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AN ULTRA-HIGH-FREQUENCY AIRCRAFT RECEIVER

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ILLUSTRATIONS

An Ultra-High-Frequency Aircraft Receiver

SUMMARY

An ultra-high-frequency aircraft receiver, which covers the band from 60 to 132 megacycles, is described herein Sections of coaxial lines are used for the radio-frequency and oscillator tuned circuits in this receiver, and the essential factors involved in their design are discussed The frequency stability of the coaxial line controlled oscillator was studied, and methods were devised to reduce the variations in frequency

INTRODUCTION

The ultra-high-frequency activities of the Civil Aeronautics Authority have been confined largely to the 60–66, 74 6–75 4, 93–95 109–111 and 123–132 megacycle bands, in which most of the aeronautical frequencies are assigned In order to carry on the development work, it was necessary to have a receiver with a continuous range to cover this spectrum Receivers were available commercially for the low-frequency end of this range, but nothing was available at the higher frequencies With these facts in mind the development of a continuously variable superheterodyne receiver of good sensitivity was undertaken

The following requirements were decided upon

1 *Stability*—After a short warming up period, the circuits should remain in tune for normal operating conditions

2 *Frequency band*—The tuning range should be continuous from 60 to 132 megacycles

3 *Selectivity*—The response at the image frequency should be at least 60 db down

4 *Sensitivity*—The sensitivity should be such that when a 5 micro-volt signal, 30 percent modulated with 400 cycles, is applied through a 50-ohm resistor to the antenna input, the output should be 6 milliwatts

5 *Intermediate-frequency amplifier band width*—The intermediate frequency amplifier should be of the band-pass type such that the flat top could be adjusted from a round nose to about 150 kilocycles

6 *Power supply*—External power supply with provisions in the receiver so that the filaments might be operated from either 6 or 12 volts, the maximum high voltage to be 225 volts

7 *Mechanical*—The receiver should be suitable for aircraft operation, and it should be as light and rugged as possible to withstand the vibration encountered in aircraft service

THE RECEIVER

Radio-frequency tuned circuits

The several factors entering into the choice of circuits to use in the radio-frequency portions of the receiver are selectivity, stability, and adaptability

Selectivity—The selectivity enters into consideration in two ways First, the adjacent channel rejection, and second, the image ratio desired

The adjacent channel rejection can best be taken care of in the intermediate-frequency amplifier by the use of band-pass filters

The image ratio obtained is determined by the selectivity of the radio-frequency circuits and the intermediate amplifier frequency Image frequency rejection is a function of the attenuation obtained by separation of the undesired signal from the resonant frequency of the circuits, this separation being determined by the intermediate frequency Given a poor radio frequency selectivity, it will be necessary to use a high intermediate frequency, in order that the image frequency will be far out on the skirt of the radio-frequency selectivity curve A high intermediate frequency, however, requires the use of an increased number of tuned circuits to obtain steep sides on the intermediate-frequency amplifier selectivity curve Steep sides are essential if high adjacent channel rejection is required A sharp radio-frequency selectivity will permit a lower intermediate frequency, and thus a reduced number of intermediate-frequency tuned circuits

A high Q radio-frequency tuned circuit can be obtained by the use of sections of coaxial line, loaded with capacity to permit a length reasonable for a receiver

Stability and adaptability—The use of a section of coaxial line will provide a mechanically rugged and electrically stable, self-shielded circuit of reasonably large physical size even at the higher frequencies.

A further reason for the use of coaxial lines was to study their application to receivers in the ultra-high-frequency range.

The inductance of the coaxial line is

$$L_0 = 2 \log_e \frac{b}{a} \times 10^{-9} \text{ henries per centimeter}$$

where

a = outside diameter of inner conductor
b = inside diameter of outer conductor
a and b measured in same units.

The high-frequency resistance of the coaxial line is

$$R_0 = \sqrt{p\ u\ f}\left(\frac{1}{a}+\frac{1}{b}\right)\times 10^{-9} \text{ ohms per centimeter}$$

where

p = resistivity in e. m. u.
u = magnetic permeability
f = frequency in c. p. s.
a = outside diameter of inner conductor
b = inside diameter of outer conductor
a and b measured in centimeters.

Since the inductive reactance is proportional to the frequency and the resistance is proportional to the square root of the frequency, the Q, or $\frac{X}{R}$ will be proportional to the square root of the frequency. For a given inductance the Q, and therefore the selectivity, will increase with the frequency. With a coil, however, the Q will decrease with the frequency. This fact gives a decided advantage in favor of the coaxial line for the tuned circuit.

The inductance per unit length of the line is a function of the ratio of the diameters of the outer and inner conductor, so, for a given ratio of outer to inner conductor diameters, the inductance is not affected by the actual diameter. The resistance, however, is inversely proportional to the diameter, making the Q proportional to the diameter, provided the ratio of diameters remains constant.

It is apparent that when the diameter and length are determined by the physical space available in the receiver, care should be exercised in the choice of materials from which the lines are made to obtain the greatest selectivity from the coaxial line tuned circuits.

Some of the characteristics of the more common metals which may be used in the construction of coaxial line tuned circuits are given in Table 1. It is interesting to note the effect of the addition of small amounts of other elements to copper, resulting in a brass or bronze. The addition of 1 percent lead reduces the conductivity but slightly, and thereby improves the machining properties so that it may be worked with approximately the same ease as brass. The addition of small amounts of zinc reduces the conductivity greatly, 5 percent being enough to reduce the conductivity to one-half that of pure copper.

When it is necessary for mechanical reasons to use a material of low conductivity, then a plating of silver or even chromium will provide a high surface conductivity. The pen-

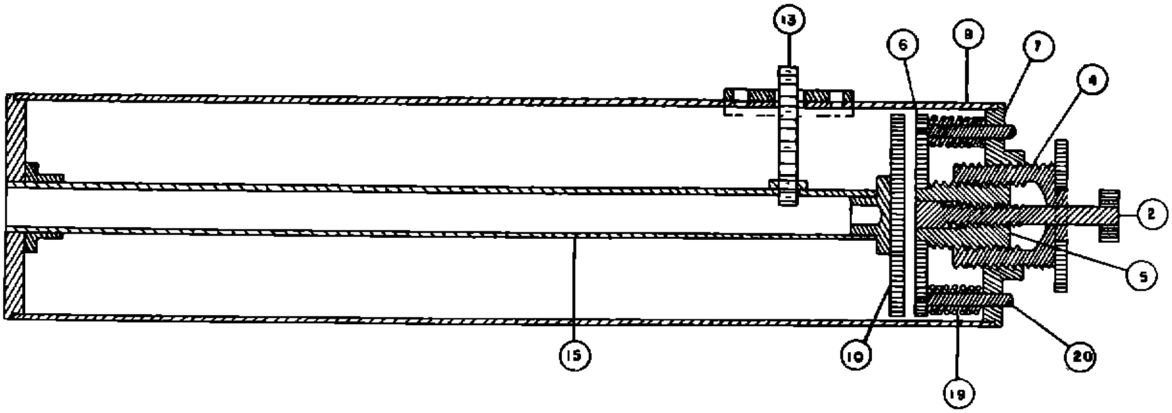


Figure 1.—Cross section of coaxial line tuned circuit showing details of micrometer tuning condenser.

etration depth being small at these frequencies makes the use of a plating possible.

The high frequency resistance of lines made up of two different materials becomes:

$$R_o = \left(\frac{\sqrt{p_a u_a f}}{a} + \frac{\sqrt{p_b u_b f}}{b} \right) \times 10^{-9} \text{ ohms per centimeter}$$

The inner conductor contributes most to the total resistance, and should therefore be of the material with the highest conductivity. This is fortunate, since in applications where weight is an important consideration, the outer conductor may be made of a light material, such as an aluminum alloy of lower conductivity, without seriously affecting the total resistance. For example, the use of aluminum alloy (17ST) in place of copper for the outer conductor of the tuned circuits, to be described later, resulted in a saving of about 10 ounces weight for each unit, with less than 20 percent increase in calculated resistance.

In addition to the saving in weight, the use of aluminum for the outer, and copper for the inner conductor, provides a measure of frequency control for changes in temperature. As the temperature of the inner conductor is raised, the length will increase, resulting in a higher inductance and a lower resonant frequency. If the tuning condenser is of the pie-plate type with one plate fastened to the inner conductor and the other to the outer conductor, and the outer conductor has a higher linear coefficient of expansion, then the spacing of this condenser will become greater as the temperature is raised. Thus, an increase in temperature will tend to increase the resonant frequency. There is, of course, only one spacing at which the effect of increasing inductance will be exactly compensated for by the decreasing capacity.

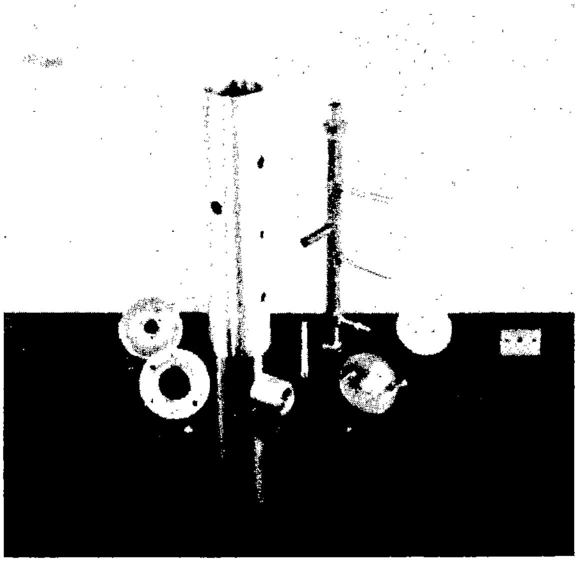


Figure 2.—Oscillator tank circuit parts.

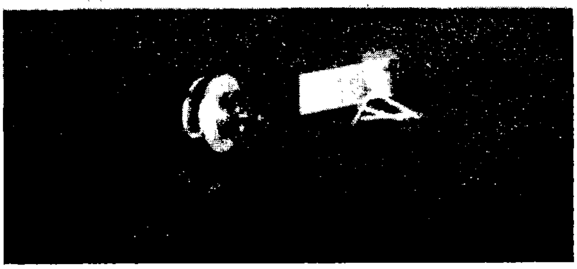


Figure 3.—Micrometer tuning head, assembled.

Figure 1 is a cross section of the coaxial line tuned circuits used in this receiver. The spacing of the condenser plates 6 and 10 is controlled by the micrometer screw consisting of parts 4, 5, and 7. The outside thread of part 4 has a pitch of 30 threads per inch, while the pitch of the inner thread is 40 threads per inch. Thus, if the inner plug is kept from turning, for each revolution of part 4, the inner plug will move the difference in pitch or 0.0083 inch. Any play which might be caused by loose threads is taken up by the springs 19. The inner plug is prevented from rotating by the guide pins 20. The small plug 2 acts as a vernier and is useful when the plates are closely spaced. The stud 13 acts as a support for the end of the inner conductor and also the tap for connection to the tube.

Figure 2 is a photograph of the oscillator tank circuit parts before assembly. Figure 3 shows the assembled micrometer head.

The heterodyne oscillator.

