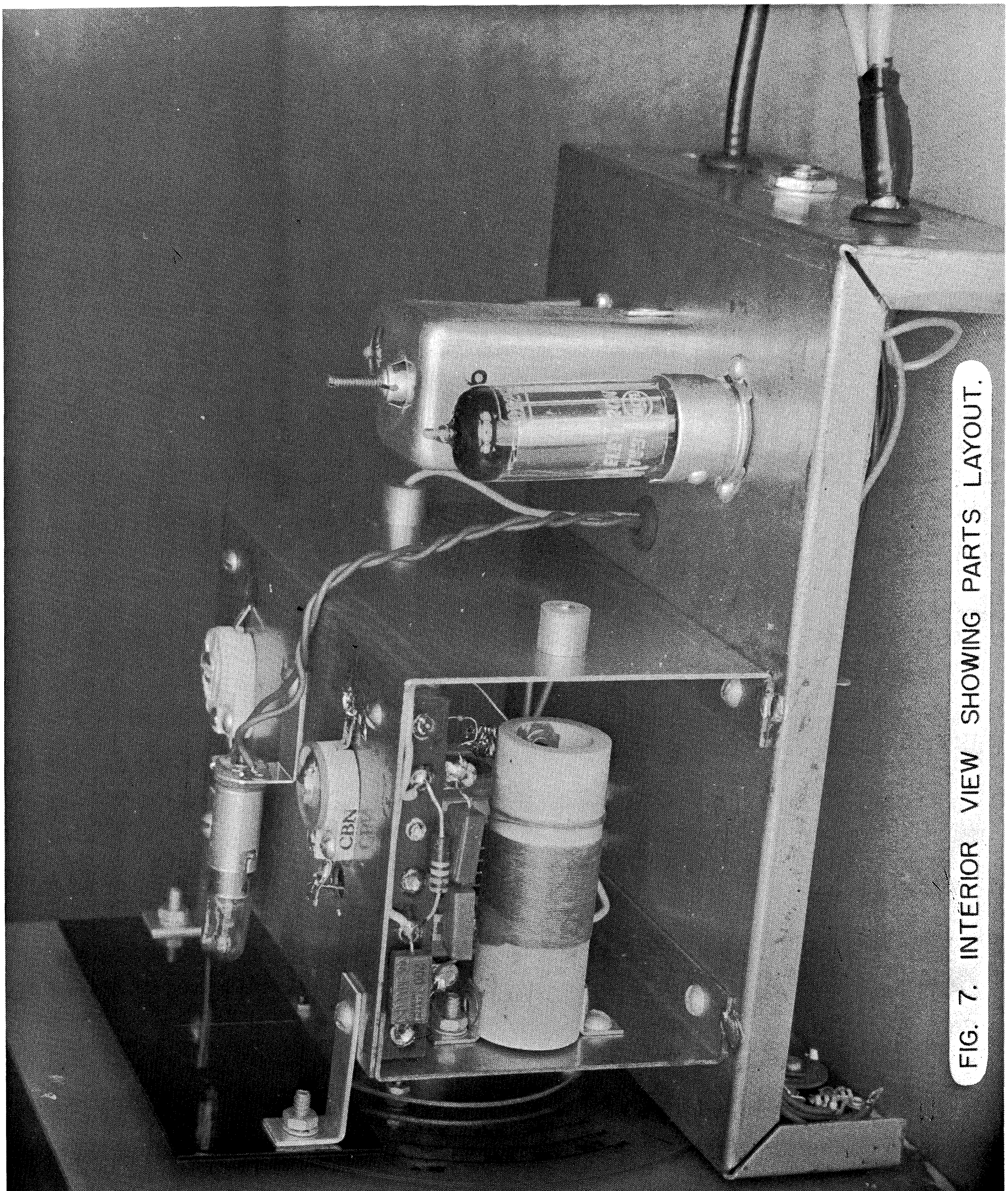


FIG. 7. INTERIOR VIEW SHOWING PARTS LAYOUT.

