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DEVELOPMENT OF AN IMPROVED CRYSTAL EXCITER UNIT

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CONTENTS

	Page
SUMMARY	1
INTRODUCTION	1
THE GRID-PLATE CONNECTED CRYSTAL CIRCUIT	1
STABILITY	2
OUTPUT POWER AND CRYSTAL CURRENT	3
THE DYNATRON CRYSTAL CIRCUIT	11
CONCLUSIONS	12
REFERENCES	14
PARTS LIST	14

ILLUSTRATIONS

Figure

1. Schematic diagram of the exciter unit
2. Frequency stability of the grid-plate connected oscillator with changes in crystal plate tank condenser setting
3. Frequency stability of the grid-plate connected oscillator with changes in plate voltage
4. Grid-plate connected crystal oscillator. Output in watts ($L_1 = 1{,}500$ microhenries)
5. Grid-plate connected crystal oscillator. Output in watts ($L_1 = 200$ microhenries)
6. Grid-plate connected crystal oscillator. Output in watts ($L_1 = 1{,}200$ and 50 microhenries)
7. Variation of output power and r-f volts across crystal (r-m-s) with different values of L_1
8. Grid-plate connected crystal oscillator. Radio-frequency volts across crystal (r-m-s) ($L_1 = 1{,}500$ microhenries)
9. Grid-plate connected crystal oscillator. Radio-frequency volts across crystal (r-m-s) ($L_1 = 750$ microhenries)
10. Grid-plate connected crystal oscillator. Radio-frequency volts across crystal (r-m-s) ($L_1 = 750$ and 80 microhenries)
11. Grid-plate connected crystal oscillator. Voltage available to drive multiplier grid
12. Comparison of power output from exciter unit when tripling in the crystal plate circuit and doubling in the driven 807 plate circuit and vice versa
13. Front view of exciter unit
14. Rear view of exciter unit with dust cover removed
15. Top view of exciter unit with dust cover removed
16. Schematic diagram of 57 crystal oscillator
17. Grid-plate connected crystal oscillator. Recommended safe crystal r-m-s volts across a crystal, and comparative crystal r-m-s voltages of the 57 dynatron oscillator and the grid-plate connected oscillator

DEVELOPMENT OF AN IMPROVED CRYSTAL EXCITER UNIT

SUMMARY

A crystal oscillator multiplier circuit of high stability and output power is described, and the factors affecting the stability, crystal current, and output power of the oscillator are discussed. An exciter unit for an ultra-high-frequency transmitter which makes use of the crystal oscillator multiplier in conjunction with an 807 type tube as a multiplier is described.

INTRODUCTION

During the past few years, the Civil Aeronautics Authority has made use of a dynatron crystal oscillator employing a type 57 tube. This oscillator was adopted because of its relatively high harmonic output with low crystal current. Recent developments in the crystal oscillator art have indicated that an oscillator with the crystal connected from grid to plate will give superior performance. It was decided, therefore, to investigate this type of circuit to determine its advantages for the purpose of providing a crystal oscillator exciter unit which would have a stability equivalent to the dynatron oscillator, but with a higher output power.

THE GRID-PLATE CONNECTED CRYSTAL CIRCUIT

The oscillator circuit investigated, shown in figure 1, is essentially an electron coupled oscillator, and makes use of a type 807 tube. The

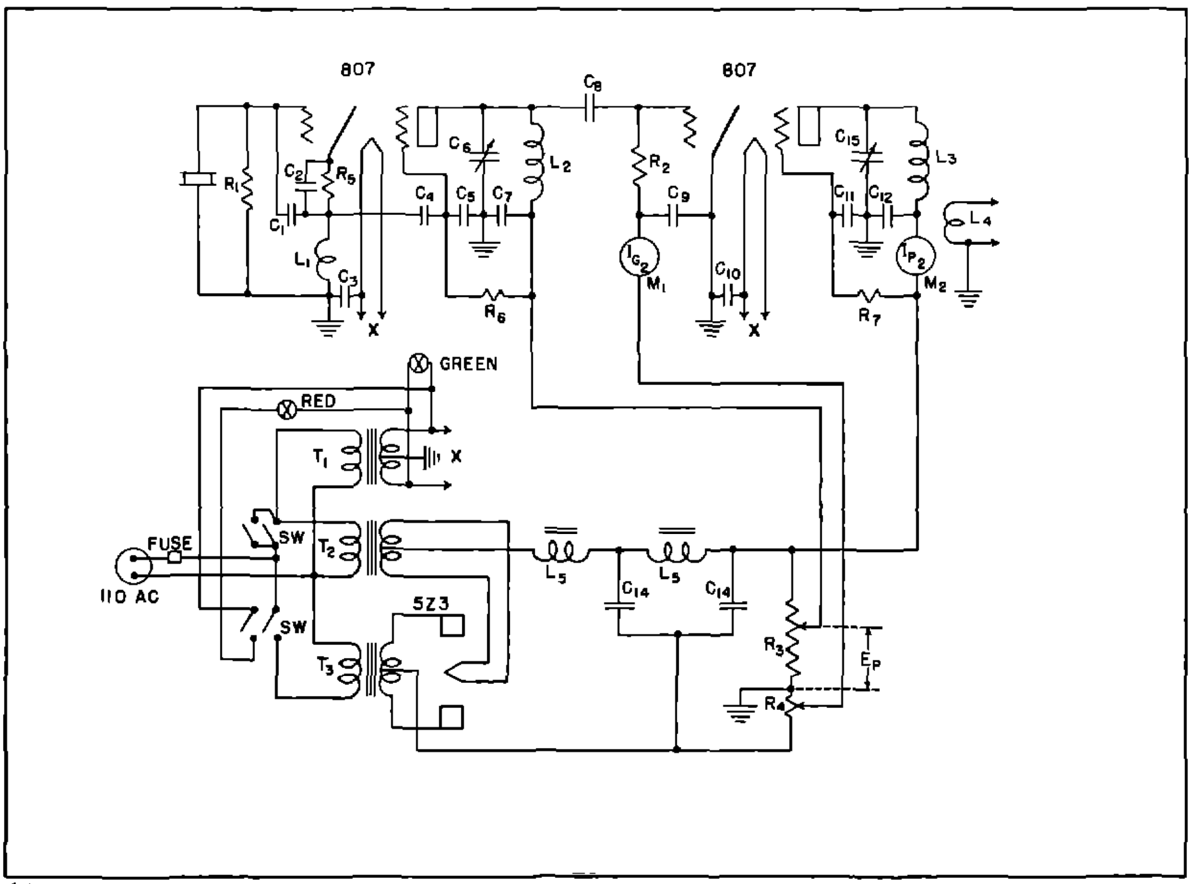

FIGURE 1.—Schematic diagram of the exciter unit.

