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NRL REPORT 3913

A FREQUENCY-STABLE VHF OSCILLATOR FOR LOW-VOLTAGE OPERATION

H. M. Bryant and R. H. Spitler

January 2, 1952

Approved by:

F. M. Gager, Head, Special Research Branch
R. M. Page, Superintendent, Radio Division III

NAVAL RESEARCH LABORATORY
CAPTAIN F. R. FURTH, USN, DIRECTOR
WASHINGTON, D.C.

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CONTENTS

ABSTRACT

In compliance with characteristics and specifications set forth by the Bureau of Aeronautics, a frequency-stable vhf oscillator for low-voltage operation has been developed at this Laboratory. As a guide to the final choice, several types of circuits were investigated primarily for their low-voltage operation, without considering too strongly their frequency stabilities. These included; a modified-butterfly oscillator; a two-wire open-line oscillator; a cathode-coupled oscillator; a prism cavity oscillator; a cathode-coupled prism cavity oscillator; a circular cavity oscillator; and various models of the cathode-coupled cavity type oscillator. The final cavity type local oscillator is continuously tunable, covers the frequency range 440 to 545 Mc, operates on a nominal anode supply of 28 v, and has a second harmonic of less than 5 percent. The final oscillator, which weighs $2\frac{1}{2}$ lb, has an inside diameter of 14.6 cm, an inside depth of 4.4 cm, and a wall thickness of 0.63 cm. Temperature control and compensation were determined which should provide a frequency stability of ±0.02 percent with an ambient temperature change of 90°C.

PROBLEM STATUS

This is the final report on the problem; unless otherwise notified by the Bureau, the Laboratory will consider this problem closed one month from the mailing date of this report.

AUTHORIZATION

NRL Problem R10-50
BuAer EL3-A-300A-C

Manuscript submitted October 25, 1951

A FREQUENCY-STABLE VHF OSCILLATOR FOR LOW-VOLTAGE OPERATION

INTRODUCTION

The Bureau of Aeronautics has continuously been interested in the development of electronic components which would operate entirely from the nominal 28-v power supply without the need of additional excitation in the form of high-voltage rectifiers or dynamotors. The following characteristics and specifications were set forth by the Bureau in the original problem request for a vhf oscillator:

1. Frequency range—440 to 545 Mc.

2. Operating-plate supply voltage—26.5 volts, plus or minus 10 percent.

3. Total frequency deviation after warm-up—Not over 150 kilocycles.

4. Output—Sufficient for local oscillator usage.

5. Harmonic content—Not to exceed 5 percent.

6. Tubes—Ruggedized JAN type.

7. Size and weight—Minimum.

A continuously tunable, local oscillator, covering the frequency range 440 to 545 Mc and operating on a nominal anode supply of 28 v, has been developed at this Laboratory.

EXPERIMENTAL SURVEY AND DEVELOPMENT

A survey of possible vhf oscillator circuits applicable to this problem showed that there were at least six types of circuits which should be investigated: a modified-butterfly oscillator; a two-wire open-line oscillator; a cathode-coupled oscillator; a prism cavity oscillator; a cathode-coupled prism cavity oscillator; and a circular cavity oscillator. Suitable vacuum tubes for use in a low-voltage oscillator would include the 955, 6F4, 6J6, and the 2C40. It is recognized that the usable upper frequency of some of the tubes considered is within the frequency range of the proposed oscillator. In this range, distributed parameters are inevitable and the efficiency of operation is subject to considerable variation. With this in mind, a number of oscillator circuits were investigated experimentally for low-voltage operation even though their frequency stability figures at the frequencies concerned might otherwise have rejected them.

Accordingly, a modified-butterfly circuit (Figure 1), using a type 6F4 vacuum tube, was constructed. It covered the frequency range 350 to 450 Mc when L_1 was $1\frac{1}{2}$ inches long.