Two general types of heterodyne oscillators are available, the crystal-controlled oscillator and the master oscillator Since a continuous tuning range is required, the master oscillator will be necessary if the receiver is to be simple

Previous experience with ultra-high-frequency oscillators using a coil and condenser for the tuned circuit has shown this type to be subject to considerable variations in frequency, with changes in operating conditions, such as temperature and supply voltages As in the case of the radio frequency circuits the use of a section of coaxial line will provide a self-shielded and rugged construction for the oscillator tuned circuit In order to determine the frequency stability of this type of oscillator, a study was made of the factors governing this stability

Several concentric line tank circuits having different physical sizes were constructed, and the frequency stability of each was observed The high Q tank circuit was used as the grid tuned circuit of a tuned-grid tuned-plate oscillator The details of these oscillators are shown in figure 4 The tuning of the plate circuit was by far the most serious factor in the frequency stability of all of the oscillators

Figures 5, 6 7, 8, 9 and 10 have been drawn to show the effect of the tuning of the plate circuit on the frequency of the oscillator, the capacity of C_3 increasing with dial divisions in all cases The several curves on each figure are for different conditions of coupling of the grid to the concentric tank The upper curves of each figure show the corresponding plate current

As is characteristic of all oscillators, the greatest frequency stability is obtained under a condition of weak oscillations under which condition very little power can be obtained As the loading is increased the degree of coupling must be raised and a stronger oscillation with a lesser frequency stability will result

Column 7 of Table II gives the slope of the tangent to the curve at the point of minimum plate current expressed in micromicrofarads per

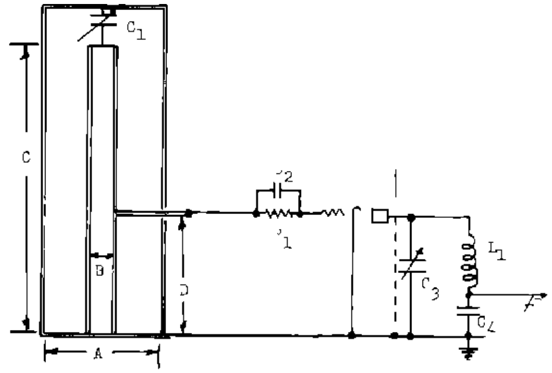
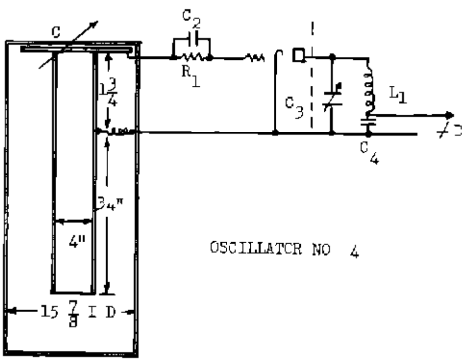
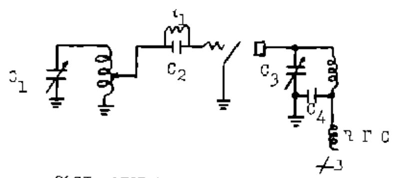


DIAGRAM FOR OSCILLATORS 1, 2 and 3

OSC NO	A (I D)	B (O D)	C	D 1	D 2	D 3	D 4	D 5
1	2 0	375	9 5/8	2 3/8	3 15/16	5 5/8	7 1/4	8 7/8
2	3 9	1 125	9 3/4	3 3/4	5 3/4	–	–	–
3	1_ 3/4	4 1/4	32 3/4	24	–	–	–	–



OSCILLATOR NO 4



OSCILLATOR NO 5

Figure 4 —Diagram and dimensions of coaxial line controlled oscillators

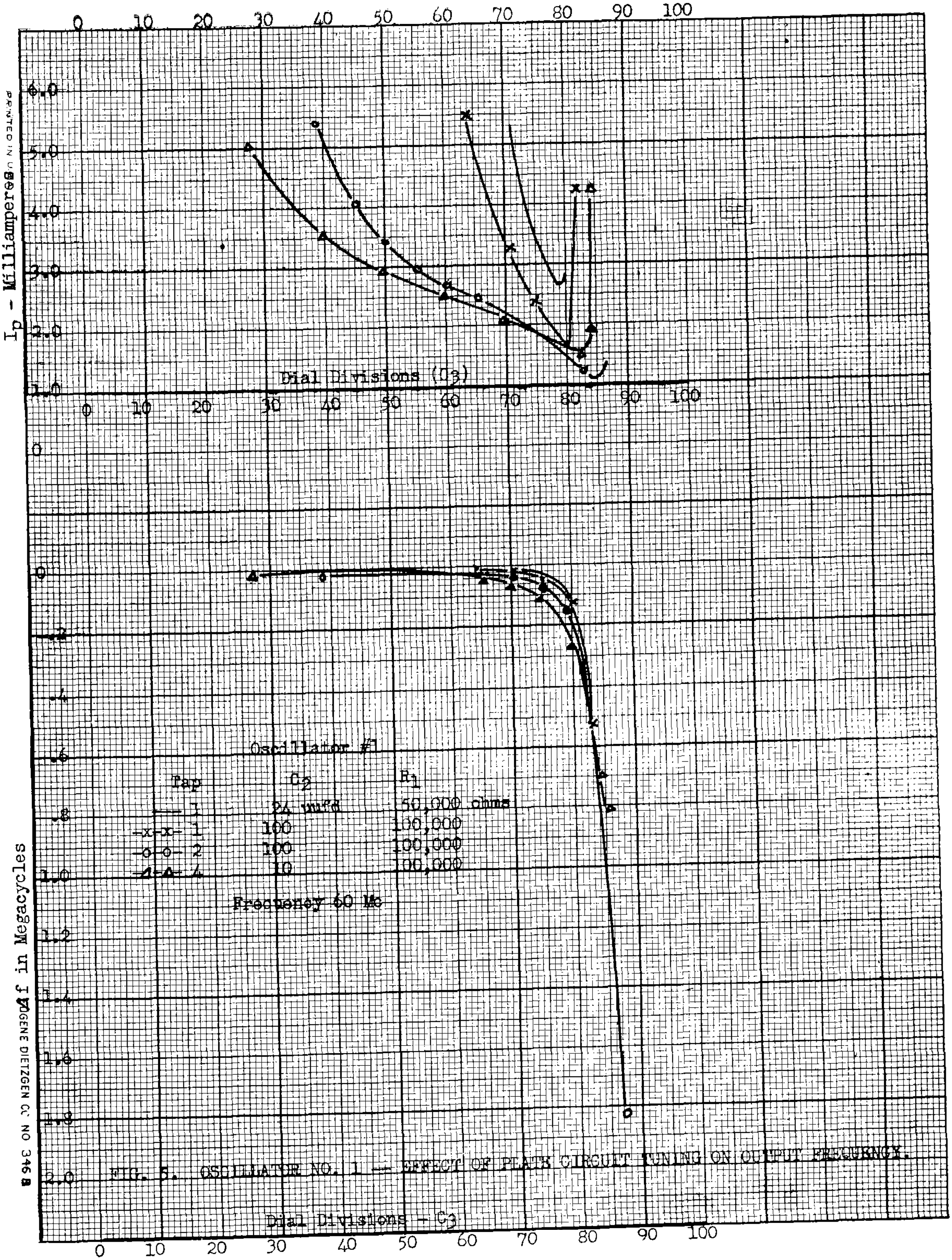


Figure 5.—Oscillator No. 1—Effect of plate circuit tuning on output frequency.

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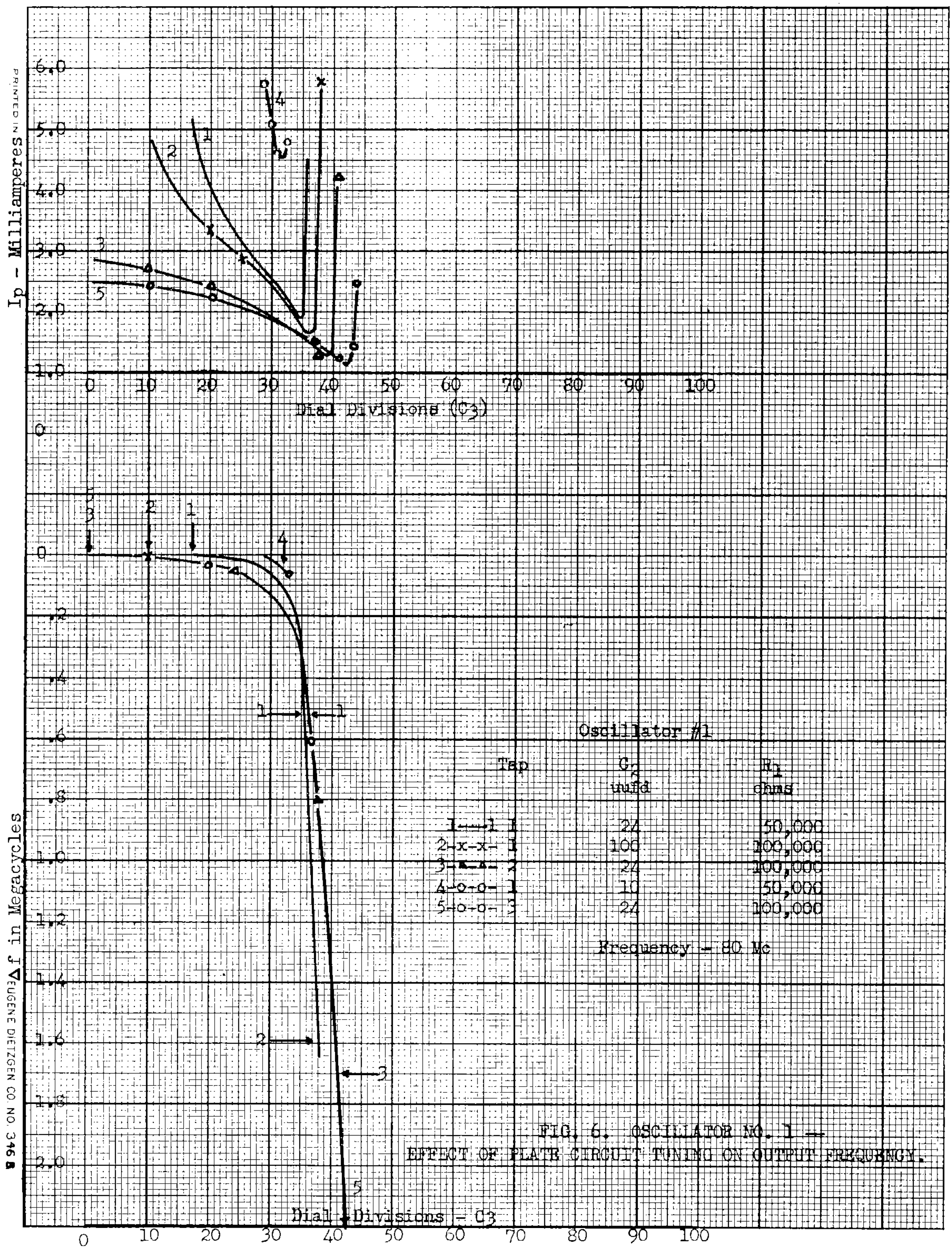

Figure 6.—Oscillator No. 1—Effect of plate circuit tuning on output frequency.