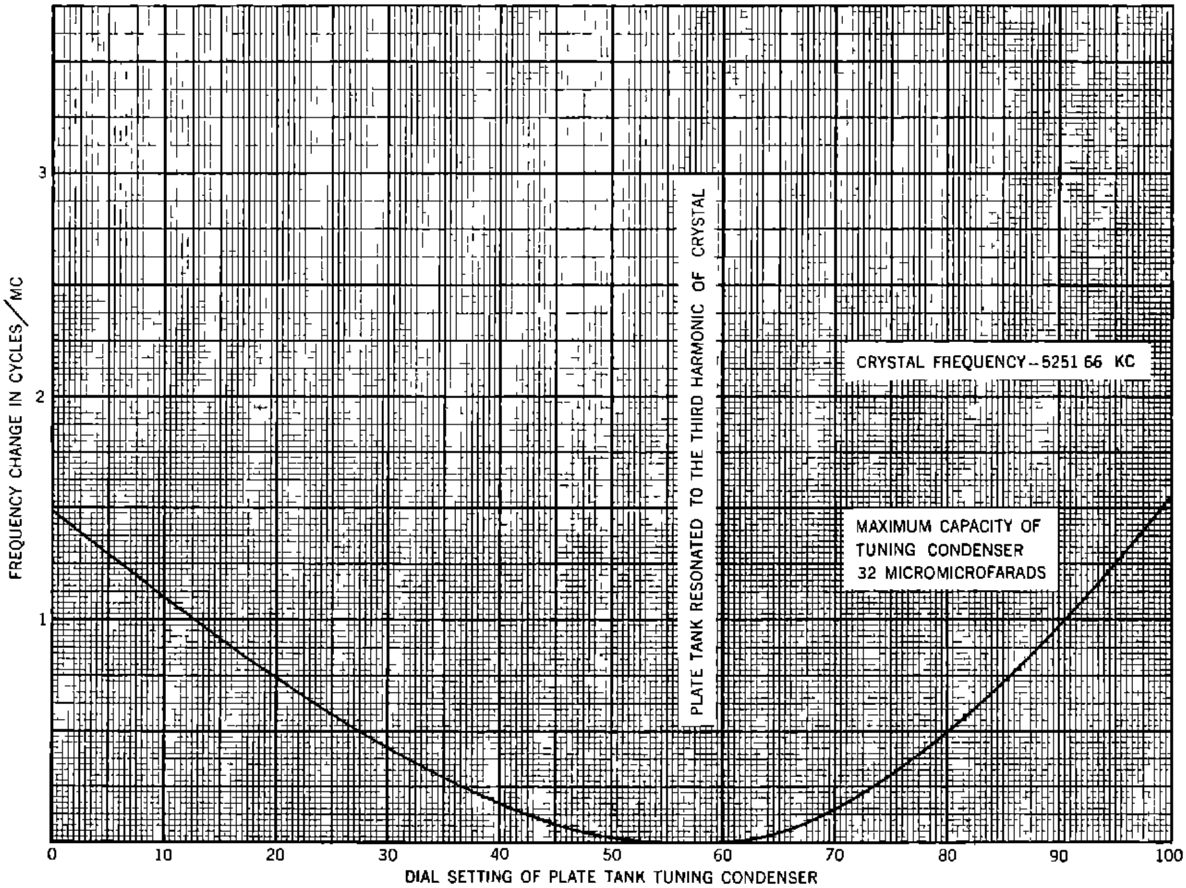

FIGURE 2.—Frequency stability of the grid-plate connected oscillator with changes in crystal plate tank condenser setting.

advantages to be derived from the use of this circuit were originally pointed out to the Authority by the Bell Telephone Laboratories. The crystal oscillator circuit is composed of the grid, cathode and screen grid—the screen grid operating at ground potential with respect to the radio-frequency voltages. Hereafter, this circuit will be referred to as the grid-plate connected crystal circuit. The circuit comprising the crystal, grid, cathode and screen operates at the fundamental frequency of the crystal. The plate tank, which delivers excitation to the 807 multiplier stage may be tuned to the fundamental or harmonic frequency of the crystal. Since the screen is at ground potential to radio frequency, it acts as a shield separating the frequency controlling part of the circuit from the load circuit.

There are four important factors by which a particular crystal oscillator circuit is judged: (1) Stability, (2) output power, (3) crystal current, and (4) ease of starting. To be a source of true frequency, the output frequency must be independent of the factors which may change under normal operating conditions such as ambient temperature, supply voltage and tuning of circuits. To be of maximum utility in transmitting circuits, it must deliver sufficient power to drive the grid of the following amplifier or multiplier tube. To be reliable, the crystal current must be kept low so that the crystal will not be subjected to undue stresses which might cause it to fracture. Furthermore, the circuit should oscillate easily so as to insure consistent operation of the transmitter.

STABILITY

The frequency variations due to changes in ambient temperature are a function of the circuit and the cut of the crystal, and may be limited to three parts per million per degree centigrade change in temperature, by proper choice of the physical and electrical dimensions of the crystal

Frequency stability measurements were made by comparing the audio-frequency beat note between the crystal oscillator and a stable variable oscillator of a National HRO receiver The short time frequency stability of an HRO receiver was found to be sufficient for this purpose

The stability of the circuit as referred to the tuning of the output tank (L_2, C_6) is shown in figure 2 In this case the maximum deviation was 1 5 parts per million

The crystal frequency changed 42 cycles for a change in high voltage (E_p) from 50 to 450 volts or 8 parts per million This variation is a linear function as shown in figure 3

OUTPUT POWER AND CRYSTAL CURRENT

The power available in the plate circuit (L_2, C_6) is largely controlled by the plate voltage and the value of L_1 (C_1 remaining fixed) For several values of L_1 the power output was measured as the plate voltage was varied from 200 to 450 volts These data were obtained with the plate tank tuned to the fundamental, 2d, 3d, and 4th harmonics of the crystal These results are shown in figures 4, 5, and 6 In order to determine the optimum values of L_1, the power output for the various values of L_1 is plotted in figure 7 for a fixed value of plate voltage (300 volts)

These curves indicated that the optimum value of L_1 for the plate tank tuned to the fundamental should be 750 microhenries This inductance, however, caused a slight instability, which was removed by inserting 750 ohms in series with the coil

