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WIDE RANGE TUNING METHODS AND TECHNIQUES APPLICABLE TO SEARCH RECEIVERS

QUARTERLY PROGRESS REPORT NO. 10, TASK ORDER NO. EDG-4
Period Covering October 1, 1953 to December 31, 1953

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ABSTRACT

This report reviews the progress of the Electronic Defense Group on Task Order EDG-4, for the quarter ending December 31, 1953. Tests have begun on magnetic cores produced under Task 6 to determine their suitability for magnetic tuning. Equipment for quantitative Barkhausen noise measurement in ferroelectric specimens is nearing completion, and is discussed briefly. Several VHF oscillator circuits have been investigated for dielectric tuning and the results are summarized. Power supplies and test equipment for the magnetron program are nearing completion.

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1. PURPOSE

The purpose of this report is to summarize the progress made by the Electronic Defense Group in the Study of wide-range tuning methods and techniques applicable to search receivers during the last quarter of 1953.

2. PUBLICATIONS AND REPORTS

Mr. H. Diamond attended the Rutgers University symposium on ferroelectric ceramics on November 14. He also visited the Bell Telephone Laboratories in Murray Hill, New Jersey.

Mr. H. Diamond and Dr. L. W. Orr visited the Glenco Corporation, Metuchen, New Jersey, on December 15, 1953 to discuss the manufacture of special ceramic capacitors for ferroelectric tuning.

3. FACTUAL DATA

3.1 Use of Ferromagnetic and Ferroelectric Materials in the Tuning of RF Components

3.1.1 Ferromagnetic Materials Study (L. W. Orr and L. C. Beavis)

3.1.1.1 Magnetic Core Tests in the 1 - 10 Megacycle Range. For magnetic tuning, a magnetic core must have reasonable values of Q and an adequate variation of permeability with the application of modest values of control field. Because many cores have a rather low value of Q (less than 3) in certain frequency ranges a method of low Q measurement was worked out. Because of certain instrumentation difficulties, this method is not yet on a production testing basis.

3.1.1.2 Magnetic Core Tests in the 100 Megacycle Range. A set of cores produced by Task 6 having composition similar to Ferramic E showed some indication of usefulness in this VHF region. By varying the firing schedule, different properties were obtained in various members of the set. Cores fired at low temperature tend to have moderate losses, low permeability and very little change in permeability with applied field. This is due to the fact that crystal growth is very small and permeability arises almost entirely from domain rotation rather than from wall motion.

Cores fired at higher temperatures tend to have excessively high losses at VHF because of wall motion effects and wall resonance, higher permeability, and larger change in permeability with applied field.

A testing schedule has been established for this set of cores. The one core tested to date (Type A-34-1) does not appear to be suitable for VHF tuning. When it was subject to a dc control field which varied from zero to 30 oersteds, (150 ampere turns on one inch OD core), the variation in permeability at 100 megacycles was barely perceptible. Under these conditions the Q varied from 6.0 at zero to 6.8 at 30 oersteds of control field.

3.1.2 Ferroelectric Materials Study.

3.1.2.1 Hysteresis in Pure Barium Titanate. (H. Diamond and L. W. Orr) Several specimens of pure crystaline barium titanate were kindly furnished by the Bell Telephone Laboratories, Murray Hill, New Jersey. Hysteresis loops were obtained on these specimens giving first hand information regarding temperature and loading effects. It was found, for example, that electrodes of silver paint loaded the surfaces of the crystal so that unnaturally fat P-E loops were produced. It was necessary to use very thin vacuum-deposited silver electrodes to avoid these loading errors. Specimens were plated in vacuum equipment in the Randall Laboratory of Physics.

Hysteresis loops for a 6 mil thick specimen of C-oriented barium titinate are shown in Fig. 1. It is quite rectangular at room temperature (Fig. 1a), but shows a double loop[1] above its Curie temperature (Fig. 1b). The circuit used to plot these loops is very similar to that previously reported.[2]

3.1.2.2 Barkhausen Noise Measurements in Ferroelectric Specimens. (M. Winsnes)

To study the Barkhausen noise in ferroelectric specimens, an analyzer is being constructed as shown by the block diagram, Fig. 2. A sinusoidal field is applied to the specimen by means of the high-voltage transformer and low-pass filter which give at least 70 db rejection of line transients and other noise above 5 kc. The high-pass filter passes the Barkhausen noise, but offers at least 70 db rejection of all power and noise voltage components below 10 kc. Attenuation characteristics of these filters are shown in Fig. 3.