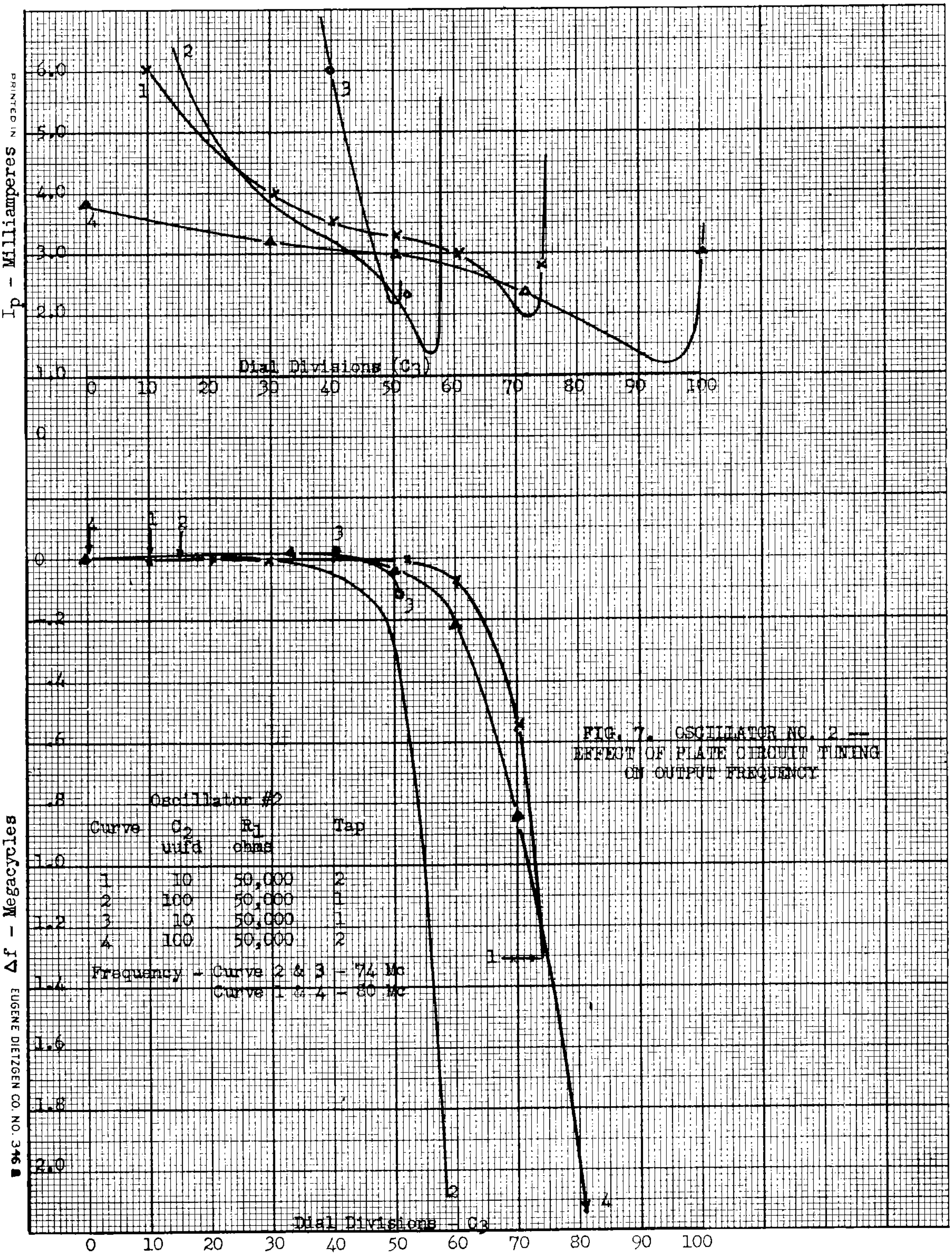

Figure 7.—Oscillator No. 2—Effect of plate circuit tuning on output frequency.

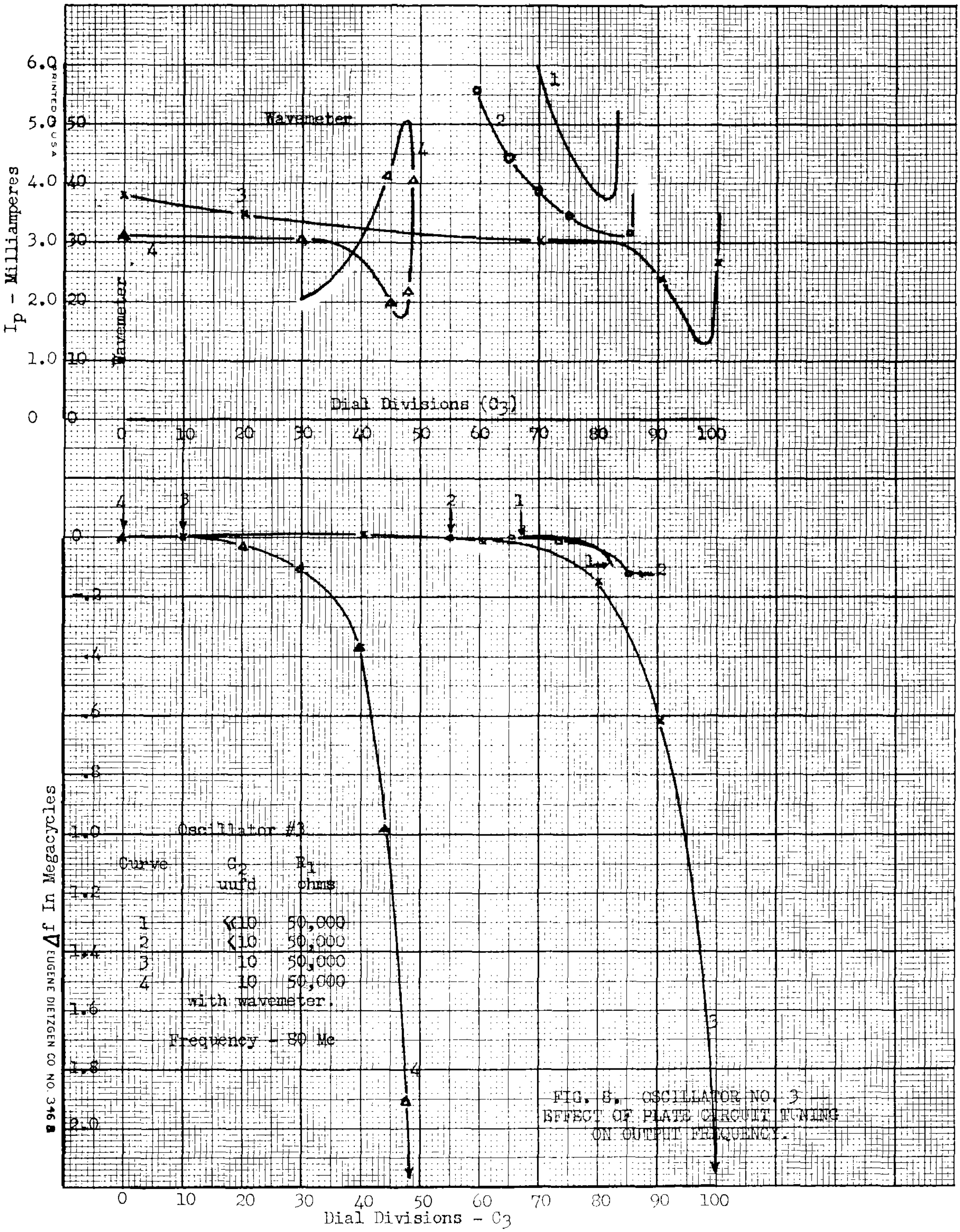

Figure 8.—Oscillator No. 3—Effect of plate circuit tuning on output frequency.

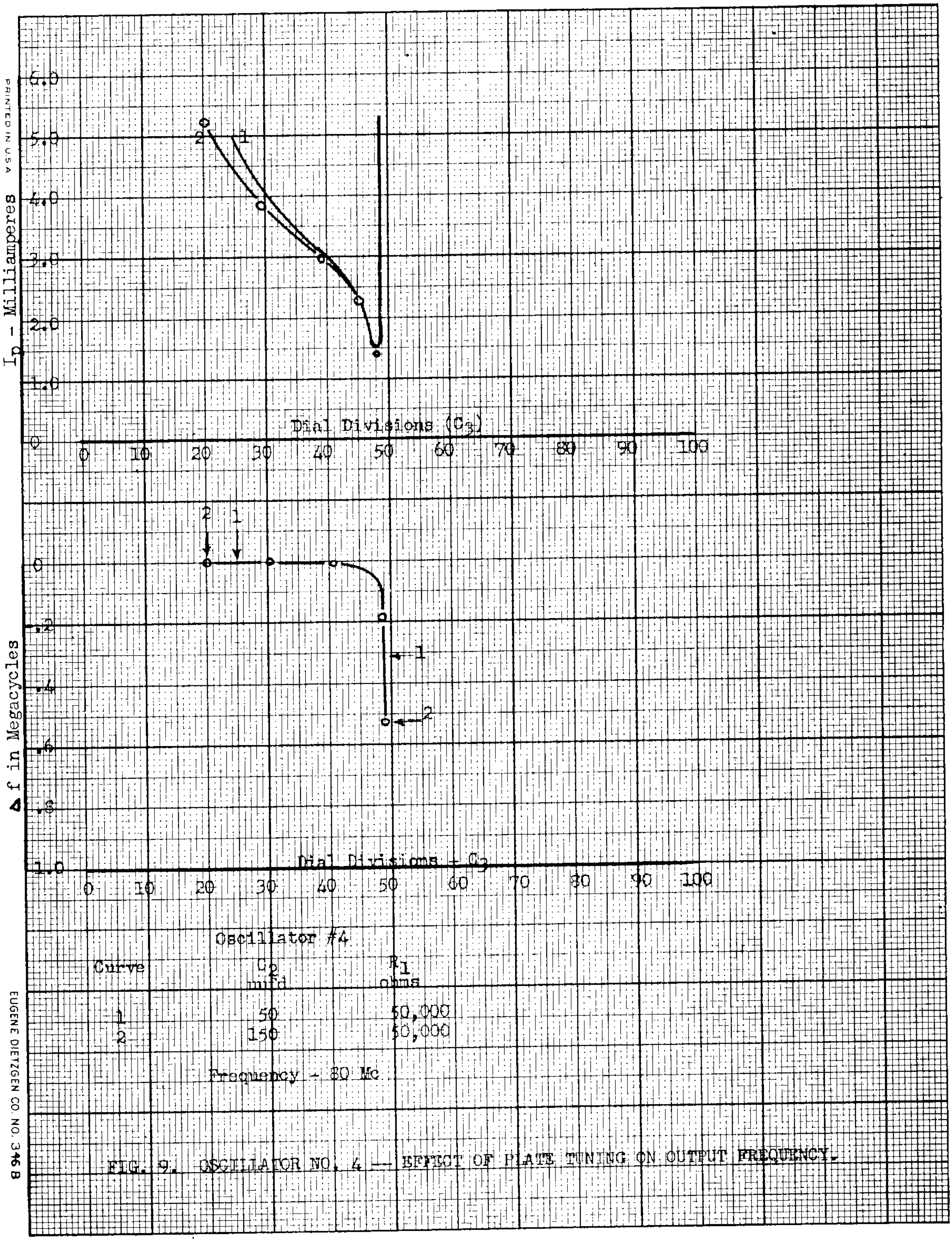

Figure 9.—Oscillator No. 4—Effect of plate circuit tuning on output frequency.

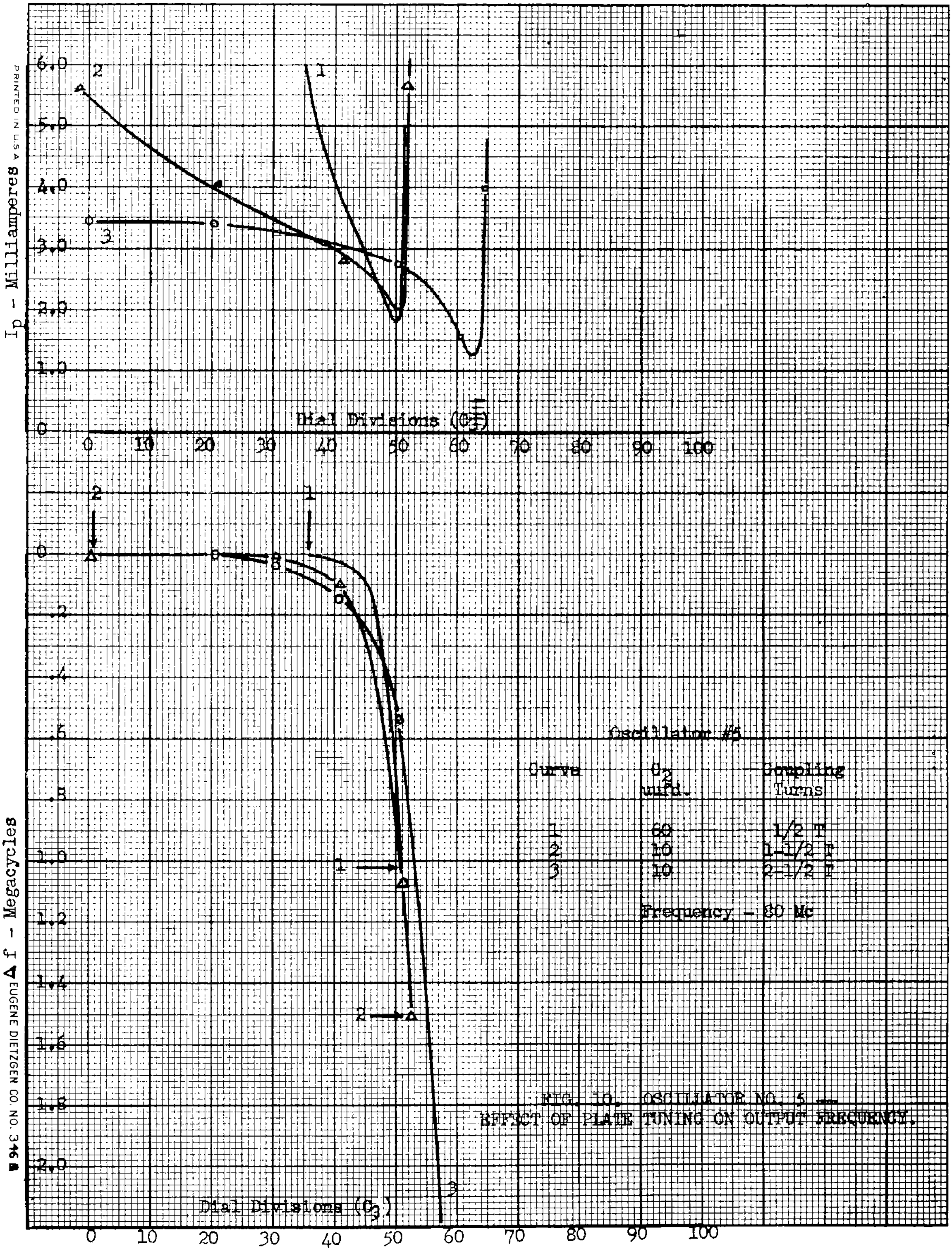

Figure 10.—Oscillator No. 5—Effect of plate circuit tuning on output frequency.