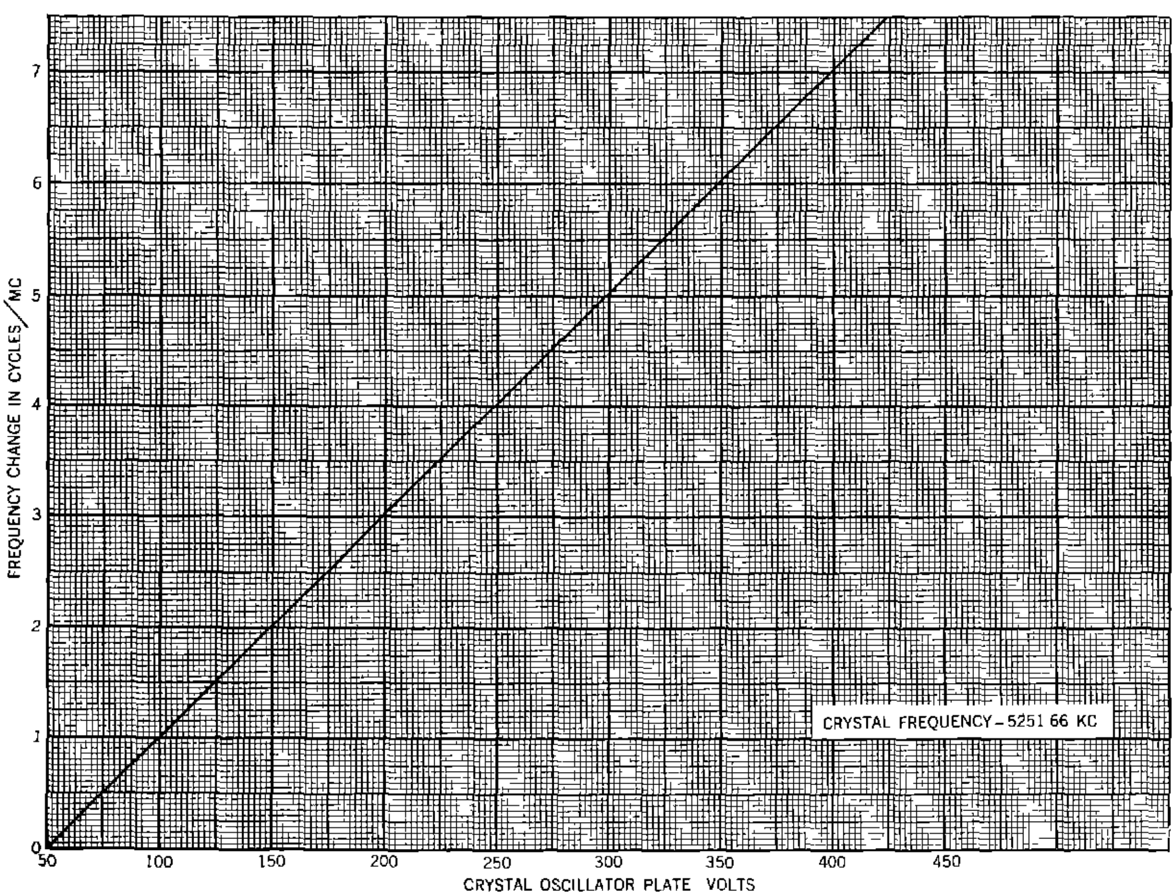

FIGURE 3 —**Frequency stability of the grid-plate connected oscillator with changes in plate voltage**