Since the Barkhausen noise varies in a cyclic manner, depending upon the phase of the applied cyclic field,[3] a sampling technique is required in making quantitative measurements. The block shown as "Noise Measuring Equipment in Fig. 2 will consist of six sub-units as follows: (a) Gate Generator, (b) Gated Amplifier, (c) Thermocouple, (d) Chopper, (e) Tuned Amplifier and (f) Detector and Meter Indicator. Figure 4 shows the circuit of the Gate Generator and Gated Amplifier. This equipment permits the measurement of the noise energy over any desired small portion of the 60 cycle wave. This is performed by taking a small

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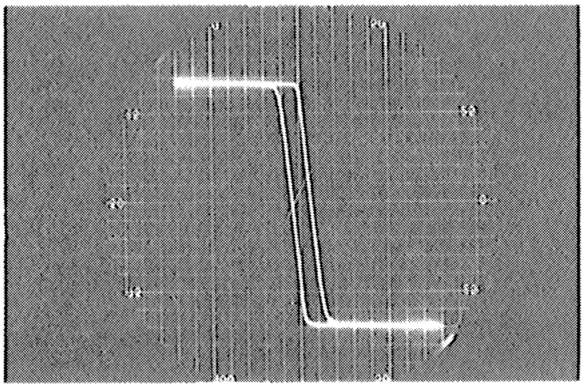
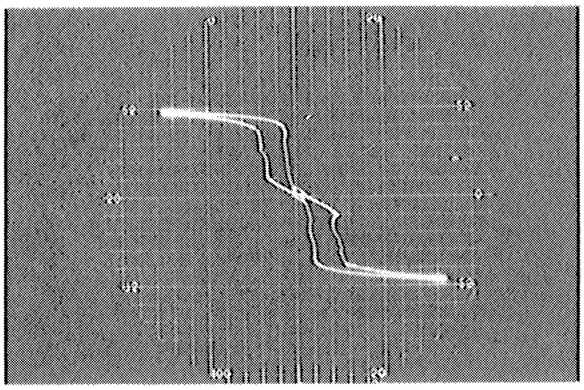
[1] This was reported by W. J. Merz, <u>Phys. Rev.</u>, V. 91, p. 513 (1953).

[2] Quarterly Progress Report No. 9, Task Order No. EDG-4, Fig. 2, Electronic Defense Group, Univ. of Mich., October 1953.

[3] <u>op. cit.</u>, footnote 2, Fig. 6, p. 13.



(a) AT 25°C.



(b) AT 115°C.

FIG. 1

HYSTERESIS IN BARIUM TITANATE CRYSTAL.

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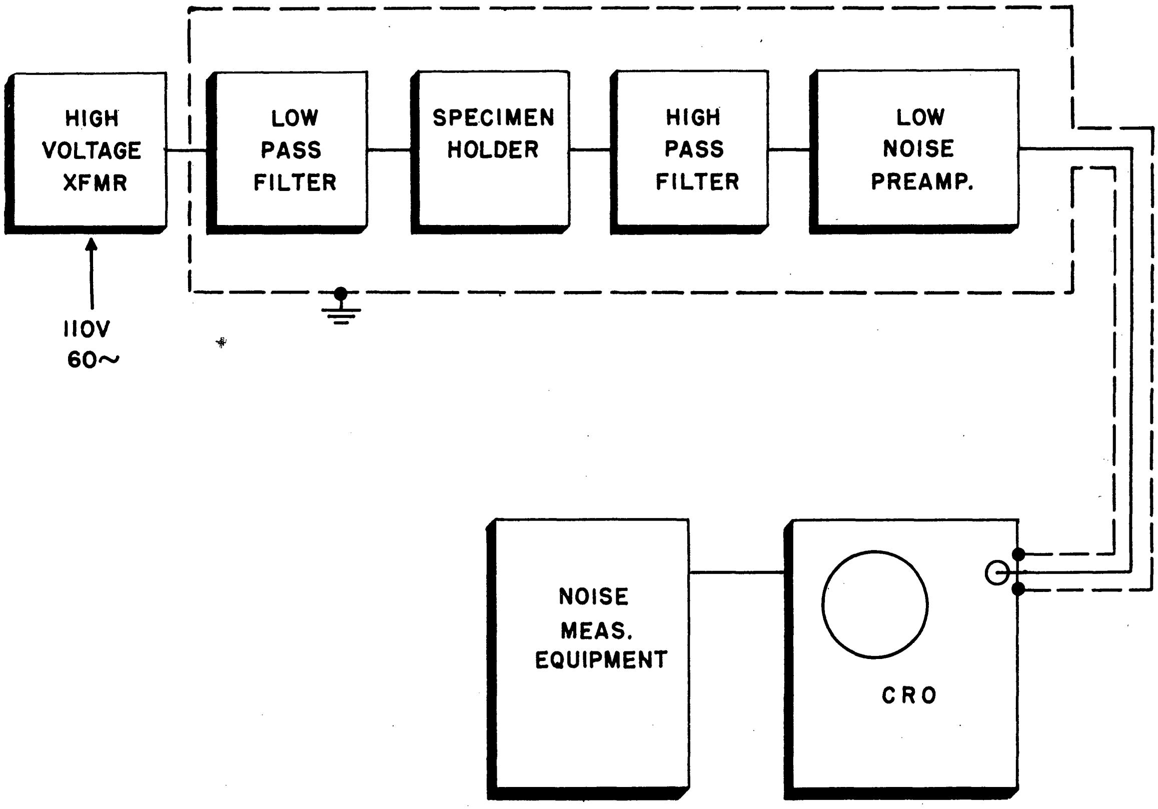

FIG. 2

BLOCK DIAGRAM
OF BARKHAUSEN NOISE ANALYSING EQUIPMENT.