megacycle Maximum output will be obtained with a slightly greater capacity for C_3 The minimum plate current was chosen as a point more easily duplicated This indicates then that even though the concentric tank be assumed to remain constant, there will be a considerable variation in frequency with the tuning of the plate circuit, and if adjusted for minimum plate current operation will then be on the steep portion of the frequency/plate tuning curve Since the pass band of the intermediate amplifier is only 0 2 megacycle, even with feeble oscillations, a change of only 2 micromicrofarads (or its equivalent) in the plate circuit will throw the receiver out of tune

It is interesting to note that even though the diameter of the concentric tank is large, as in No 3 and No 4 oscillator, approximately the same plate circuit tuning stability results

The frequency stability being dependent on the coupling of the grid to the concentric tank indicates that with a fixed coupling condenser, a variation of 2/1 in frequency would change the effective stability appreciably Since the intermediate frequency is the same for all the radio frequencies, the same frequency stability expressed in cycles should exist throughout the band to be covered

The use of an oscillator of the type shown in figure 11 will provide a circuit in which the frequency determining elements are included in one tuned circuit and furthermore tuning may be accomplished by a single control

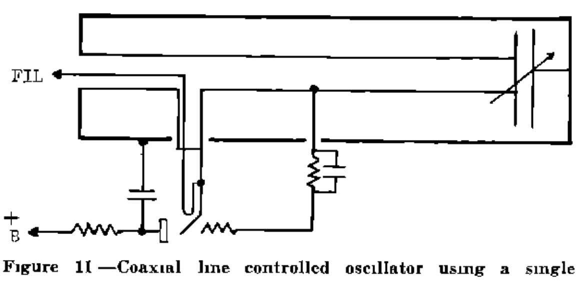

Figure 11 —Coaxial line controlled oscillator using a single tuning control

Tubes

As the frequency is increased, the conventional type of tube becomes less efficient, and at some high frequency (about 80 megacycles for a type 57), the amplification becomes unity or less and they act simply as coupling devices With the introduction of the acorn type of tube, stage gains of unity or more have been obtained at frequencies as high as 300 megacycles

Previous experience at frequencies between 60 and 65 megacycles indicate a life of some 2,000 hours for these acorn tubes although some investigators found the life to be extremely short

Since the frequencies to be covered in this receiver were high, the use of the acorn type of tube was practically essential Consequently, they were chosen for the high-frequency portions of the receiver with conventional tubes for the intermediate frequency and audio stages

This gave further opportunity to study the life characteristics of the tubes, especially in aircraft where the operating conditions are especially severe

First detector

The first detector is a 954, with the heterodyne voltage introduced into the cathode circuit Cathode injection was chosen because the radio-frequency voltage required for this type of modulation is low Suppressor injection could have been used but the radio-frequency voltage would then necessarily be high since the control of the suppressor grid is small

The radio-frequency voltage for the detector cathode is obtained from a tap on the oscillator tank circuit The cathode lead is brought up through the inner conductor, which places the cathode at the radio-frequency potential of the tap on the tuned circuit and permits the cathode resistor to be at ground potential

Intermediate-frequency amplifier

The intermediate-frequency amplifier consists of two stages (three transformers) with a mid-band frequency of 5 5 megacycles

Each transformer consists of two tuned circuits inductively coupled to form a band-pass filter The coupling is adjusted by varying the spacing between the coils, making it possible to overcouple the two circuits and broaden the pass band The coils are tuned by air dielectric condensers to provide stable circuits

The intermediate-frequency amplifier operating at 5 5 megacycles places the image frequency 11 megacycles from the desired signal which with the high Q circuits in the radio-frequency amplifier results in a high image frequency rejection

The plate circuit of the second intermediate-frequency amplifier is brought out to terminals in the connection socket and provides a means of determining the input signal to the receiver since, due to a g c (automatic gain control) action, this current is proportional to the input signal

Each intermediate-frequency amplifier cathode circuit includes a resistor to furnish the initial bias for the tube whether in a g c or m g c (manual gain control) condition

Second detector, a g c, and audio amplifier

The second detector, a g c, and first audio amplifier are combined in a single tube of the double diode triode type

The rectified voltage developed across the load resistor in the diode circuit provides a control voltage which varies with the amplitude of the intermediate-frequency signal This voltage applied through a filter to the grids of the intermediate-frequency amplifier then provides a means of automatically regulating the gain of the amplifier in relation to the input signal, resulting in essentially constant audio output from the receiver The audio-frequency voltage developed across the diode load resistor is applied to the grid of the triode section of the tube

The triode audio amplifier is resistance capacity coupled to a pentode audio output tube The output audio transformer is designed for a 300- or 500-ohm output for the receiver

Manual gain control

Manual gain control is obtained by varying the potential of the cathodes of the first and second intermediate-frequency amplifier tubes above ground, the grids being at ground potential To permit complete cut-off of the tubes, this cathode potential is obtained from

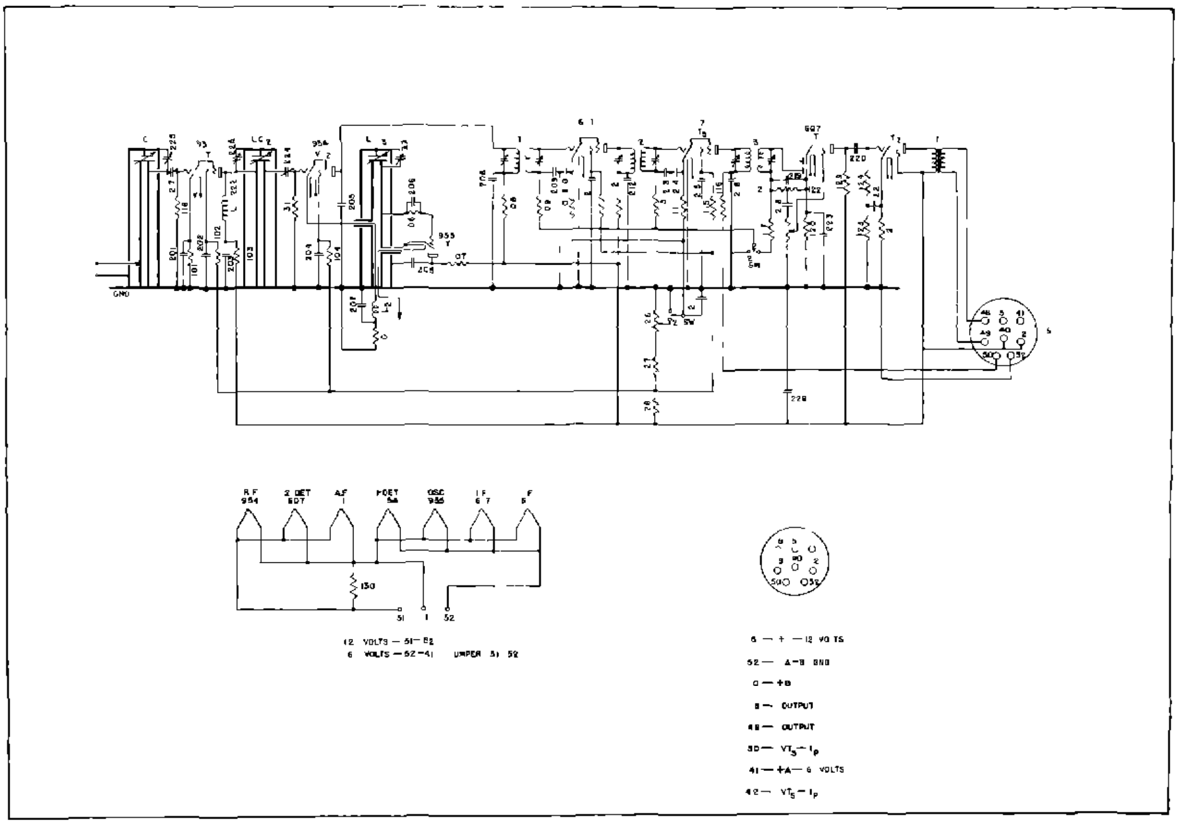

Figure 12 —Schematic diagram of receiver

the bleeder. Since the plate and screen voltages are reduced at the same time that the grid voltage is increased, the range of control is somewhat greater than would be obtained by varying the negative grid potential only.

A switch is provided so that operation may be with a. g. c. or m. g. c. When in a. g. c. condition, the grids of the intermediate-frequency amplifiers are connected to the a. g. c. voltage from the diode rectifier and their cathodes connected to ground through the individual cathode resistors. In m. g. c. condition, the grids are grounded and the cathodes connected to the variable arm of the m. g. c. potentiometer.

Filament operation.

The heaters of the tubes are connected in a series parallel combination which permits operation from either a 6- or 12-volt supply. When operating from a 6-volt supply, all heaters are in parallel, while for 12-volt operation there are two groups in series, each group consisting of several filaments in parallel.

The schematic diagram of the receiver is shown in figure 12.

Mechanical arrangement of receiver.

The photographs, figures 13, 14, and 16, are of the completed receiver. The outside dimensions of the case are 9⅜ inches wide by 7⅞ inches high by 10⅝ inches deep. The chassis or receiver unit slides into the case and is held by two trunk fasteners. The shock mounting is a separate assembly to which the receiver case is fastened by gauged snap fasteners.

Figure 13 is a front side view. The intermediate-frequency transformers and amplifier tubes, second detector tube, audio output tube, and output transformer occupy the right half of the chassis with the associated resistors and bypass condenser mounted underneath. The controls on the front panel are: upper left corner, shielded antenna input socket; upper center, radio-frequency input tuned circuit micrometer control; middle, radio-frequency plate tuned circuit micrometer control; lower left, oscillator tuned circuit micrometer control; the left-hand pointer knob is the audio gain control and the right-hand pointer knob the intermediate amplifier gain control. The toggle switch below the handle changes operation from a. g. c. to m. g. c. All power input and audio output connections are made through the shielded socket in the lower right-hand corner.

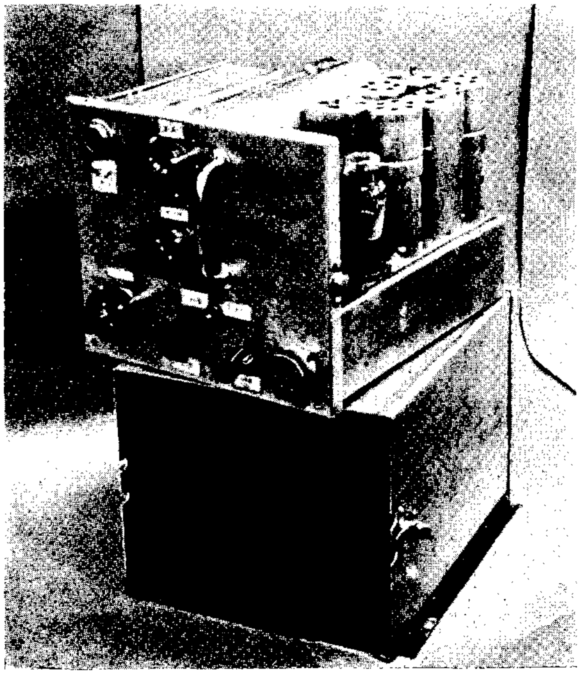

Figure 13.—Front side view of receiver.