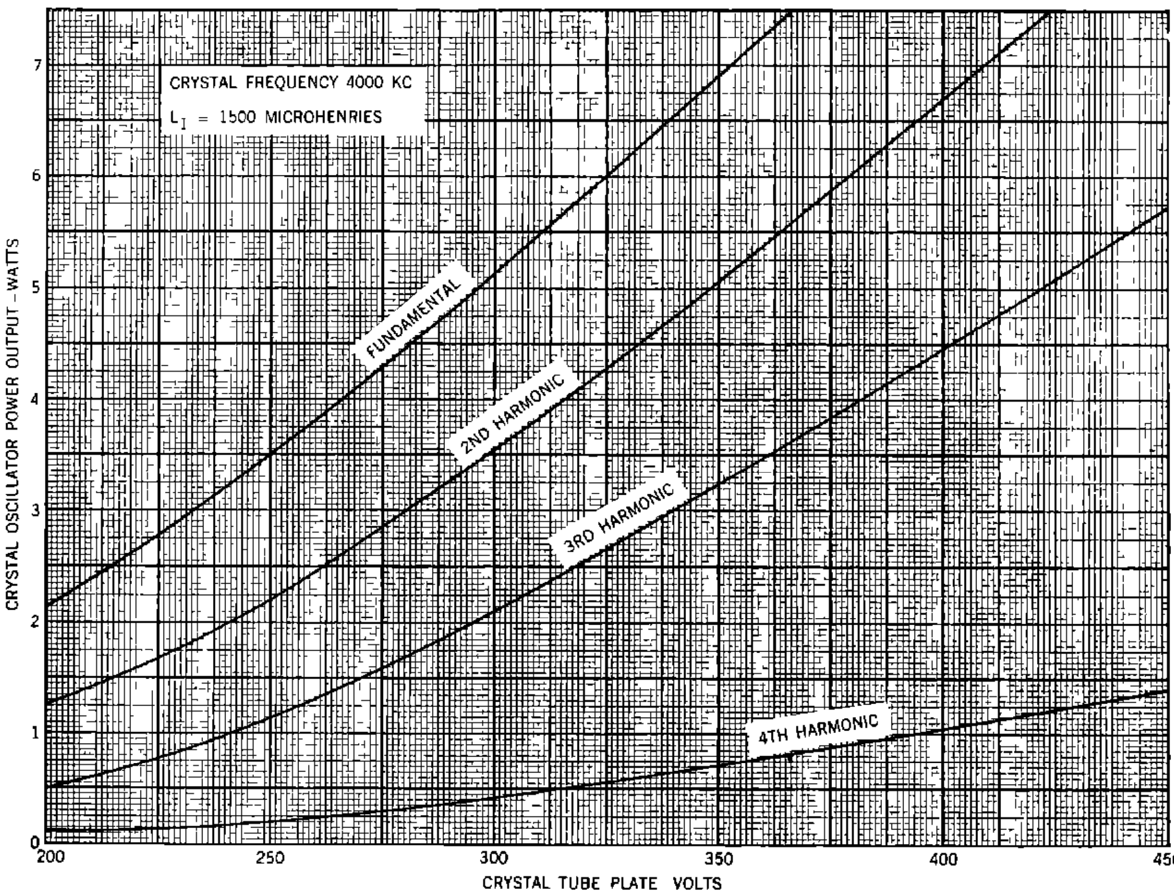

FIGURE 4.—**Grid-plate connected crystal oscillator Output in watts**

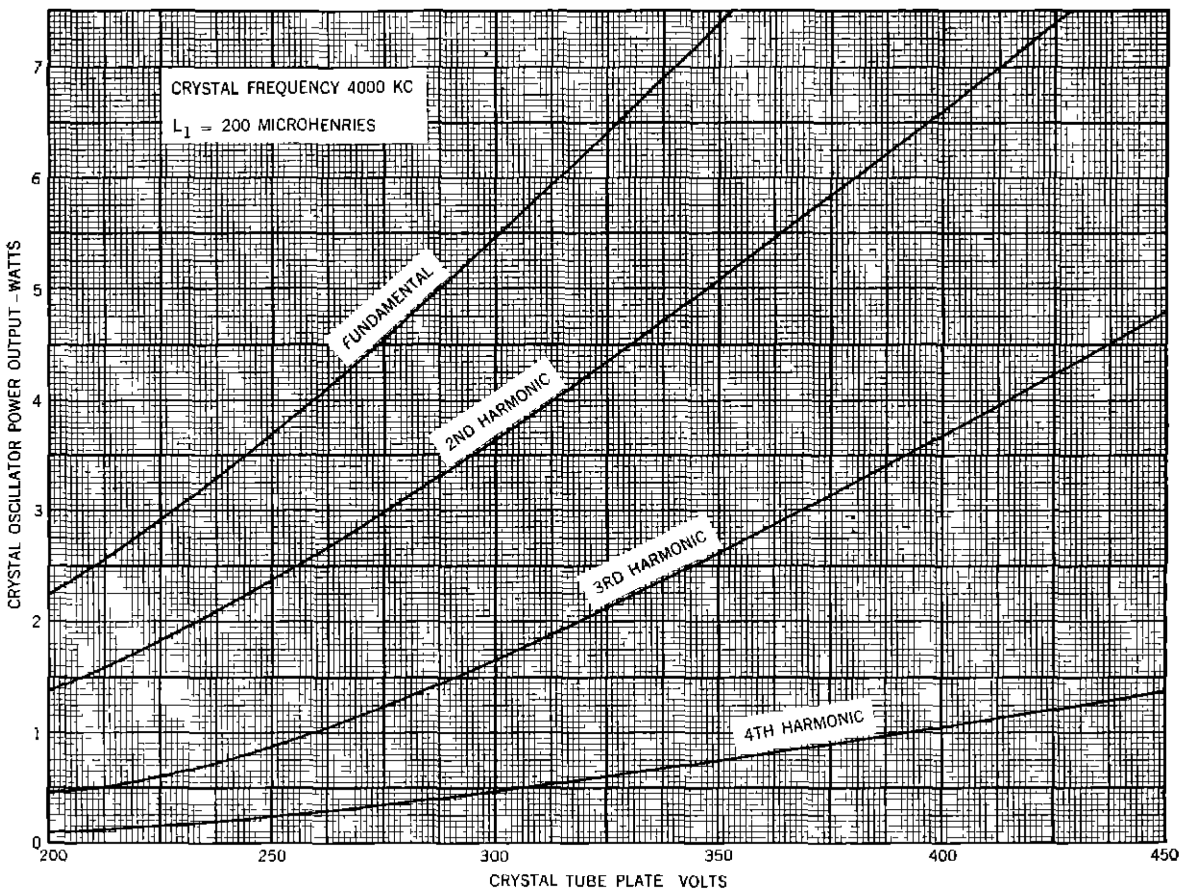

FIGURE 5 — Grid-plate connected crystal oscillator Output in watts

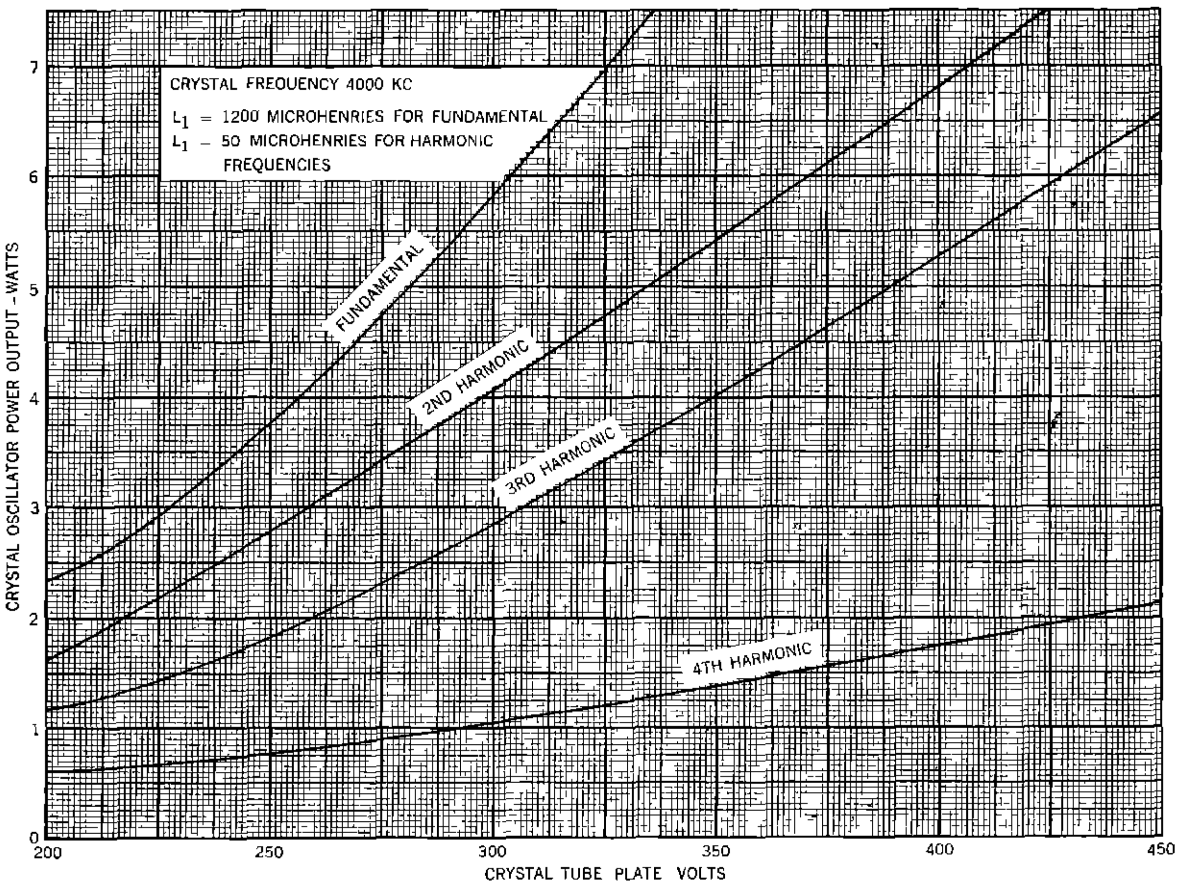

FIGURE 6.—**Grid-plate connected crystal oscillator Output in watts**

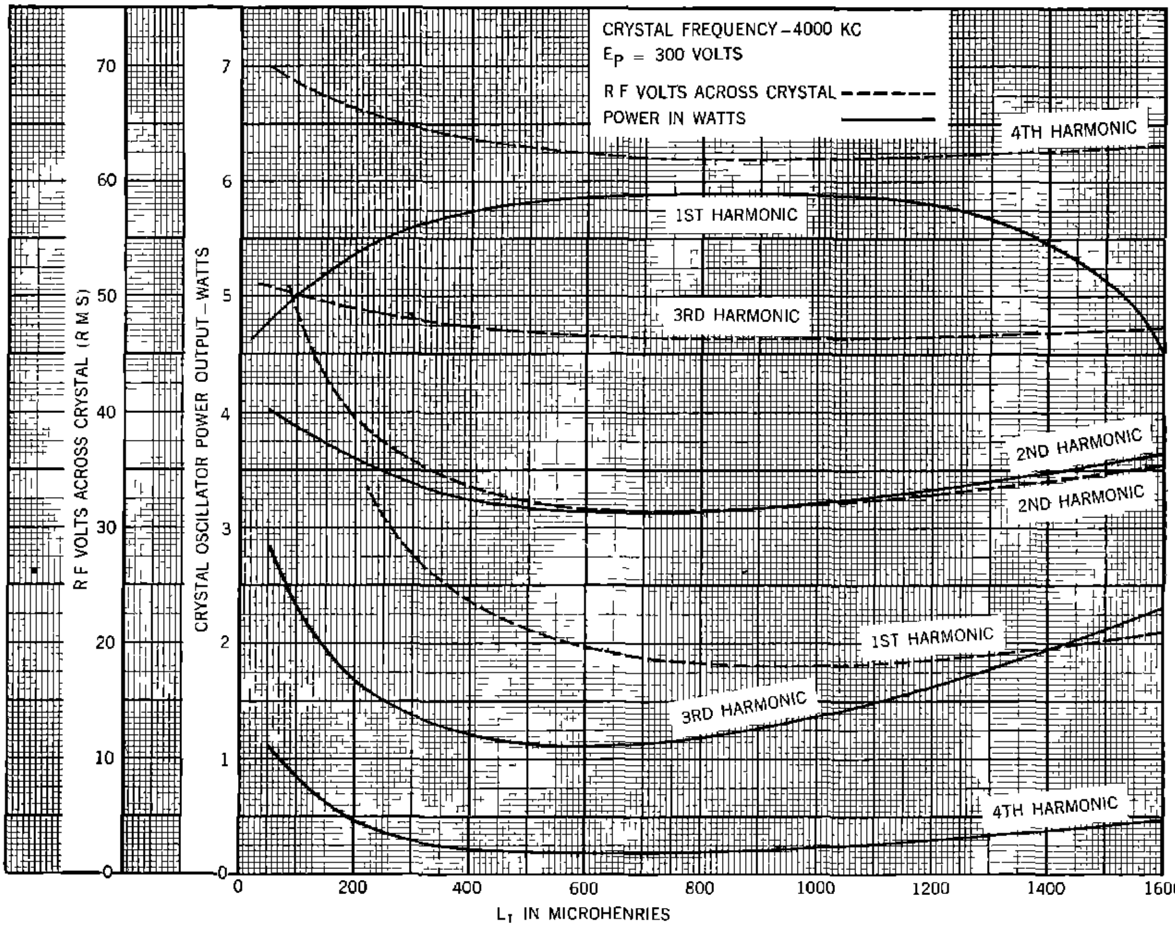

FIGURE 7—Variation of output power and R-F volts across crystal (r-m-s) with different values of L_t.