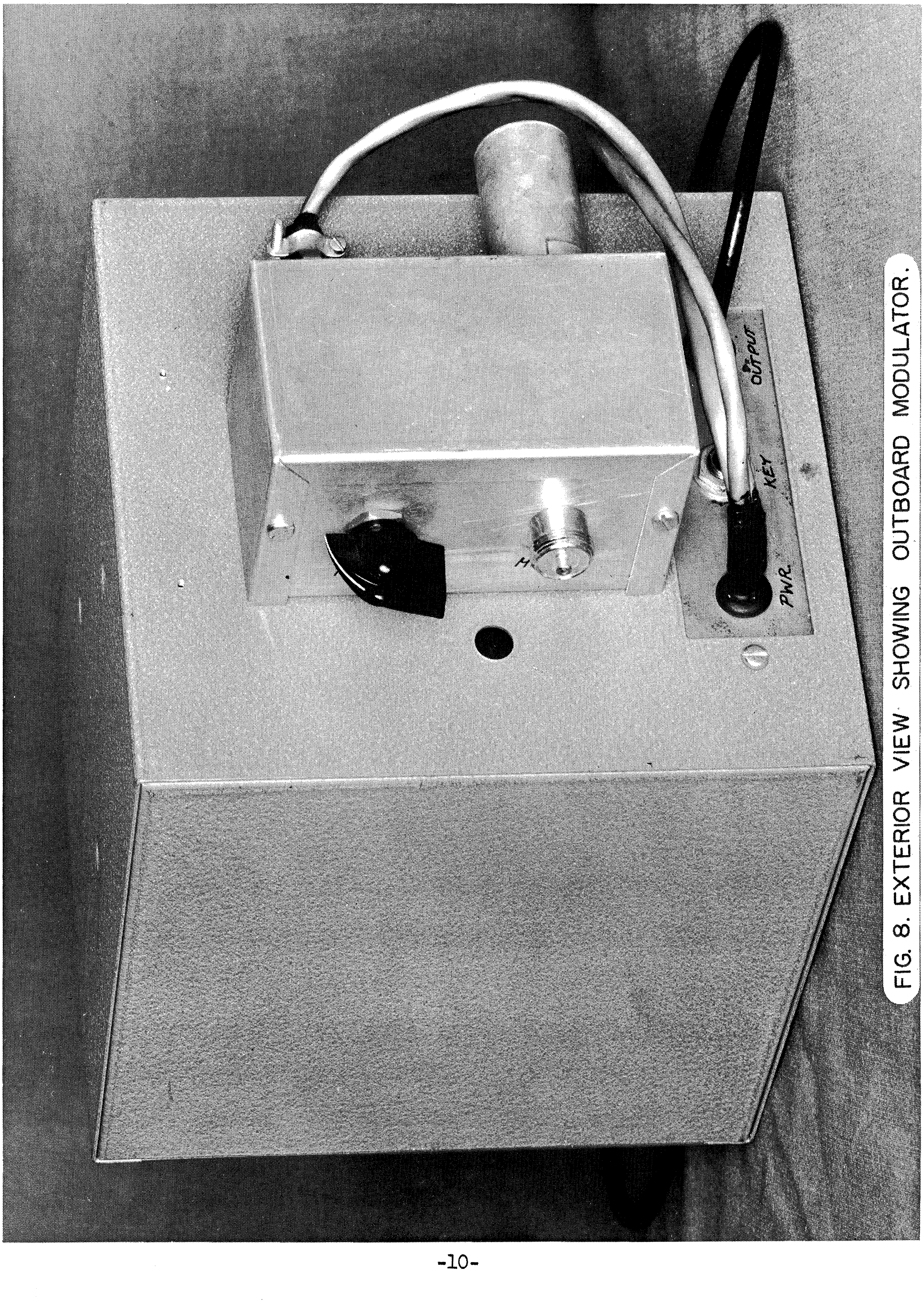


FIG. 8. EXTERIOR VIEW SHOWING OUTBOARD MODULATOR.

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 µµf 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 µµf capacitor C_{22}. The 330 K resistors, R_2 and R_3, and the 400 µµf capacitor C_{22}, 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, R_{12}, 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 Handbooks[3].

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.