The radio-frequency and oscillator tuned circuits and tube compartment occupy the left half of the chassis, the oscillator tuned circuit being mounted inside the chassis below the radio-frequency and detector tube compartment.

The bottom view is shown in figure 14. The oscillator tube compartment and tuned circuit are shown in this view as well as the resistors and bypass condensers for the intermediate and audio-frequency circuits.

A chassis lay-out, showing the position of the component parts, is shown in figure 15.

The radio-frequency and first detector tube compartments are shown in figure 16. The radio-frequency amplifier tube is mounted with its grid projecting into the upper right compartment which contains the grid tuned circuit loading condenser and grid coupling capacity. The lower right compartment contains the radio-frequency tube plate choke and coupling condenser, detector grid coupling capacity, and

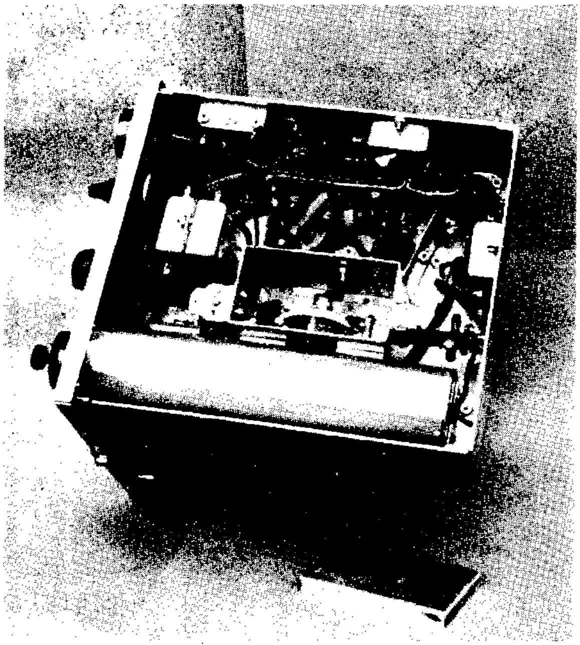

Figure 14.—Bottom view of receiver.

tuned circuit loading condenser. The first detector tube grid extends into this compartment.

Standard acorn sockets were modified for the radio-frequency and first detector tubes to provide a high capacity directly from the tube prongs to ground. This was accomplished by

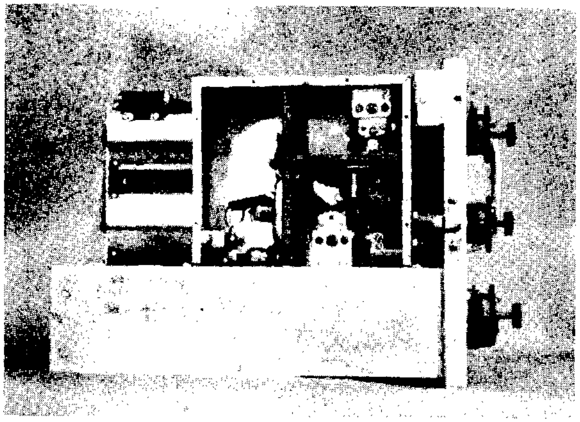

Figure 16.—Left side view of receiver showing radio frequency and first detector tube compartment.

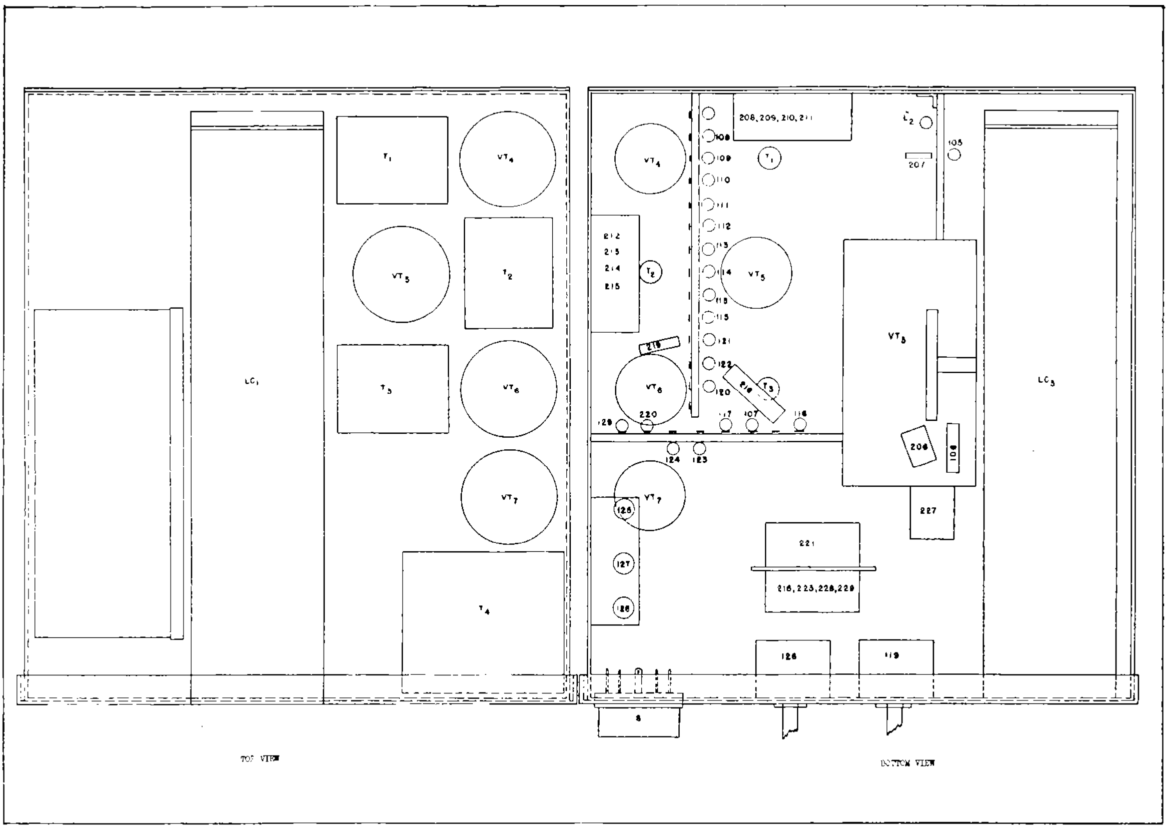

Figure 15.—Chassis layout.

replacing the rivet holding the clip to the isolantite base with one the head of which came flush with the bottom surface of the isolantite thin copper plates were then soldered to the rivets The socket was separated from ground by a thin sheet of mica This arrangement gave a high capacity to ground directly at the tube prongs In the case of the detector, the cathode plate was omitted, since the heterodyne voltage is introduced at this point A cylindrical shield extending from the flare at the filament seal to a point opposite the internal shield was used The construction is shown in figure 17

The acorn tubes are retained in their sockets by springs to prevent their being loosened by vibrations

The weight of the complete receiver in the case is approximately 15 pounds

TESTS

Radio-frequency amplifier and tuned circuits

Theoretical considerations indicate that the use of coaxial lines will provide circuits of extremely high Q and consequently great selectivity Practically, however, high values of Q are difficult to obtain due to the loading of the circuits and tubes associated with them For example the lines used in this receiver have the following dimensions

Inside diameter of outer conductor (17ST aluminum)—2 12″

Outside diameter of inner conductor (copper)—0 5″

Length of inner conductor—8 375″

Inductance=0 06 microhenry

Frequency	Q
60 Mc	3000 approx
120 Mc	4100 approx

The input resistance of vacuum tubes at ultrahigh frequencies has been investigated by W R Ferris,[2] who found that the input resistance can reach very low values, this resistance being approximately 55,000 ohms for a 954 at 60 megacycles and 14,000 ohms at 120 megacycles This resistance of 55 000 ohms connected across the entire tank circuit will reduce the Q to approximately 1,300 which will be reduced to about 650 if an antenna be connected in for maximum transfer of energy

At 120 megacycles the Q of the circuit alone would be approximately 4100 The tube grid load will reduce the Q then to 290, which for optimum antenna coupling becomes 145

It is apparent from these simple relations that grid loading is a major consideration at

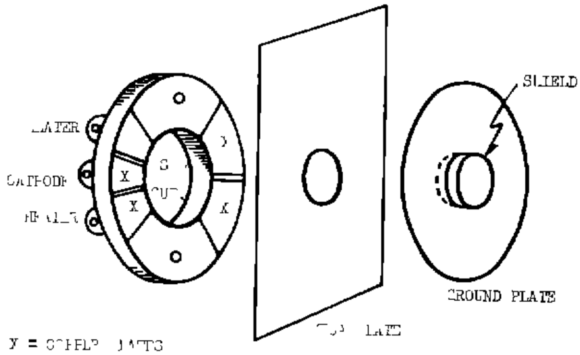

Figure 17—Acorn socket modified to provide high capacity from tube prongs to ground

these frequencies and that even though the grid be biased negative its effect cannot be neglected as at the lower frequencies

The effect of grid loading is brought out in figures 18 and 19, which are the selectivity curves of the radio-frequency plate and grid tank circuits under several conditions of grid loading Curves 1 and 2 in each case show the selectivity under different values of the grid coupling condenser to the detector The input in this case was connected directly to the grid of the radio-frequency amplifier tube

The curves 3 and 4 in each case show the selectivity under different values of the grid coupling condenser to the radio-frequency stage From these curves, the effects of grid loading can readily be seen The plate resistance of the tube does not decrease as rapidly with frequency and therefore plate loading is not as serious a problem as grid loading

A voltage gain of the order of ten is obtained in the radio-frequency tube A voltage step-up of two to four in the antenna tuned circuit gives a total gain of from twenty to forty from antenna input to the grid of the first detector

No difficulties were encountered from regeneration in the radio-frequency stage The frequency response curve of the radio-frequency amplifier shown in figure 20 is quite sym-