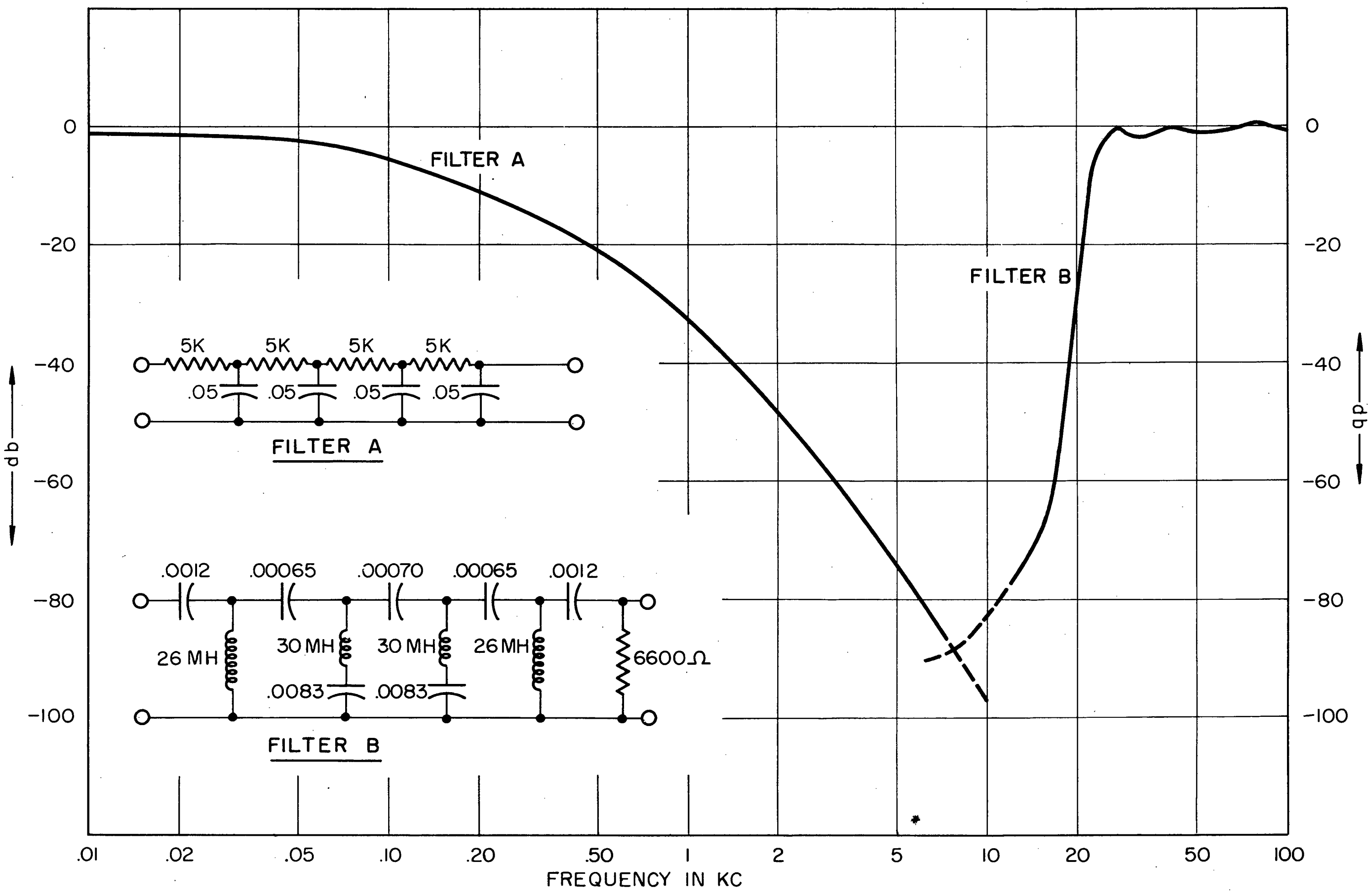

FIG. 3

FILTER CHARACTERISTICS FOR FERROELECTRIC BARKHAUSEN NOISE APPARATUS.