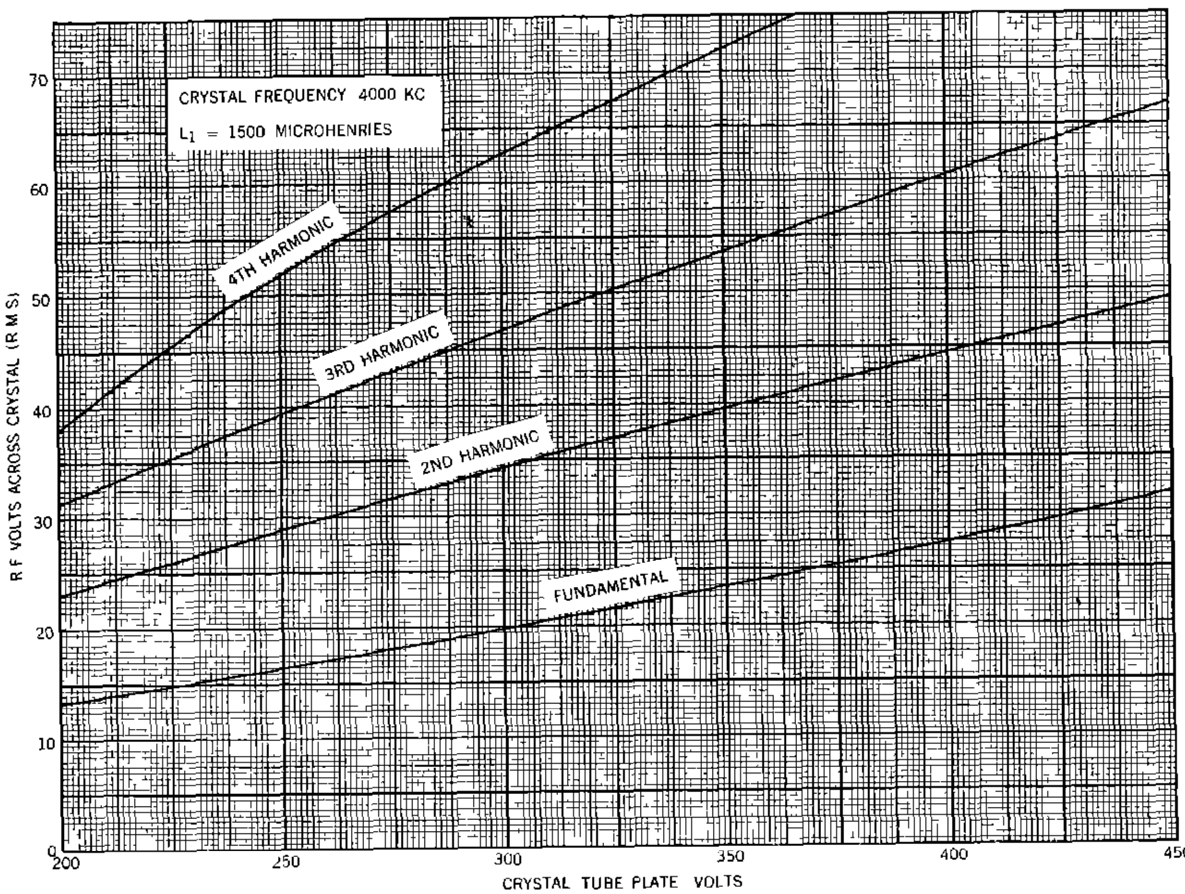

FIGURE 8—Grid-plate connected crystal oscillator R-F volts across crystal (r-m-s)

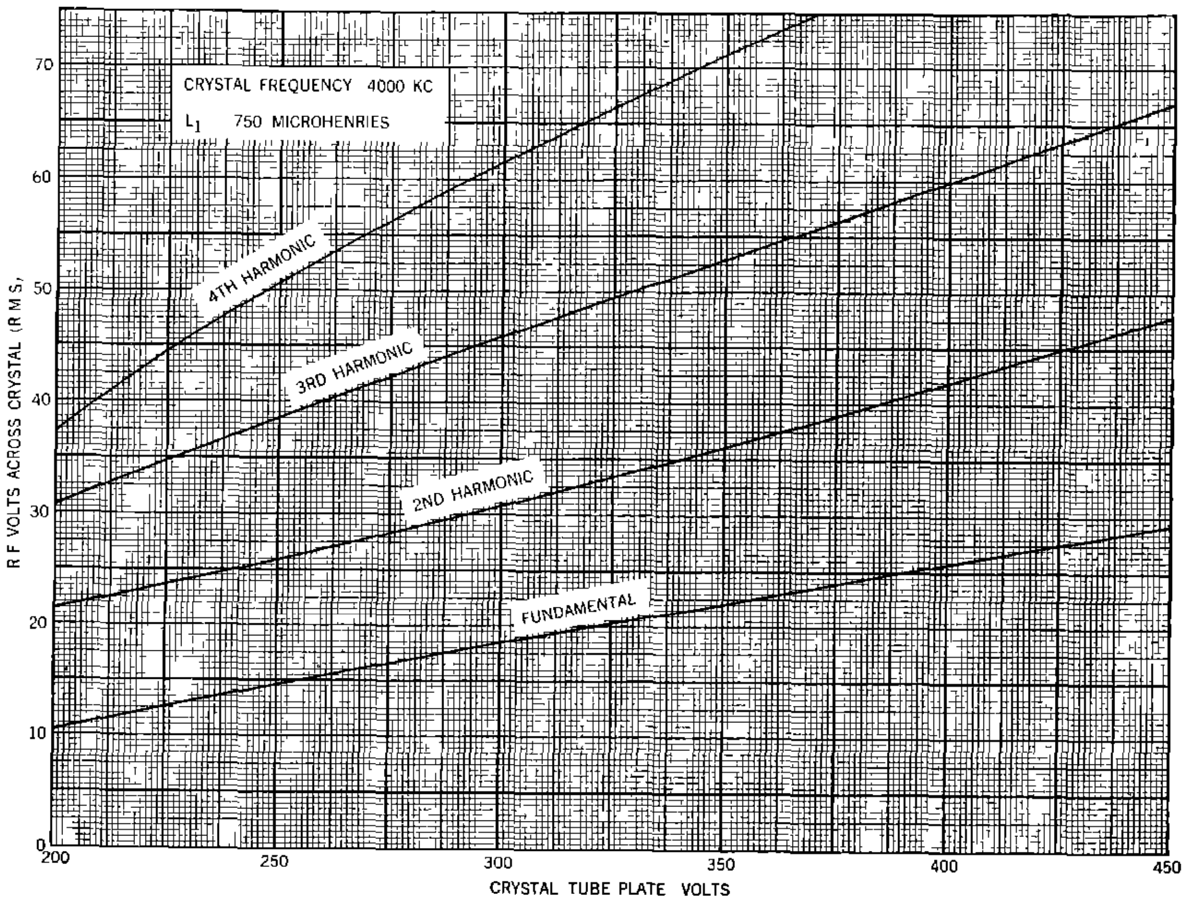

FIGURE 9—Grid-plate connected crystal oscillator R-F volts across crystal (r-m-s)