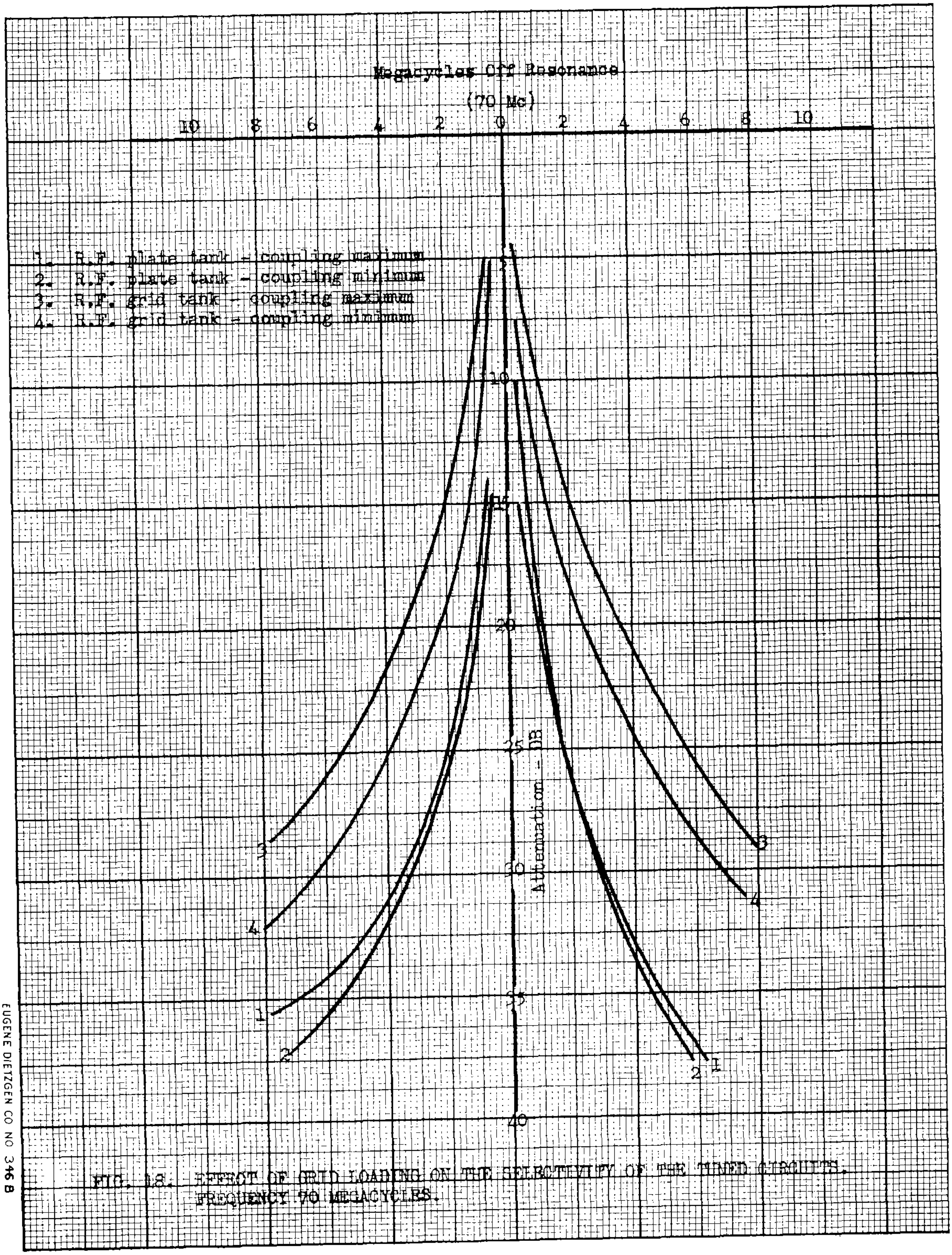

Figure 18.—Effect of grid loading on the selectivity of the tuned circuits. Frequency 70 megacycles.

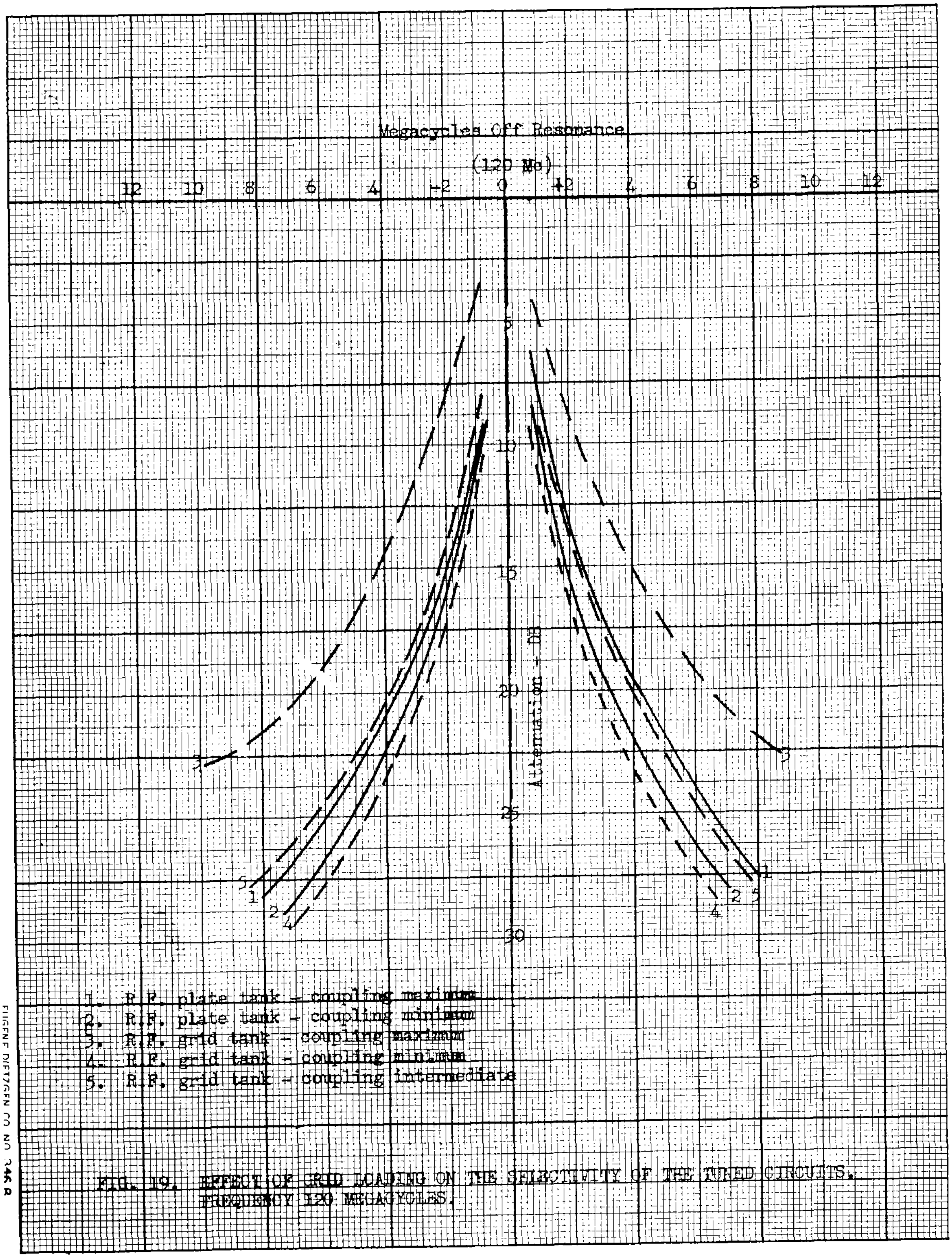

Figure 19.—Effect of grid loading on the selectivity of the tuned circuits. Frequency 120 megacycles.

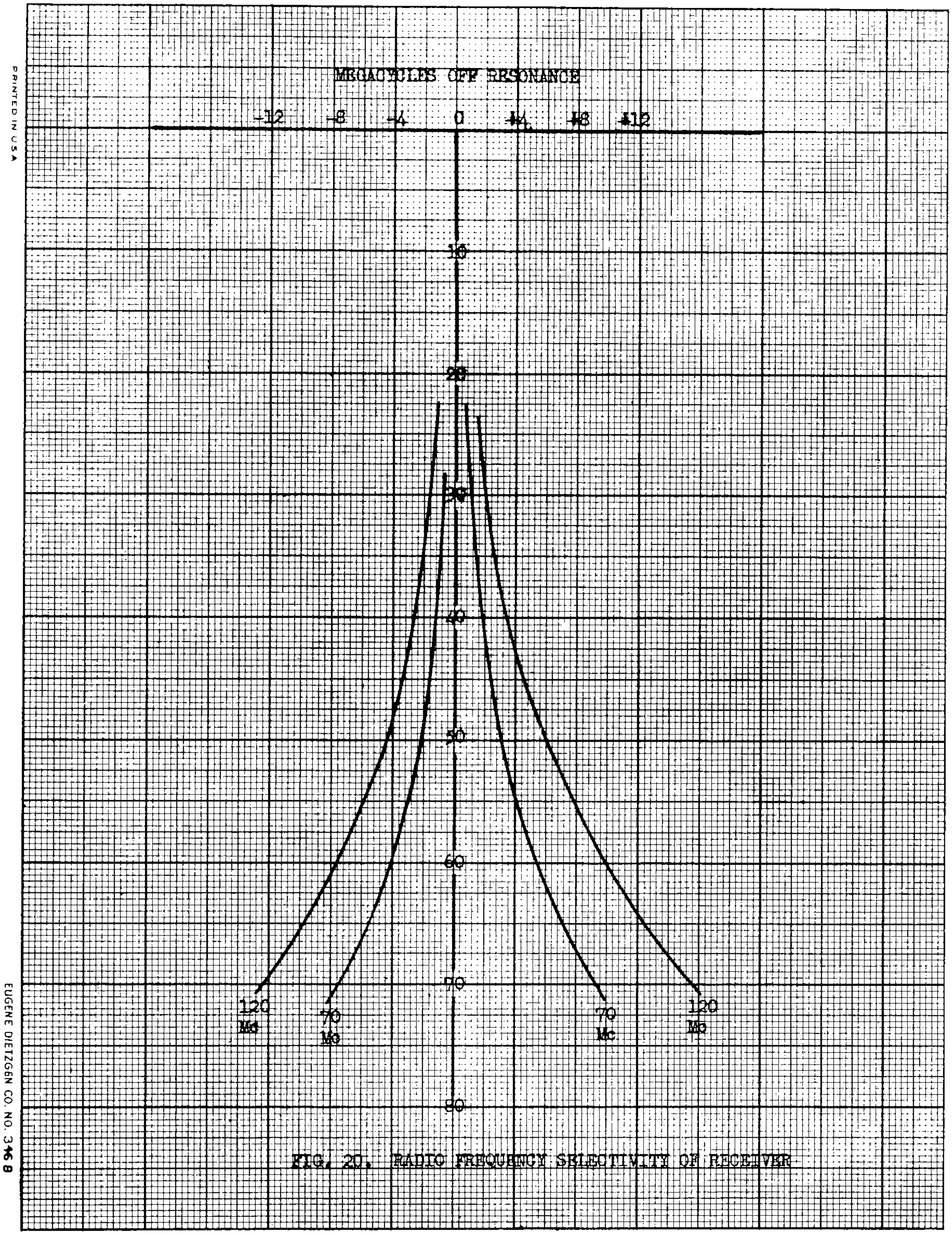

Figure 20. Radio-frequency selectivity of receiver.

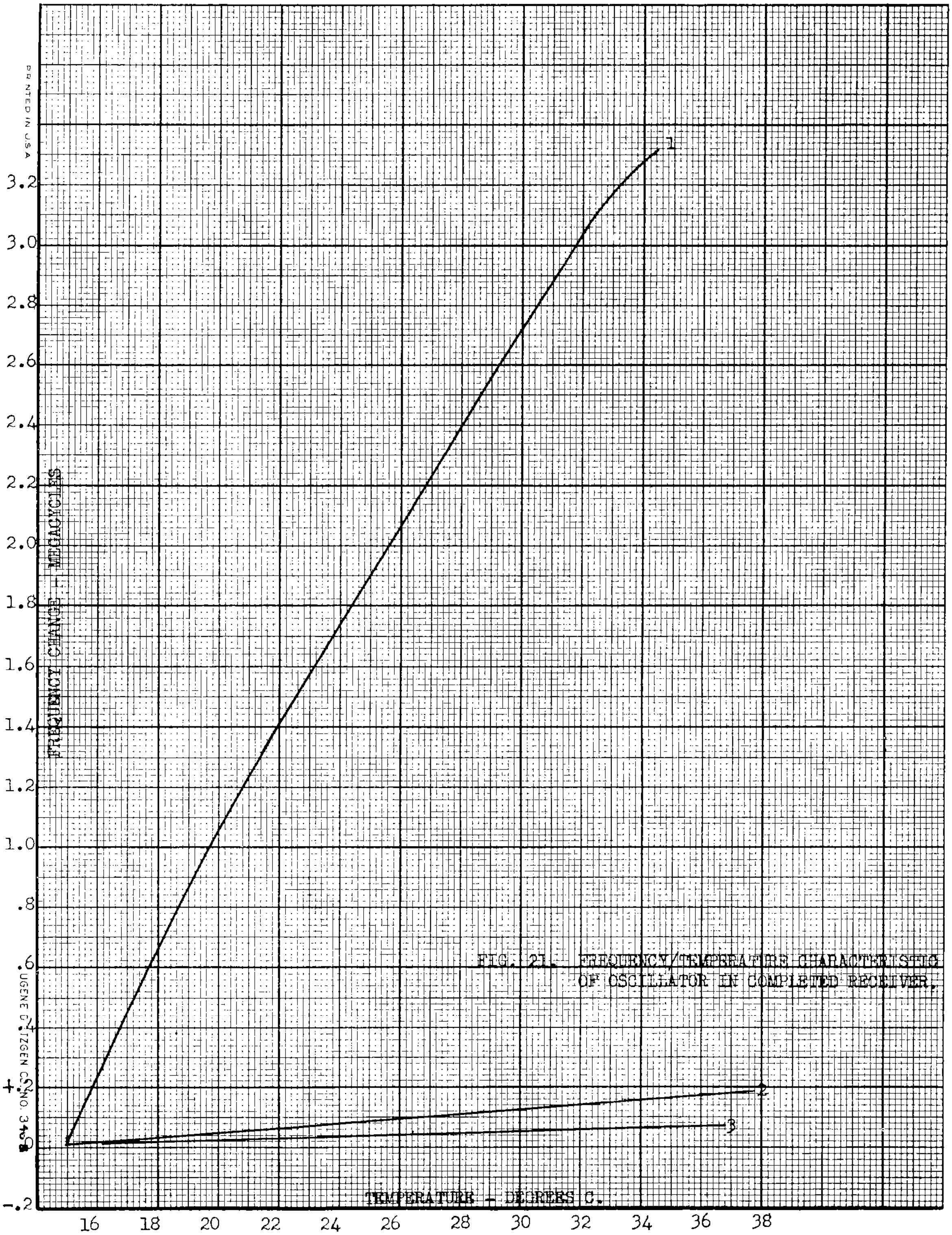

Figure 21.—Frequency/temperature characteristics of oscillator in completed receiver.

metrical, indicating that regeneration is extremely low.