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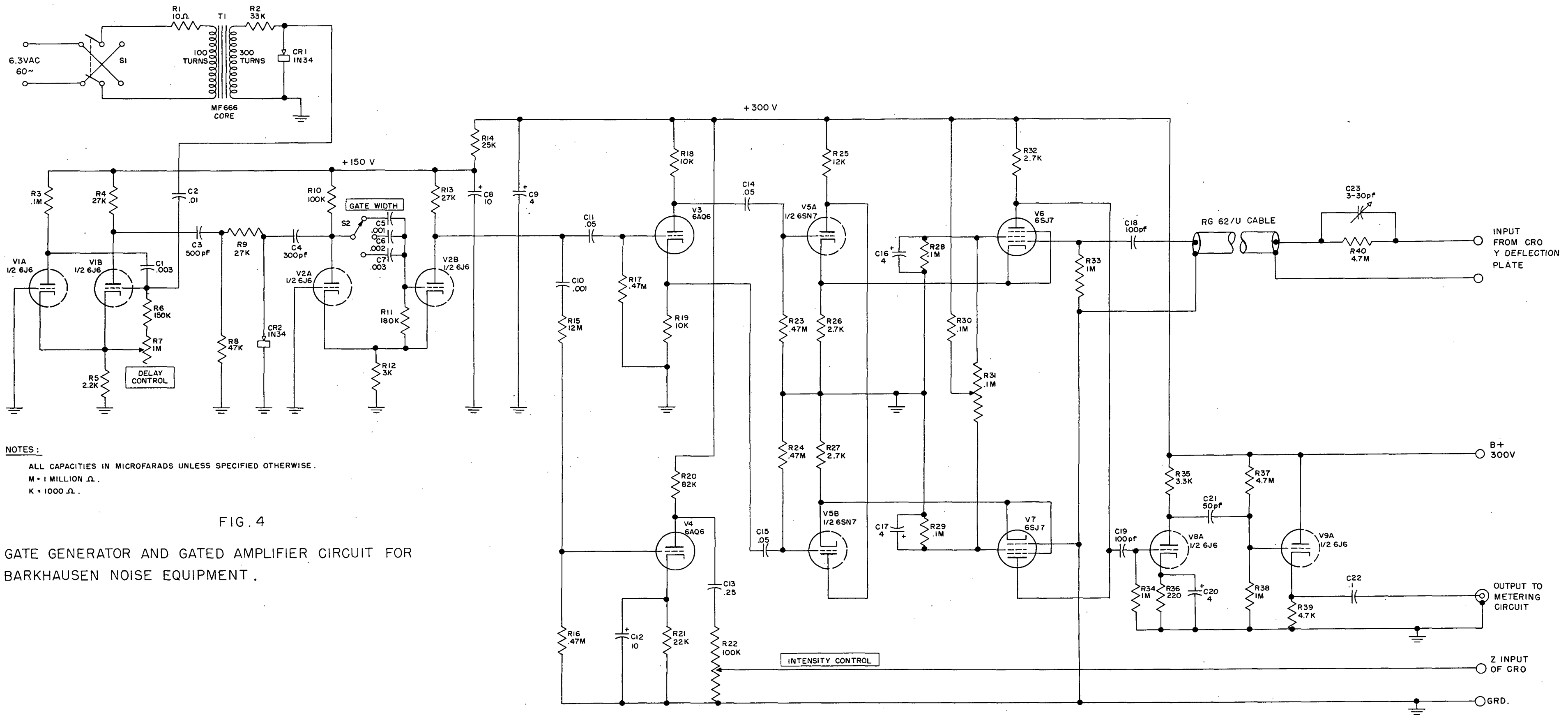

NOTES:
ALL CAPACITIES IN MICROFARADS UNLESS SPECIFIED OTHERWISE.
M = 1 MILLION Ω.
K = 1000 Ω.

FIG. 4

GATE GENERATOR AND GATED AMPLIFIER CIRCUIT FOR BARKHAUSEN NOISE EQUIPMENT.

sample of the noise from each cycle and averaging the result. To identify the phase position of the sample, a portion of the sampling gate voltage is used to intensify the trace on the oscilloscope.

Construction of these units is nearing completion. Several methods of squaring and metering the gated noise have been tried which proved unsatisfactory because of insufficient sensitivity or instability. The present method using a thermocouple appears to be satisfactory, and no major problems are anticipated.

3.1.3 Applications of Ferroelectric Materials.

3.1.3.1 Electric Tuned High Frequency Oscillators. (H. Diamond) A survey of various lumped-constant oscillator circuits suitable for electric tuning in the HF and VHF ranges is being made. Breadboard models were constructed in each case, and representative results to date are shown in Table I.

TABLE I

Representative Results on Electric Tuned HF Oscillators

Freq. Range mc	FM* %	Range of Bias Field volts/mil	Capacitive Circuit Element **	Type of Oscillator Circuit	Tube Type	Tube g_m μmhos
50 - 100	100	0 - 100	A	Harley	6AH6	11,000
95 - 115	21	0 - 60	B	Push-pull	6J6	5,300
110 - 140	27	0 - 60	B	Colpitts	6J4	12,000
135 - 160	18.5	10 - 60	B	Push-pull	6J6	5,300
365 - 375	2.7	0 - 60	B	Ultra-audion	6J4	12,000

* The per cent FM expresses the increase in frequency above the lowest frequency as a percent of the lowest frequency.

** Capacitive circuit element A consisted of two 120 $\mu\mu$f Glenco K3300 capacitors in series across the tank. Element B consisted of a stack of six 200 uuf Glenco K3300 capacitors connected in series as shown in Fig. 5.