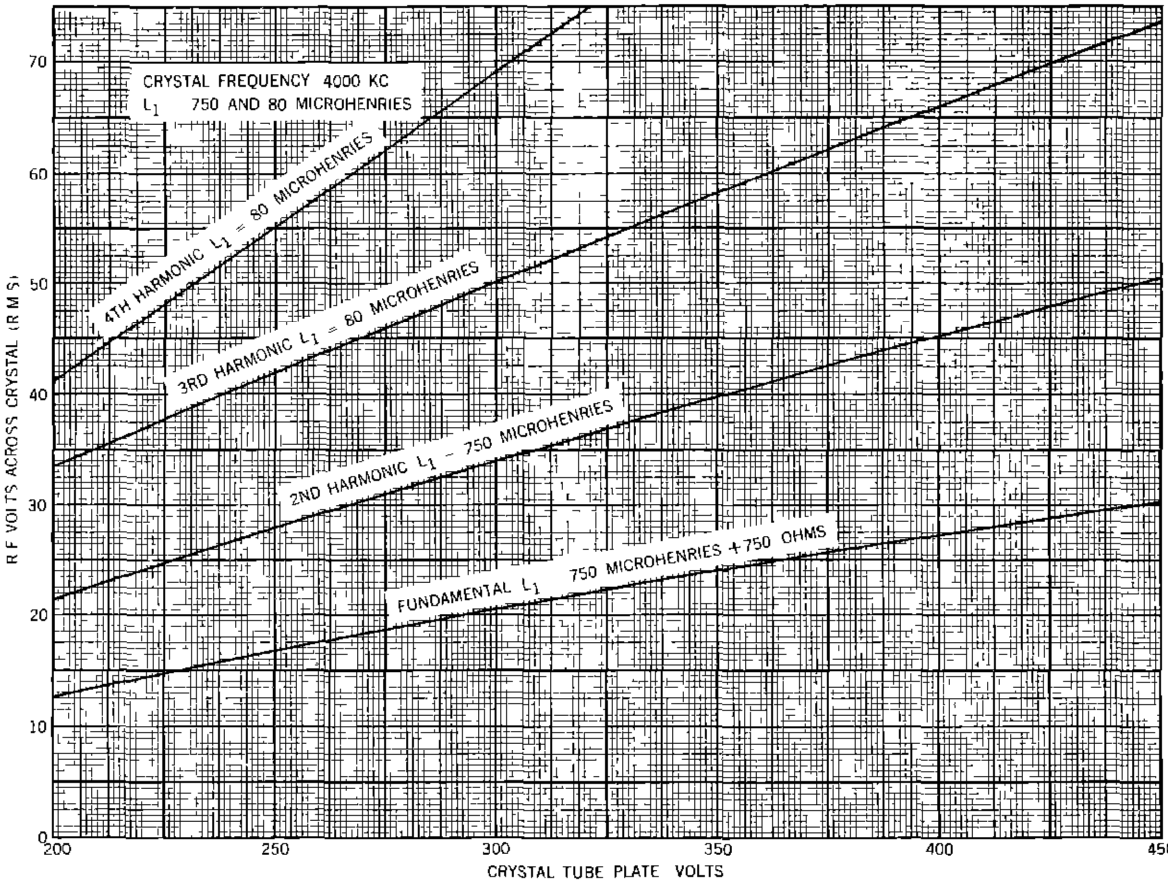

FIGURE 10—**Grid-plate connected crystal oscillator R-F volts across crystal (r-m-s)**

A similar procedure was followed to determine the effect of L_1 and plate voltage on crystal current These data are shown in figures 8, 9, and 10 The crystal current for various values of L_1 is also plotted on figure 7 for the same plate voltage (300 volts)

From figure 7 it is seen that the optimum value of L_1 will be a compromise between maximum power output and minimum crystal current The optimum values chosen from the curve are

Plate tank tuned to—	L_1 in microhenries
Fundamental	750 plus 750 ohms
2d harmonic	200
3d harmonic	80
4th harmonic	80

In the final design, 750 microhenries were used for the 2d harmonic since it represented a reduction of only about 12 percent in output and reduced the number of different coils required In this particular oscillator it was found that the crystal radio frequency current in milliamperes was twice the radio-frequency voltage (r-m-s) across the crystal

The output voltage available to drive an amplifier or multiplier stage was determined and is shown in figure 11 In this case the second stage is also an 807 With a 4-megacycle crystal, the power output of the multiplier stage at 24 megacycles is shown in figure 12 for various values of multiplier plate voltage Two curves are shown, one for tripling in the oscillator plate circuit and doubling in the multiplier, the other for doubling in the oscillator and tripling in the multiplier The power output from the multiplier is greater when tripling in the crystal oscillator and doubling in the multiplier than when doubling in the oscillator and tripling in the multiplier state This is due to the fact that the multiplier is more

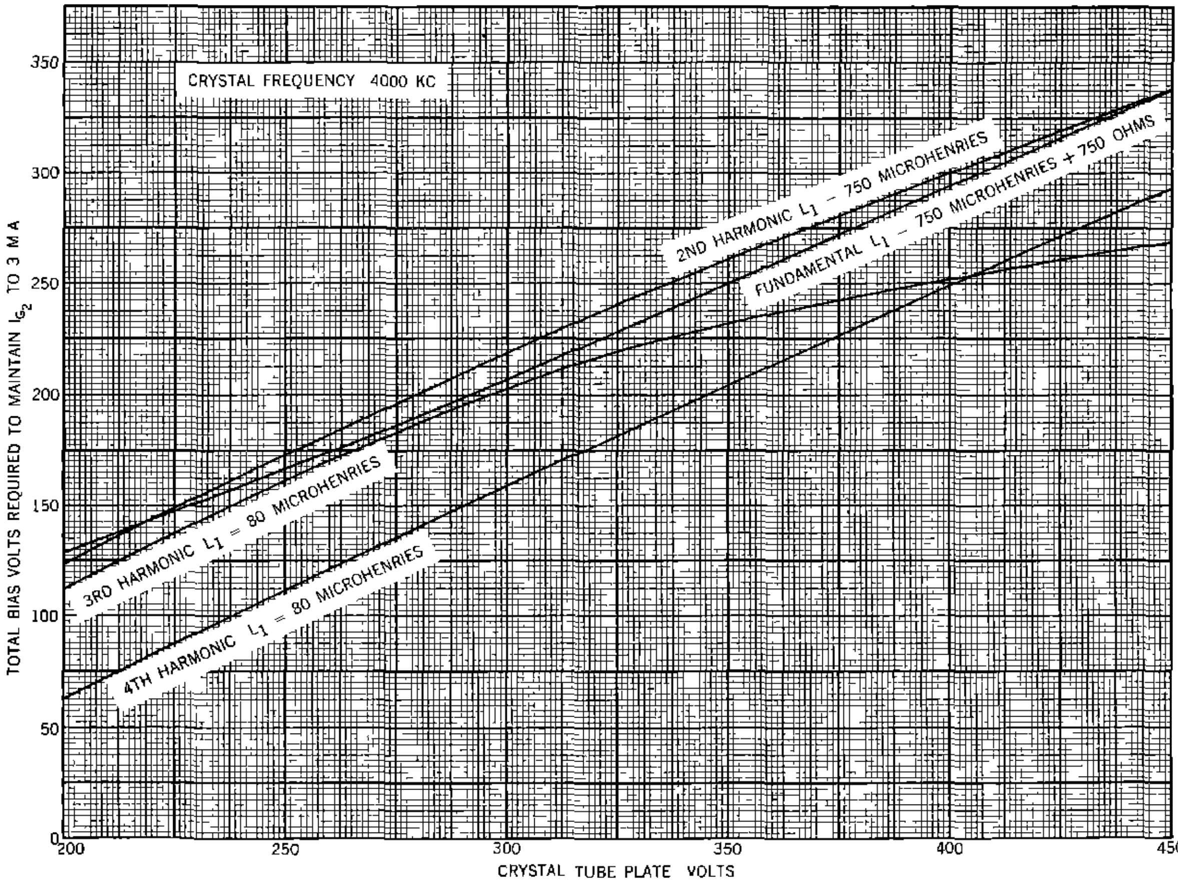

FIGURE 11.—**Grid-plate connected crystal oscillator Voltage available to drive multiplier grid**

efficient when operating as a doubler With a multiplier plate voltage of 500, an output of 20 watts was obtained at 24 megacycles In either case ample power is available to excite an amplifier or multiplier of the HK54 type