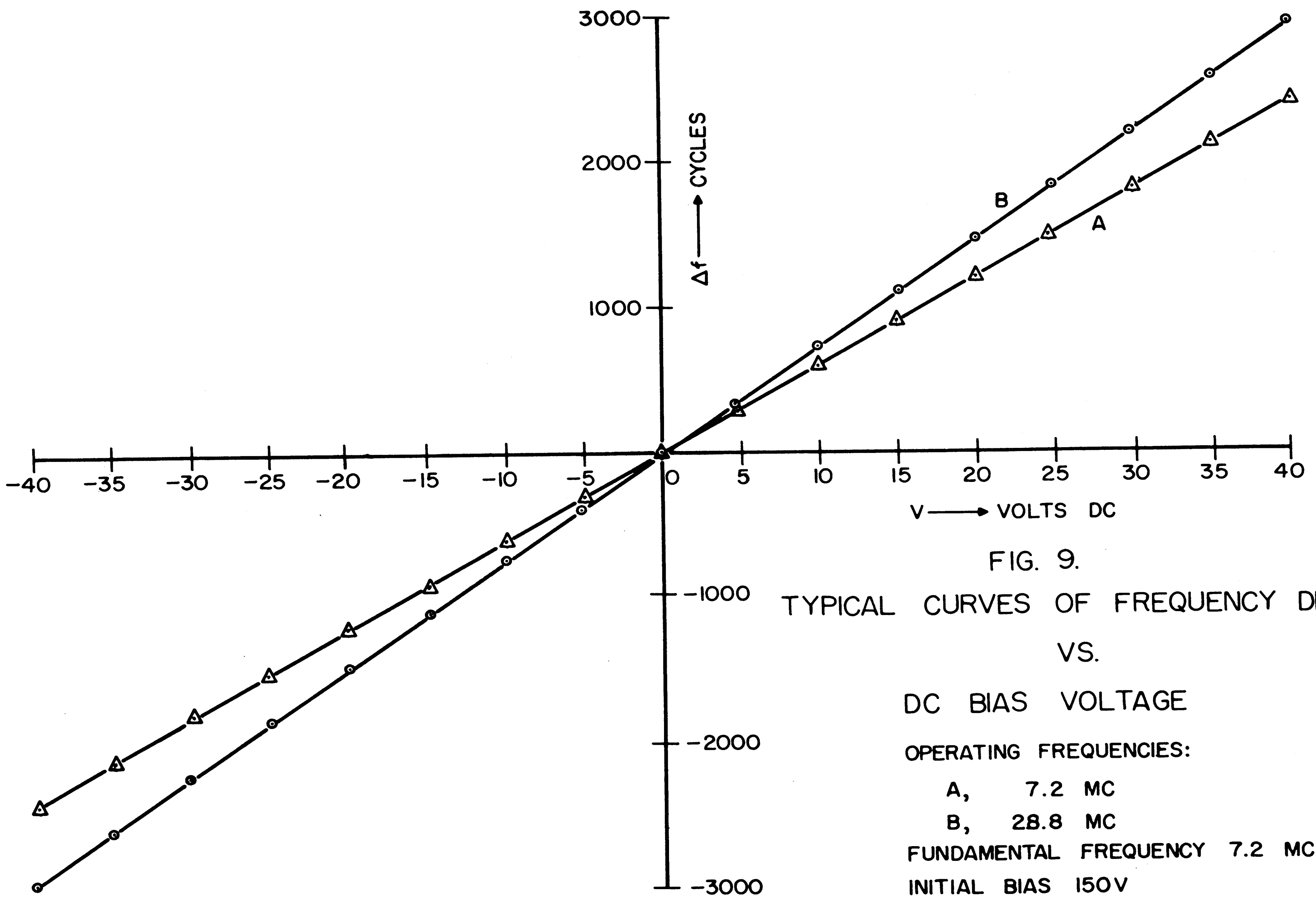


FIG. 9.

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.