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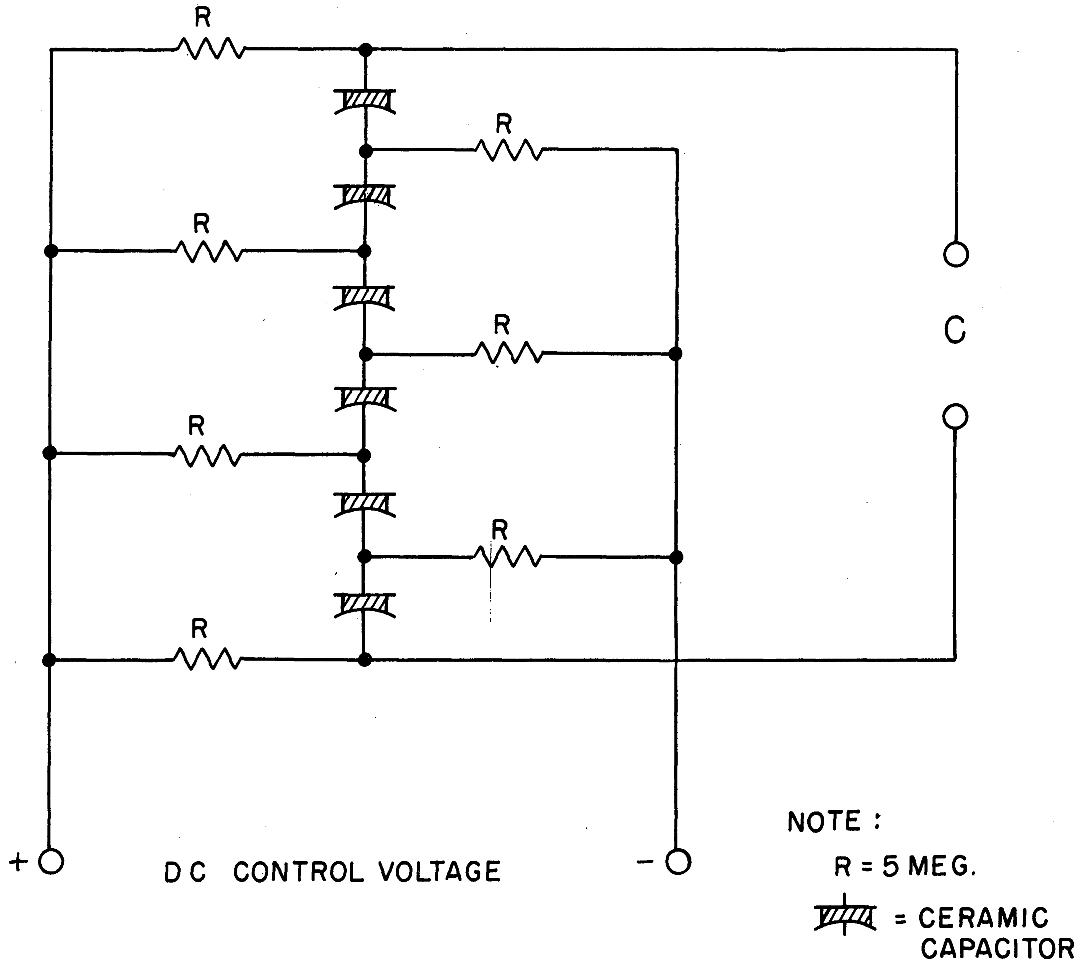

FIG. 5

LOW CAPACITY STACK.

This arrangement permits application of the full polarizing voltage to each capacitor, but offers the desired low capacity (approx. $33\mu\mu f$) for the tank circuit. This device was used because low value capacitors were not available in materials suitable for electric tuning. Special capacitors of low value made with thin dielectric are now on order. With thin dielectric it is possible to obtain the required polarizing field with reasonable values of applied voltage.

The condition for oscillation in a Colpitts circuit may be shown to be approximately

$$g_m' > \frac{4}{Q}\sqrt{\frac{C}{L}} + G_g \qquad (1)$$

where g_m' is the effective tube transconductance

Q the total Q of the resonant circuit

C and L the capacity and inductance of the resonant tank and

G_g the input conductance of the grid and grid circuit exclusive of the tank.

For other oscillator circuits, the condition for oscillation has the same general form as relation (1). Because the Q of ferroelectric capacitors is greatly reduced[1] at HF and VHF, it is necessary to use tubes of high transconductance, and tank circuits of large L/C ratio for successful operation in this frequency region. Some of these circuits refuse to oscillate at VHF because of this reduced Q. However, as the electric field is applied to the ceramic, the Q is often improved sufficiently to permit oscillations. It has been observed while varying the field about the point where oscillations begin that the starting field (value at which oscillations start) is larger than the dropout field.

The highest frequency so far observed in lumped-constant electric tuned oscillators was with the ultra-audion circuit shown in Fig. 6. The inductive

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[1] See for instance Quarterly Progress Report No. 8, Task EDG-4, Fig. 5, Electronic Defense Group, University of Michigan, July 1953, p. 8.