Figures 13, 14, and 15 are front, rear, and top views of the grid-plate connected exciter unit complete with crystal oscillator multiplier stage, and power supply designed for relay rack mounting

THE DYNATRON CRYSTAL CIRCUIT

The dynatron crystal circuit referred to in the introduction is shown schematically in figure 16 In this circuit a type 57 tube was used with the screen operated at a higher potential than the plate This circuit was used principally because it was possible to obtain high order harmonics in the plate circuit and yet maintain low crystal currents The greatest disadvantage was in the relatively low output power and the high plate and screen voltages on a receiving type tube Although the 57 operated for extended periods with 500 to 600 volts on the screen, this is not a desirable condition Furthermore, even though the crystal current seldom exceeded 45 milliamperes, the measured crystal voltage was excessive The r-m-s crystal voltage of the circuit described in this report and the crystal dynatron circuit have been plotted in figure 17 together with the curve of safe values as recommended by the Bell Telephone Laboratories From figure 17 it is evident that the voltage across the crystal in the dynatron circuit is greater than the recommended safe value, whereas, in the circuit described in this report, the voltage across the crystal is well within the safe value and the power output is twice that of the dynatron circuit

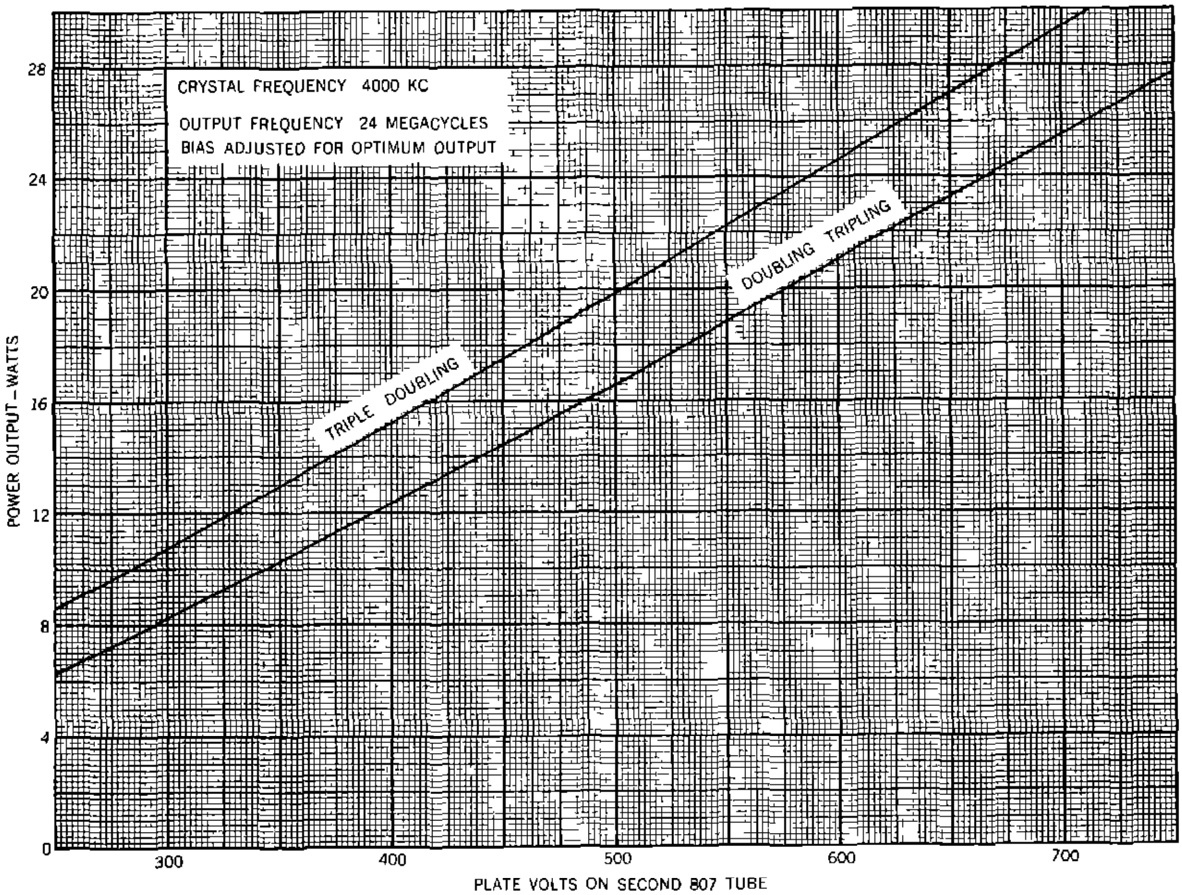

FIGURE 12 —**Comparison of power output from exciter unit when tripling in the crystal plate circuit and doubling in the driven 807 plate circuit and vice versa**

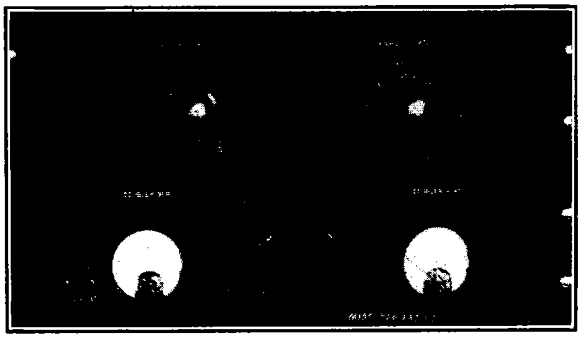

FIGURE 13.—Front view of exciter unit.

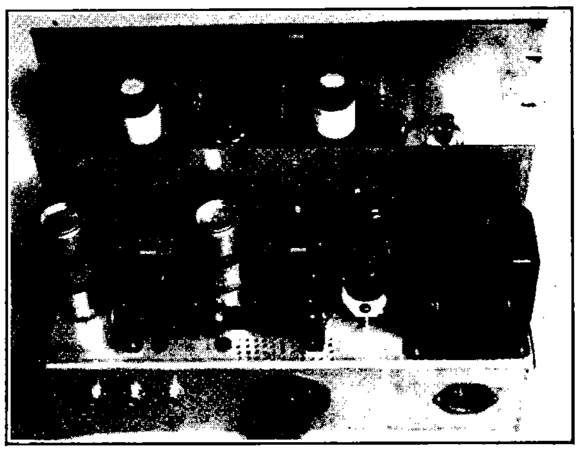

FIGURE 14.—Rear view of exciter unit with dust cover removed.