The response at the image frequency obtained from figure 20 is more than 60 db down at 120 megacycles and approximately 75 db down at 70 megacycles.

The range of tuning which can be obtained with the micrometer tuning capacity alone is from 70 to 142 megacycles. The addition of the loading condensers 225 and 226 of figure 12 changes the range from 60 to 132 megacycles.

Heterodyne oscillator.

The frequency stability of a superheterodyne receiver is limited for the most part by the constancy of frequency of the heterodyne oscillator. At the ultra-high frequencies, this becomes a serious problem since the drift, although only a small percentage of the fundamental frequency, may be sufficient to throw the heterodyne frequency outside of the pass band of the intermediate-frequency amplifier.

Three common variables which will affect the frequency, aside from purely mechanical considerations, are: filament voltage, plate voltage, and temperature. The frequency variation resulting from a 2/1 change in filament or plate voltage was of the order of 150 parts per million for the several oscillators described in the early part of this report. This variation is of minor importance since the pass band of the intermediate-frequency amplifier is about 100 kilocycles and no attempt was made to reduce it.

The frequency variation with temperature of the oscillator in the completed receiver with normal plate and filament voltage is shown in figure 21. Curves 2 and 3 were taken with the micrometer condenser at the middle of its range; curve 2 was taken at 115 megacycles with the padding condenser 227 at minimum capacity. Curve 3 was taken with the padding condenser at about ¾ maximum and a frequency of 71 megacycles. For curve 1, the padding condenser 227 was with minimum capacity and the micrometer condenser adjusted to give 71 megacycles. From these curves, it is apparent that the oscillator is overcompensated for temperature change, the frequency increasing with temperature. Since the capacity of the micrometer condenser varies inversely with the spacing, the capacity change due to the change in spacing brought about from the unequal linear expansion of the copper and aluminum tubes will be greatest when this spacing is close. This is clearly shown by curve 1.

From figure 21, it can be seen that properly proportioning the tuning capacity between the padding condenser and the micrometer condenser will give a frequency stability satisfactory for normal temperature changes after a short warming up period. Several months of use in an airplane has shown this to be the case, the drift being very slight at 125 megacycles.

Intermediate-frequency amplifier.

Adjustable coupling between the tuned circuits in each intermediate-frequency transformer serves two purposes: first, a means of obtaining the desired pass band for the amplifier; and second, the adjustment of the amplifier with a minimum of test equipment.

The two coils of each transformer are connected so that the inductive and capacity coupling oppose each other, permitting a closer spacing between the coils and consequently a smaller unit. Since the two tuned circuits are overcoupled to obtain a flat top on the resonance curve, each circuit must be tuned to resonance when the coupling is at some value less than critical. The line-up procedure then is to start with the diode transformer, reduce the coupling to less than critical value and tune each circuit to resonance, the test signal being introduced at the grid of the second intermediate-frequency amplifier tube. The coupling is then increased until the desired pass band is obtained, no further adjustments being made in the tuning of the circuits. The input is then moved to the first intermediate amplifier grid and the same procedure followed as before. This is again repeated with the input at the grid of the first detector.

Curves 1, 2, and 3 of figure 22 show the frequency response of the diode transformer for several values of coupling. Couplings A, B, and C refer to two, eight, and ten turns of the adjusting screw. Curve 4 is for the complete amplifier adjusted for a band width of 90 kilocycles.

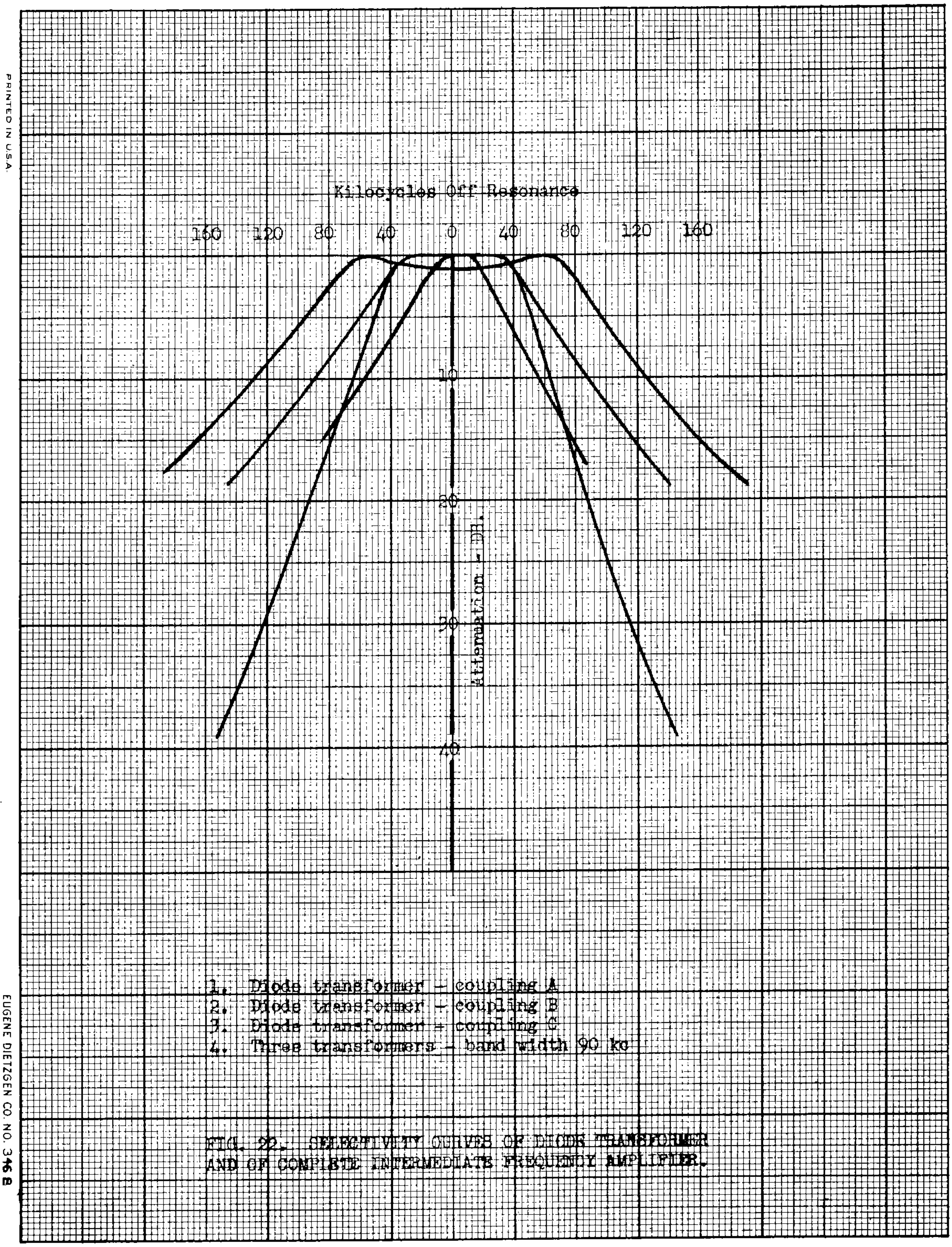

Figure 22.—Selectivity curves of diode transformer and of complete intermediate-frequency amplifier.

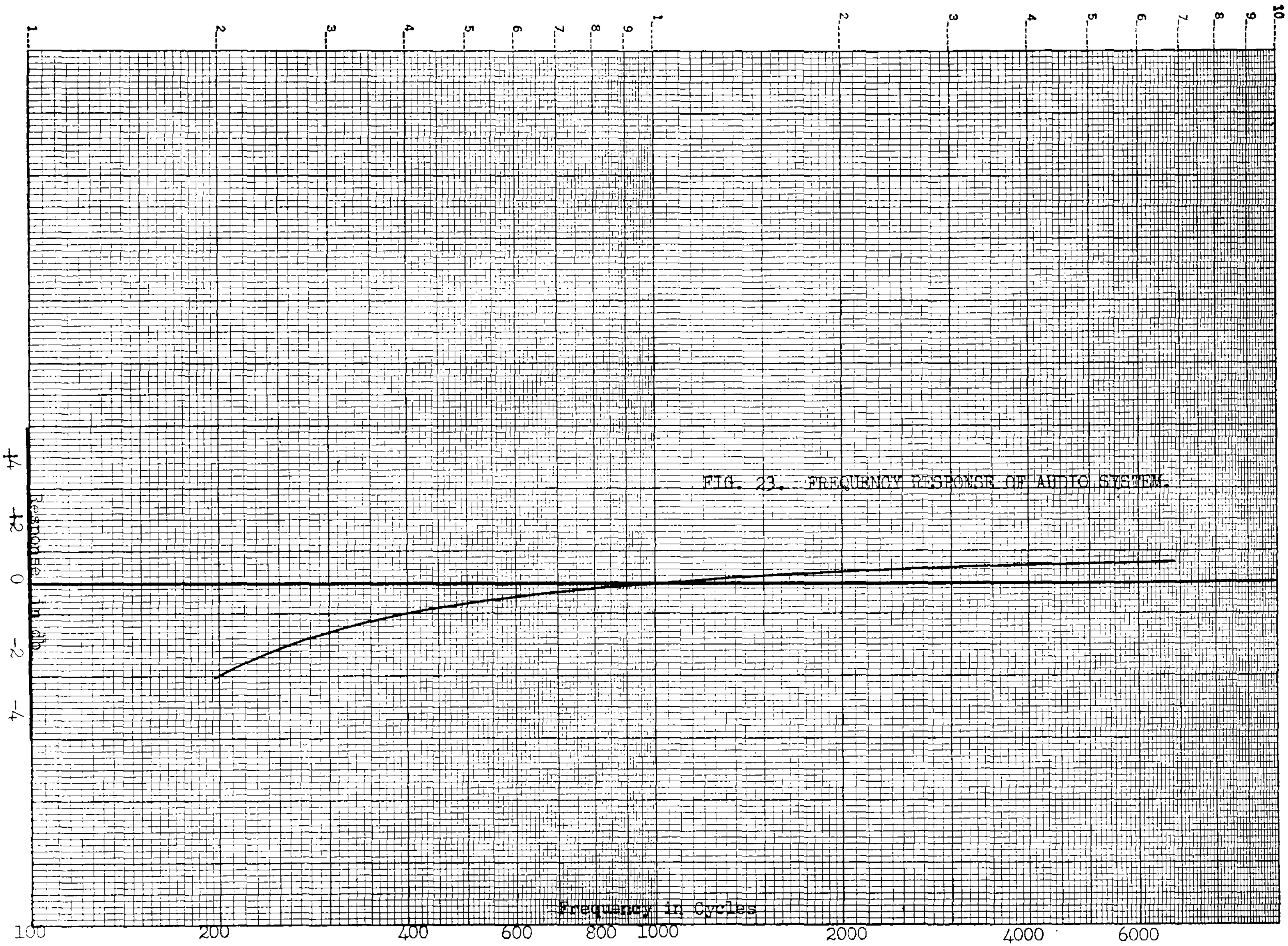

Figure 23.—Frequency response of audio system.