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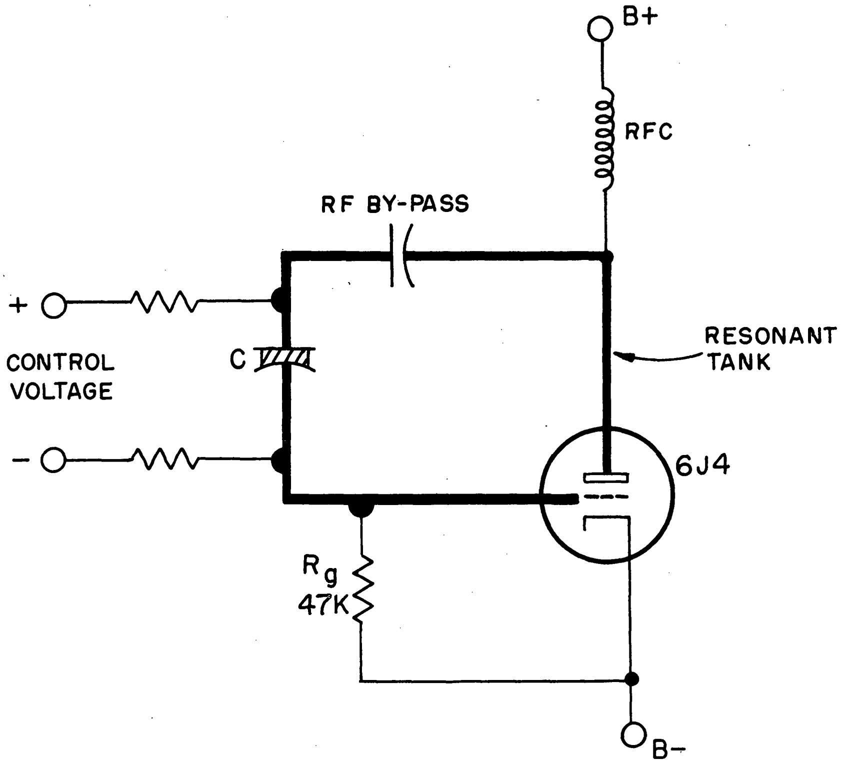
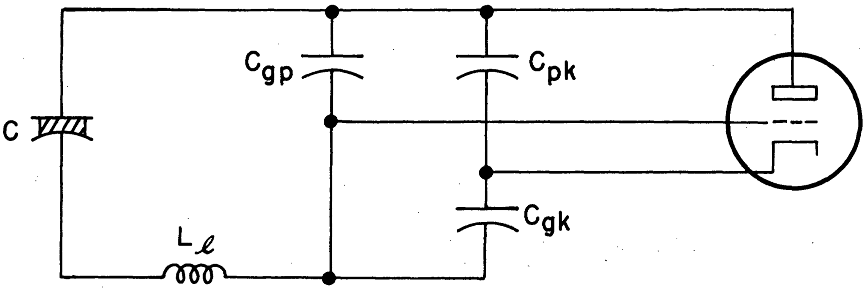


(a) ACTUAL CIRCUIT



(b) EQUIVALENT CIRCUIT

FIG. 6

ULTRA-AUDION OSCILLATOR.

part of the tank circuit is composed entirely of the grid and plate leads L_ℓ, while the variable capacitive element C is used to vary the resonant frequency of the tank. At resonance we find the relation

$$\omega^2 L = \frac{1}{C} + \frac{1}{C'} \qquad (2)$$

where

$$C' = C_{gp} + \frac{C_{gk} \cdot C_{pk}}{C_{gk} + C_{pk}}$$

By differentiation it follows that

$$\frac{\partial \omega}{\partial C} = - \frac{1}{2C} \sqrt{\frac{C'}{LC(C + C')}} \qquad (3)$$

or

$$\frac{\partial \omega}{\omega} = - \frac{C'}{2(C + C')} \cdot \frac{\partial C}{C} \qquad (4)$$

which shows that C should be kept small in relation to C' to obtain the best frequency shift.

<u>3.1.3.2 The Use of the Temperature-Epsilon Surface in Electric Tuned Oscillator Design.</u> (L. W. Orr) The tuning of an electric tuned oscillator is done by changing the electric field applied to the tank capacitors. The ratio of maximum to minimum capacity must be the square of the required frequency ratio. It is desired to have a relatively small control field for the desired frequency range. At the same time the temperature coefficient of capacitance should be kept at a minimum.

Given a particular material and tuning ratio, the correct operating temperature and required control field are to be determined. An example shows how the T-ϵ surface may be employed to simplify this design problem.

Example: Find the operating temperature and required control field for an electric tuned oscillator of frequency ratio 1.5 to 1 using capacitive elements of Aerovox Hi-Q 41.

The T-ϵ surface for this material is shown in Fig. 7. At any given value of field the small circles indicate the maximum capacity, and hence the temperature at which the temperature coefficient is zero. It may be seen that as the electric field increases, the zero point temperature also increases. Thus, it is not possible to obtain a zero temperature coefficient over the entire tuning range.

The solution is shown by the heavy dashed lines in Fig. 4. A temperature of 46° C is chosen, which is slightly higher than the zero point temperature for zero field. The curve for this temperature is followed as the field is increased until one obtains a capacity ratio of $(1.5)^2$ or 2.25. This is obtained at a field of 10.4 kilovolts per cm. It is seen from the surface that at this field the zero point temperature is slightly higher than 46°C. Therefore, at the minimum capacity there is a small positive temperature coefficient, and at the maximum capacity (zero field) there is a small negative temperature coefficient.

It is frequently desirable to have the zero temperature coefficient at the mid-frequency. The tuning ratio for mid-frequency is 1.25, and therefore, the capacity ratio for this point is $(1.25)^2$ or 1.562. On our curve for 46°C we find that this capacity ratio occurs at a field of 6 kv/cm as indicated by the dot-dash line. The temperature coefficient at this field and temperature is nearly zero.