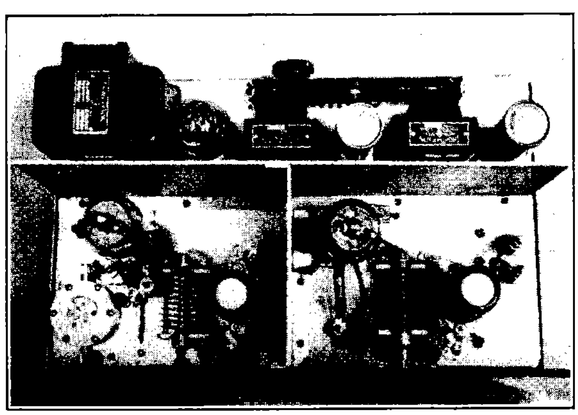

FIGURE 15.—Top view of exciter unit with dust cover removed.

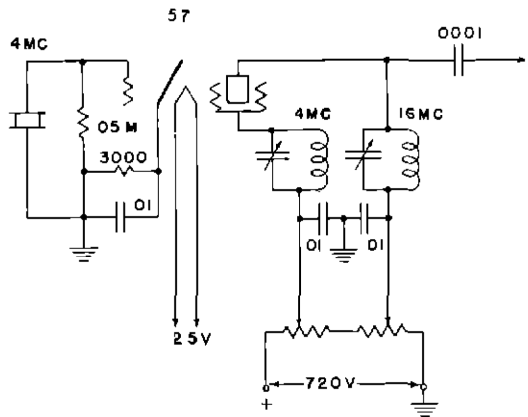

FIGURE 16.—**Schematic diagram of 57 crystal oscillator**

CONCLUSIONS

A crystal oscillator multiplier circuit of high output with low crystal voltage and one which is substantially free from frequency changes experienced under normal operating conditions such as varying plate voltage and circuit adjustment, has been investigated and found superior to the dynatron crystal circuit previously used by the Civil Aeronautics Authority In addition, the filament supply is simplified by the use of similar tubes in the oscillator and multiplier stages

An exciter unit combining this crystal oscillator multiplier circuit with an 807 type tube in a multiplier stage has been developed for application to ultra-high-frequency transmitters The exciter unit constructed is capable of delivering at least 20 watts at 24 megacycles using a 4000-kilocycle crystal

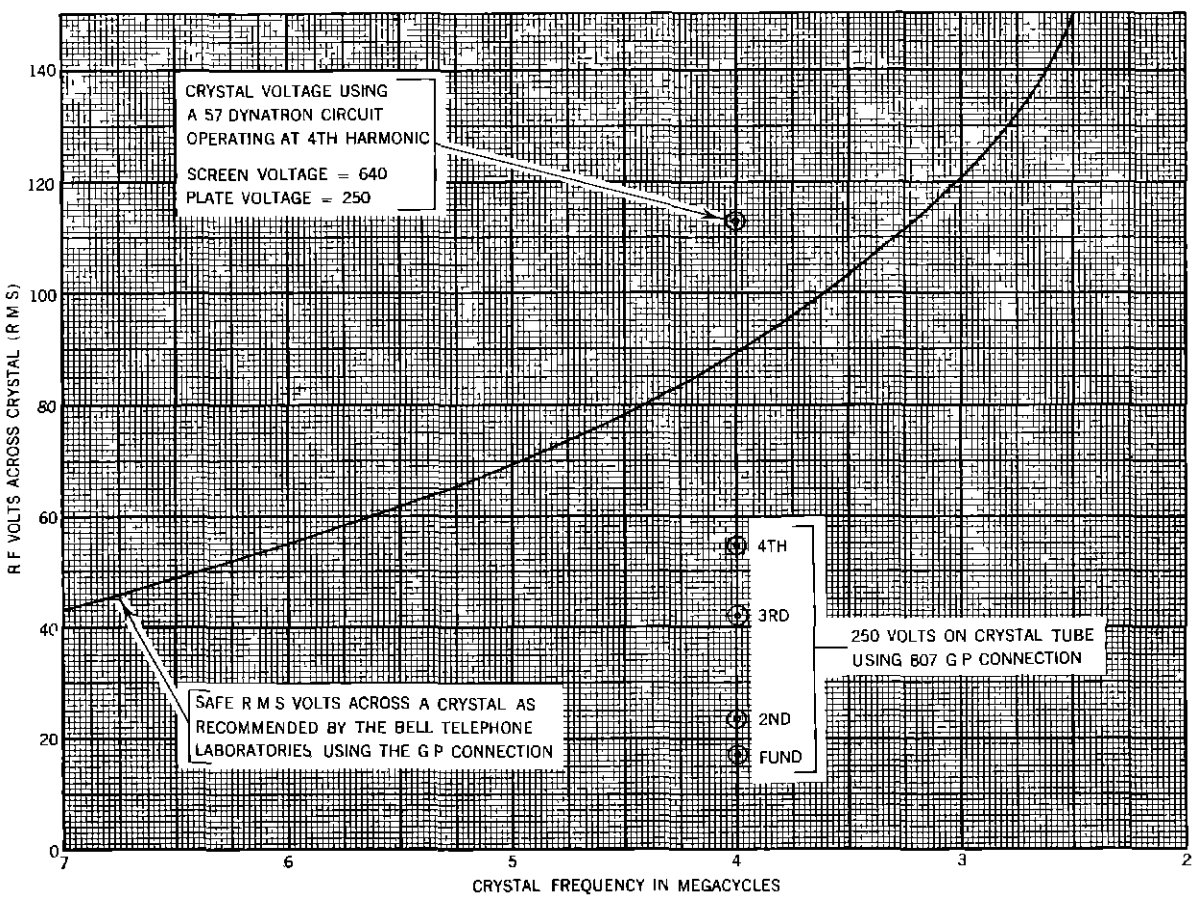

FIGURE 17.—**Grid-plate connected crystal oscillator Recommended safe crystal (r-m-s) volts across a crystal, and comparative crystal (r-m-s) voltages of the 57 dynatron oscillator and the grid-plate connected oscillator**

REFERENCES

1. Peter Modrak, "Small Temperature Coefficient of Frequency of Quartz Plates," Wireless Engineer p. 6, January 1939.
2. James N. Whitaker, "Oscillation Generator," Patent No. 1,995,164, March 19, 1935.

PARTS LIST

R_1 Resistor, 100,000 ohm, 1 watt
R_2 Resistor, 17,500 ohm, 10 watt
R_3 Resistor, 20,000 ohm, 100 watt, variable
R_4 Resistor, 3,500 ohm, 50 watt, variable
R_5 Resistor, 1,500 ohm, 10 watt
R_6 Resistor, 20,000 ohm, 20 watt
R_7 Resistor, 40,000 ohm, 20 watt
M_1 Milliammeter, Weston, 0–5
M_2 Milliammeter, 0–100
C_1 Condenser, 0.00005 mfd
C_2, C_3, C_5, C_7, C_9, C_{10}, C_{11} Condensers, 0.01 mfd
C_4 Condenser, 0.0005 mfd
C_6 Condenser, Hammarlund, variable, MC35SX
C_8 Condenser, 0.0001 mfd
C_{12} Condenser, 0.005 mfd
C_{14} Condenser, 2.0 mfd
C_{15} Condenser, Hammarlund, variable, MC35SX
L_1 Inductance, R.F. choke, 750 microhenries
L_2 Inductance, Hammarlund coil form 1½-inch diameter, No. 20 enameled wire, 15 turns—spaced wire diameter
L_3 Inductance, same as L_2 only No. 17 wire—8 turns
L_4 Inductance, 3 turns enameled wire No. 20
L_5 Inductance, 10-henry choke—110 ma
SW Toggle switch
T_1 Filament transformer—6.3 volts—C.T.
T_2 Filament transformer—5 volts—C.T.
T_3 Power transformer—1,600 volts—C.T.