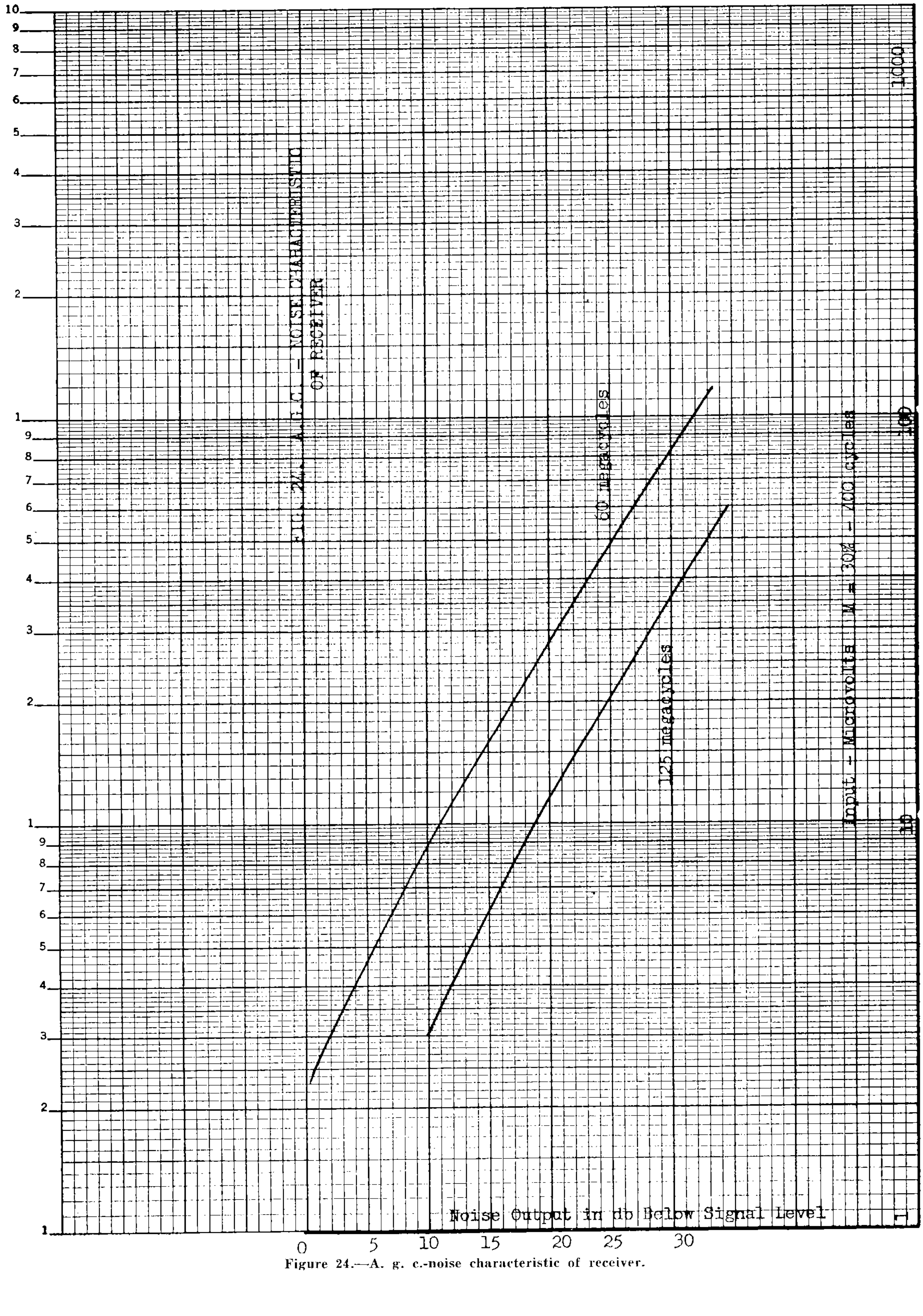

Figure 24.—A. g. c.-noise characteristic of receiver.

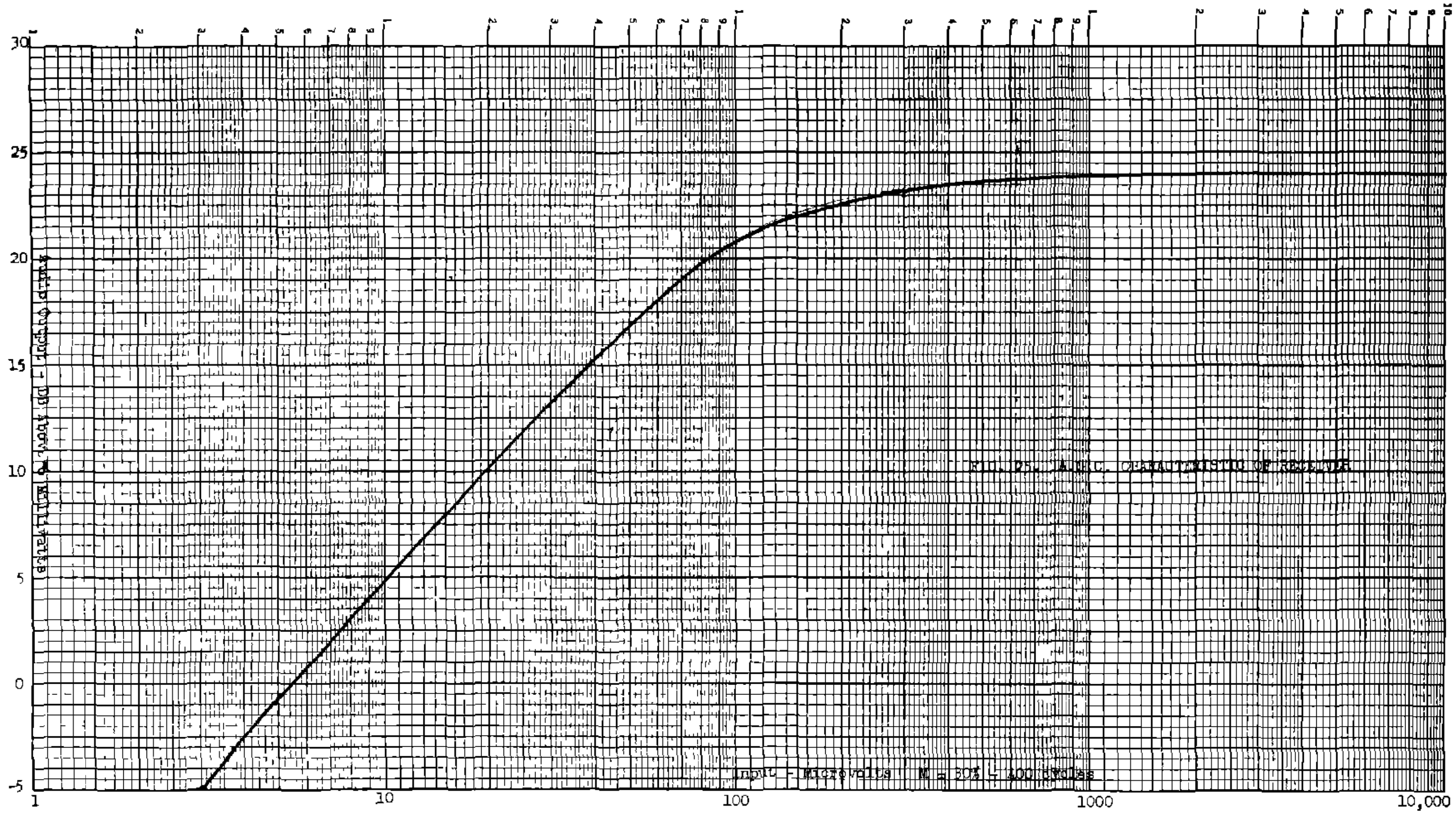

Figure 25—A g c characteristic of receiver

Audio amplifier, a. g. c., and noise test

The frequency response of the audio system is shown in figure 23.

A curve found useful in evaluating the over-all performance of a receiver is the a. g. c.-noise curve. These data are obtained by measuring the audio output of the receiver with and without modulation for various input signal levels. A modulation of 30 percent at 400 cycles is used for this test. Figure 24 is the a. g. c.-noise curve of the receiver taken at 60 and 125 megacycles and indicates the minimum signal levels at which the receiver may be used as limited by the receiver noise.

The a. g. c. characteristic of the receiver is shown in figure 25. From this curve, it is observed that the sensitivity of the receiver is about 5.5 microvolts.

CONCLUSION

Although the space required for the coaxial line type of tuned circuit is greater than that necessary for the conventional coil and condenser type, it is felt that the advantages of greater selectivity, more effective shielding, and constancy of tuning justify the additional space required. The circuits, being of high Q, are more susceptible to the effects of loading and proper consideration must be made for the low grid impedance of tubes at the higher frequencies. The frequency drift with temperature is sufficiently low over the greater proportion of the tuning range. The frequency drift could be further reduced by separating the functions of tuning and compensating condensers. This could be accomplished with a type of construction simple enough to be practical.

Several months of use in flight testing ultra-high-frequency radio ranges have proven that the application of the coaxial type of tuned circuit to a receiver for use in aircraft is entirely practical and the performance obtained justifies the slight additional weight and space required. The acorn tubes have performed satisfactorily with no evidence of short life.

REFERENCES

1 C W Hansell and P S Carter, "Frequency control by low power factor line circuits," Proc I R E, April 1936

2 W R Ferris "Input resistance of vacuum tubes as ultra-high frequency amplifiers," Proc I R E, January 1936

3 E J Sterba and C B Feldman, "Transmission lines for short wave systems" Proc I R E, July 1932

Table I

Metal	Weight (lb /cu in)	Conductivity (% IACS)	Resistivity (ohms/cm³ × 10⁶)	Coefficient of expansion (parts per 10⁶ per degree C)
Copper	0 323	100	1 730	17 7
Copper, 1% lead	323	99	1 750	17 9
Copper, 5% zinc	320	55	3 145	18 1
Copper, 15% zinc [1]	316	38	4 55	18 7
Copper, 30% zinc	308	27	6 4	19 9
Bronze, copper 97 5, silicon 1 5, zinc 1 0 [2]	315	13	13 3	17 9
Aluminum, 2S–H	098	57	3 04	25 9
Aluminum, 51S–T	097	45	3 85	25 4
Aluminum, 17S–T	101	30	5 77	24 8
Silver		106	1 63	
Chromium		67	2 6	
Bronze, copper 98 25, manganese 0 25, silicon 1 5 [3]	316	12		18
Iron (99 98%)		17 6	9 83	

[1] Red brass used for plumbing pipe [2] Olympic bronze type D [3] Everdur No 1015

Table II

Osc No	Curve No	Tap	C_1	R_g	f_{mc}	Slope dial div /Mc	Slope uufd/Mc
1	4	1	10	0 050	80 475	38 0	8 55
	1	1	24	050	80 44	5 5	1 24
	2	1	100	050	80 415	2 5	0 56
	3	2	24	100	78 88	4 0	0 9
	5	3	24	100	78 035	4 0	0 9
	1	1	24	050	61 2	35 0	7 9
	2	1	100	100	61 26	27 0	6 1
	3	2	100	100	61 1	10 0	2 2
	4	4	100	100	60 996	3 0	0 67
2	3	1	10	050	73 78	40 0	9 0
	2	1	100	050	73 70	4 0	0 9
	1	2	10	050	79 98	8 0	1 8
	4	2	100	050	79 676		
3	1		((10	050	83 73	40 0	9 0
	2		(10	050	83 645	33 0	7 42
	3		10	050	82 53	5 0	1 125
	4		10	050	82 585	4 0	0 9
4	1		50	050	80 8785	34 0	7 65
	2		150	050	80 878	34 0	7 65
5	1	½T	60	050	80 635	4 0	0 9
	2	1½T	10	050	80 625	4 0	0 9
	3	2½T	10	050	78 050	1 0	0 225

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