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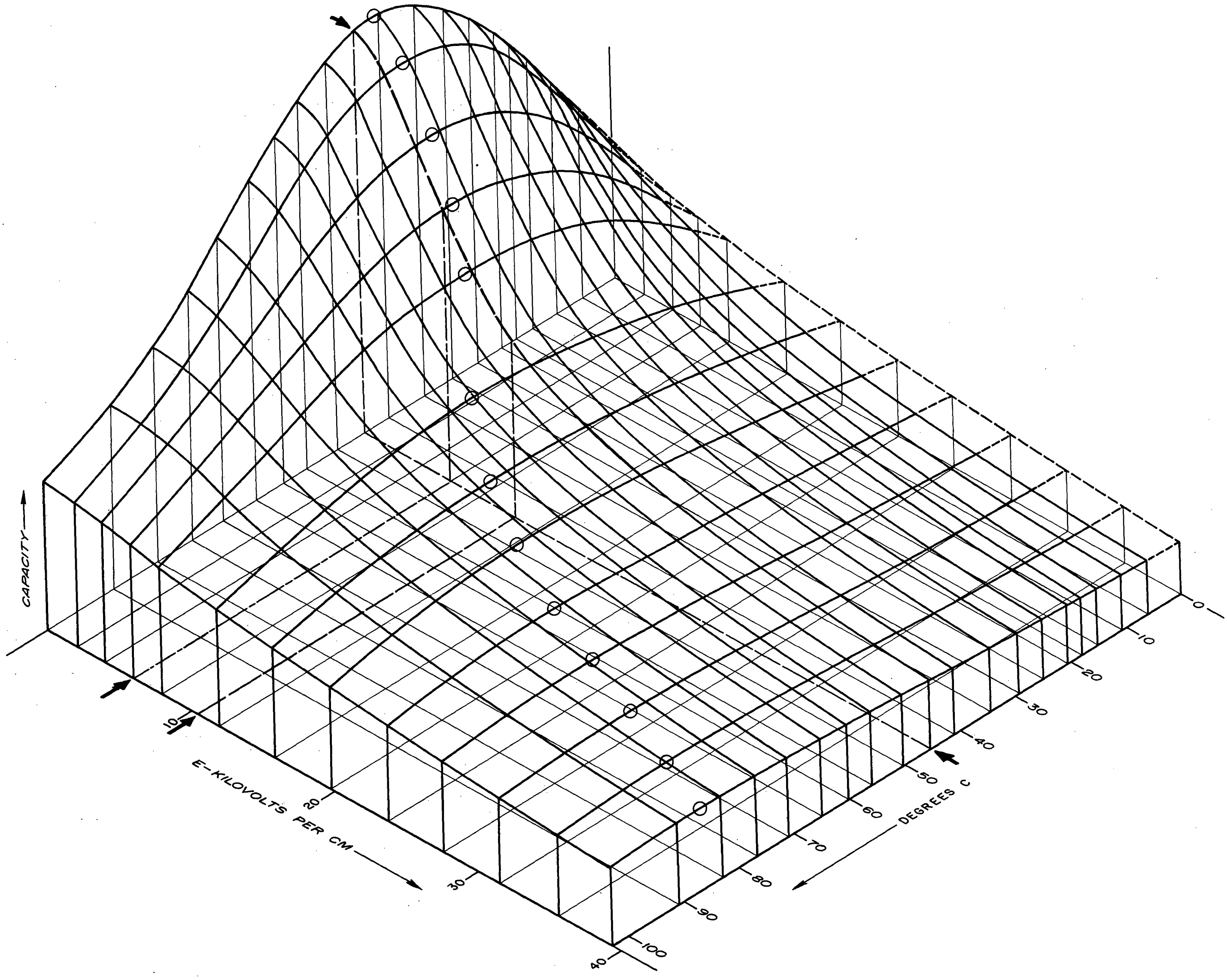

FIG. 7

EPSILON-TEMPERATURE SURFACE
FOR AEROVOX HI-Q 41.

3.1.3.3 Negative Capacity Element (L. W. Orr, L. Beavis and H. Diamond) The maximum range in dielectric tuning is limited by the ratio of maximum to minimum capacity available from a particular ferroelectric capacitor. Since this ratio is of the order of 8 or 9 for most useful materials, electric tuning cannot compete in tuning range with ferromagnetic tuning in the MF range. However, if some method could be found to decrease both the maximum and minimum capacity of a ferroelectric capacitor by an equal amount, this ratio could be greatly increased.

A negative capacity amplifier[1] may be used to perform this service. The input capacity of this amplifier is negative. If this negative capacity is placed in parallel with a ferroelectric capacitor of the proper value, it may be possible to make tuning elements which will compete with ferromagnetic tuning. The behavior of various negative capacity amplifiers over different frequency ranges will be studied to determine the feasibility of this technique.

3.2 Investigation of Techniques for Signal Detection and Frequency Determination

3.2.1 Voltage Tunable Magnetrons (R. Bradley) The study of the voltage tunable magnetron as a local oscillator for receiver use has been interrupted for the past several months while the equipment was in use for studies conducted under other tasks and Part II of this task was being completed (Part II was terminated last quarter). A second system is under construction which incorporates various features to overcome previous difficulties[2]. To overcome magnetic FM produced by the 60-cycle heater current in the magnetron, a storage battery heater supply is employed. For closer and more accurate voltage control, the anode voltage regulator circuit has been redesigned. The construction of the regulator is now complete. (See Fig. 8). The new regulator furnishes currents

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[1] See for instance MIT Radiation Laboratory Series, Vol. 19, Appendix A, p. 767.