The frequency limits were increased 30 Mc when L_2 was placed in parallel with L_1. This system oscillated uniformly over its frequency range with a minimum of 8-v anode potential and produced a vigorous output with 28-v plate-supply voltage. The frequency stability, as noted by a visual evaluation with a panoramic adapter and an aural check with a commercial receiver (Hallicrafters type S-27), indicated satisfactory 6F4 oscillator efficiency but otherwise poor conformance with the problem specifications. It was known that this type of oscillator was not capable of the marked improvement in the order of frequency stability required by the problem and no further development of its capabilities was attempted.

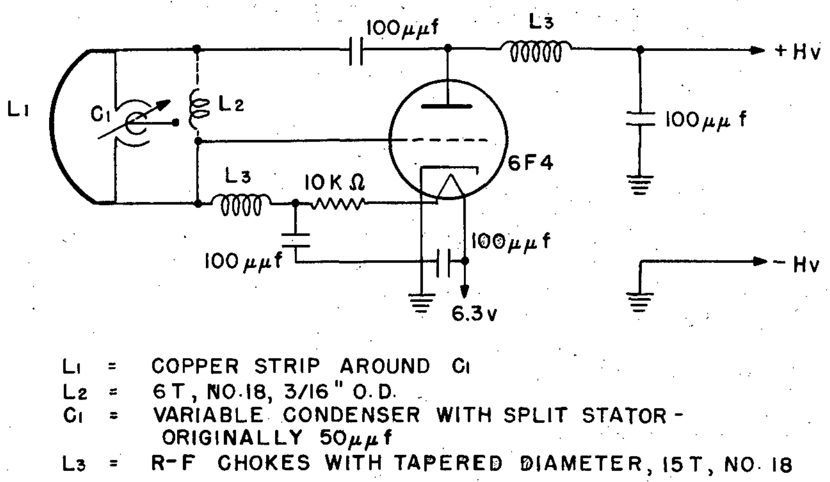

Figure 1 - "Modified-butterfly" oscillator

Another oscillator circuit, a quarter-wave, two-wire, open-line tank circuit, was constructed using the type 6F4 tube in the "ultra-audion" manner (Figure 2). This type of oscillatory circuit has considerable radiation loss due to its distributed nature and, consequently, its frequency stability, like that of the oscillator (Figure 1), would not be satisfactory. However, with the circuit constants as shown by Figure 2, the system oscillated as high as 500 Mc with less than 28-v plate supply, indicating favorable frequency and low anode voltage characteristics for the type 6F4 tube.

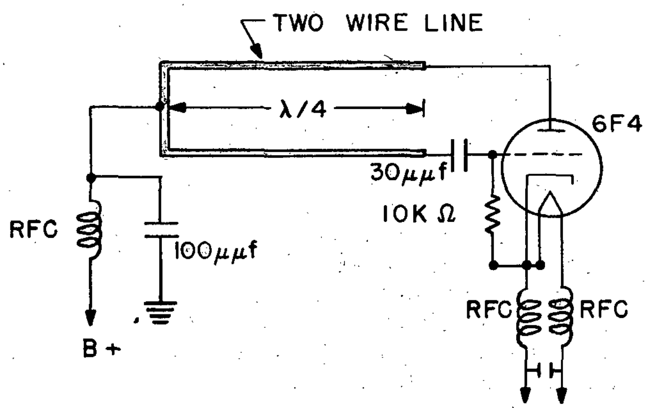

Figure 2 - Two-wire, open-line oscillator

A third experimental oscillator (Figure 3) is known to be capable of augmenting any distributed constant peculiarities of the type 6F4 tube. This oscillator was noted to be quite active and frequency-stable by comparison, but the upper frequency limit was found to be only 270 Mc when the main oscillatory coil, L_1, consisted of a linear element between grid and common lead. Since the input and output impedances of the type 6F4 tube were employed in this oscillator in a different manner with respect to the previously mentioned circuits, it was concluded that the type 6F4 tube had no peculiar internal distributed constant effect.