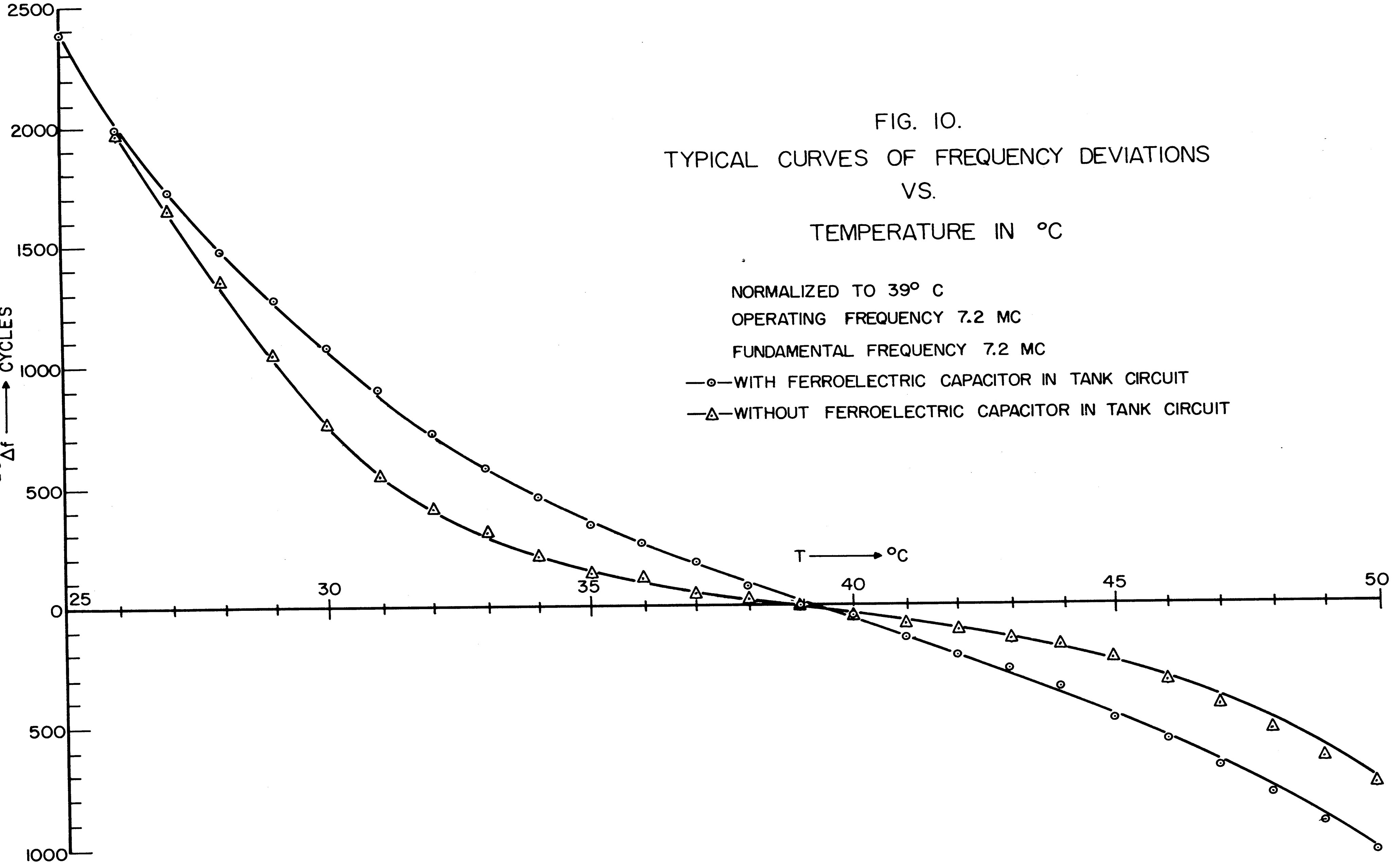


FIG. 10.

TYPICAL CURVES OF FREQUENCY DEVIATIONS
VS.
TEMPERATURE IN °C

REFERENCES

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

2. T. W. Butler, Jr., "Electric Tuned, Capacitor-Modulated VHF Oscillator," Electronic Defense Group, Technical Memorandum No. 59, University of Michigan Research Institute.

3. "Radio Amateurs Handbook," pp. 145, 34th Edition, 1957, A.R.R.L., West Hartford, Connecticut.

DISTRIBUTION LIST

1 Copy	Document Room Stanford Electronic Laboratories Stanford University Stanford, California
1 Copy	Commanding General Army Electronic Proving Ground Fort Huachuca, Arizona Attn: Director, Electronic Warfare Department
1 Copy	Chief, Research and Development Division Office of the Chief Signal Officer Department of the Army Washington 25, D. C. Attn: SIGEB
1 Copy	Chief, Plans and Operations Division Office of the Chief Signal Officer Washington 25, D. C. Attn: SIGEW
1 Copy	Countermeasures Laboratory Gilfillan Brothers, Inc. 1815 Venice Boulevard Los Angeles 6, California
1 Copy	Commanding Officer White Sands Signal Corps Agency White Sands Proving Ground Las Cruces, New Mexico Attn: SIGWS-EW
1 Copy	Commanding Officer White Sands Signal Corps Agency White Sands Proving Ground Las Cruces, New Mexico Attn: SIGWS-FC
1 Copy	Commanding Officer Signal Corps Electronics Research Unit 9560th USASRU Mountain View, California

65 Copies	Commanding Officer USASRDL Fort Monmouth, New Jersey FOR - USASRDL Accountable Officer Inspect at Destination File No. 22824-PH-54-91(1701)
1 Copy	H. W. Farris University of Michigan Research Institute Ann Arbor, Michigan
1 Copy	Technical Documents Services Willow Run Laboratories University of Michigan Ypsilanti, Michigan
11 Copies	Electronic Defense Group Project File University of Michigan Ann Arbor, Michigan
1 Copy	University of Michigan Research Institute Project File Ann Arbor, Michigan