[2] See Quarterly Progress Report No. 6, Task EDG-4, Fig. 7, Jan. 1953, p. 15.

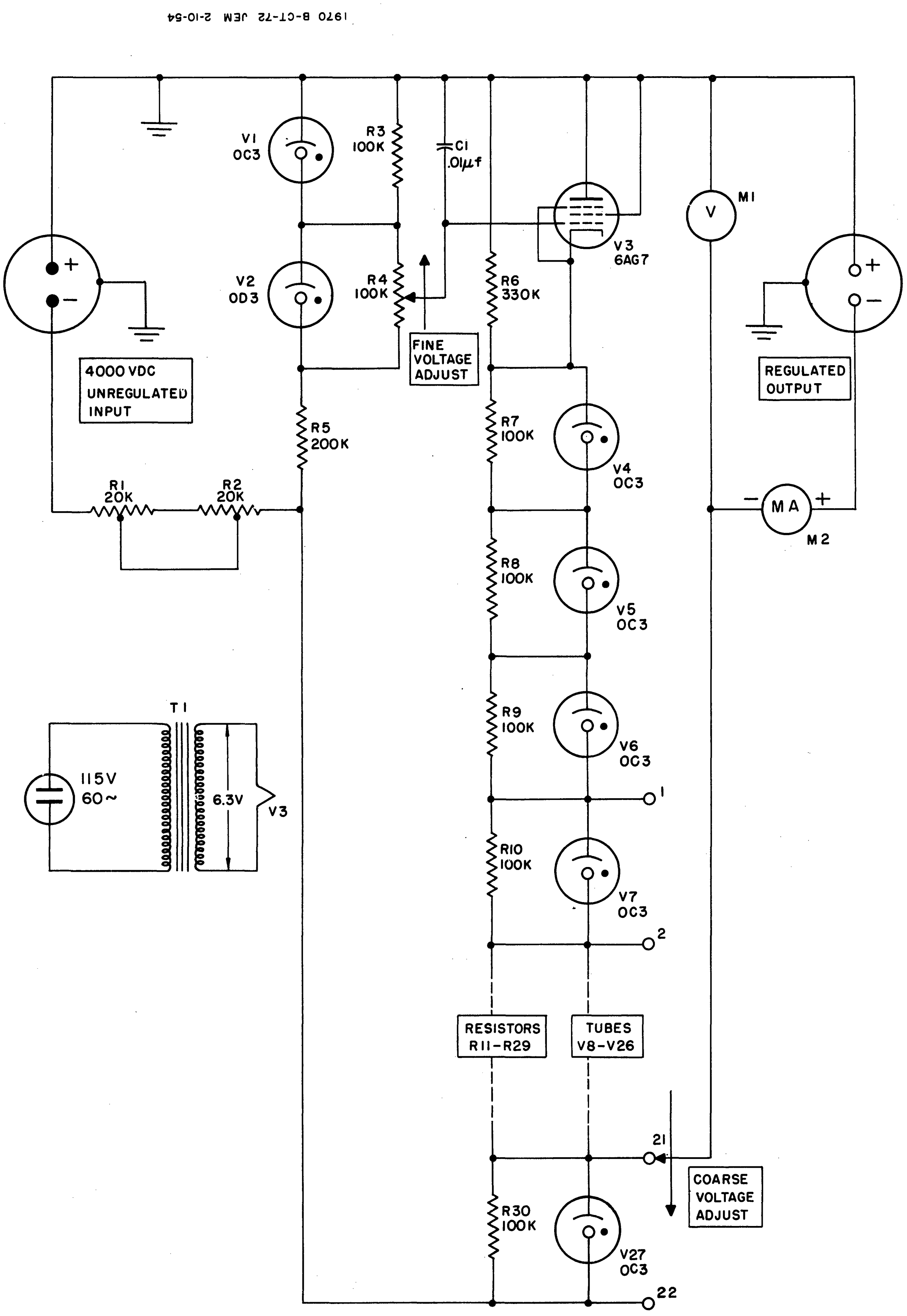

FIG. 8

HIGH VOLTAGE REGULATOR CIRCUIT FOR MAGNETRON.

up to 35 ma with good regulation, and can be adjusted for any voltage from 600 volts to 2700 volts.

4. CONCLUSIONS

In spite of the expected delay in the research programs caused by the major move to the North Campus, the major objectives for the period have been accomplished.

5. PROGRAM FOR NEXT INTERVAL

5.1 Ferromagnetic and Ferroelectric Tuning

Solutions to the instrumentation problems will be sought in the low-Q measurements on ferrite cores, and a routine testing procedure will be established. The investigation of ferroelectric materials will continue, and further tests made of materials suitable for electric tuning including measurements of Barkhausen Noise.

The negative capacity amplifier circuit will be investigated as a possible method of extending the frequency range of electric tuned oscillators.

5.2 Voltage Tunable Magnetron

Construction of the new equipment will continue. The completed system will include power supplies, modulator, broad-band mixer, IF amplifiers, attenuators, and appropriate noise measuring equipment. Upon completion of the apparatus, the investigation program will begin. This will include noise figure measurements, and a study to indicate the effects of various parameters on noise figure in voltage tunable magnetrons.

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