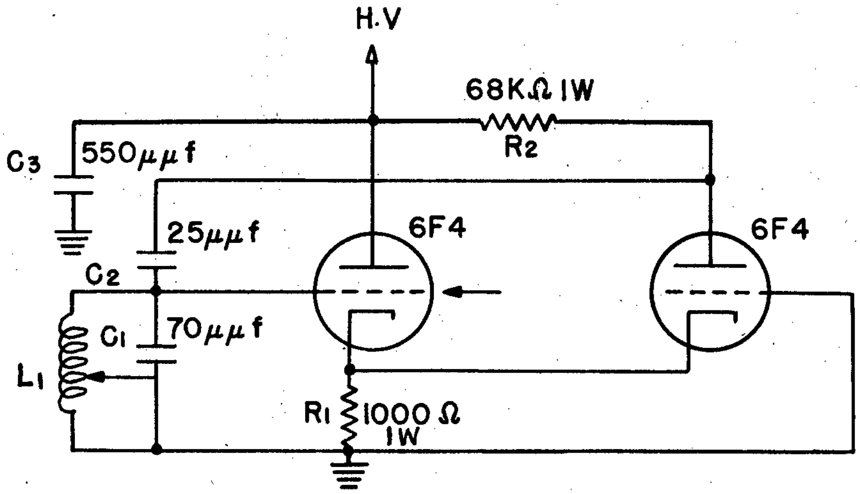

Figure 3 - Cathode-coupled oscillator

At this juncture, a prism cavity oscillator, driven by a type 6F4 tube, was constructed by covering the bottom of a cadmium-plated chassis, 7 x 7 x 2 inches, with a copper plate and arranging connections (Figure 4). This cavity oscillator system oscillated on 455 Mc with encouraging frequency stability with only 8-v plate supply. An all-copper version of this system was constructed with dimensions 5 x 5 x 1-3/4 inches, and operated similarly to its predecessor at 580 Mc with plate-supply voltages as low as 8 v. Since a means of tuning this type of oscillator would be required, simple methods of introducing slugs from the perimeter of the cavity were investigated. Some of these methods afforded a limited tuning range, but the necessary mechanical complexity was not further developed to cover the desired frequency range.

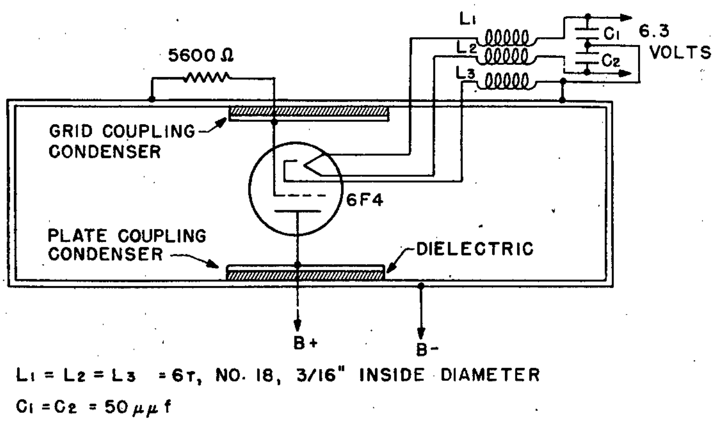

Figure 4 - Prism cavity oscillator

The prism cavity oscillator (Figure 4) was originally constructed as shown with the vacuum tube placed at the center of the cavity end plates. Upon considering known impedance relations it was decided to move the vacuum tube off center, tapped down, so to speak, and accomplish tuning with a small tuning capacitor at the center of the cavity. Experiments indicated that with the vacuum tube halfway between the center and the edge of the cavity, coupling condensers of the order of 100 to 150 $\mu\mu$f provided sufficient feedback for satisfactory operation with excellent frequency stability. Indeed, this type of oscillator appeared promising.

A fifth type of oscillator, the cathode-coupled cavity type, (Figure 5) was constructed and evaluated. This oscillator worked quite well and operated within the desired frequency range, but difficulty was experienced with obtaining proper phase relationship for the tube elements. This was partially reflected in the fact that a plate voltage as high as 60 v was required for suitably stable operation. The latter feature did not meet the requirements of the problem, and the phasing problem was left unresolved because it was believed that such a critical circuit offered nothing over what could be accomplished in another manner with a single tube device.

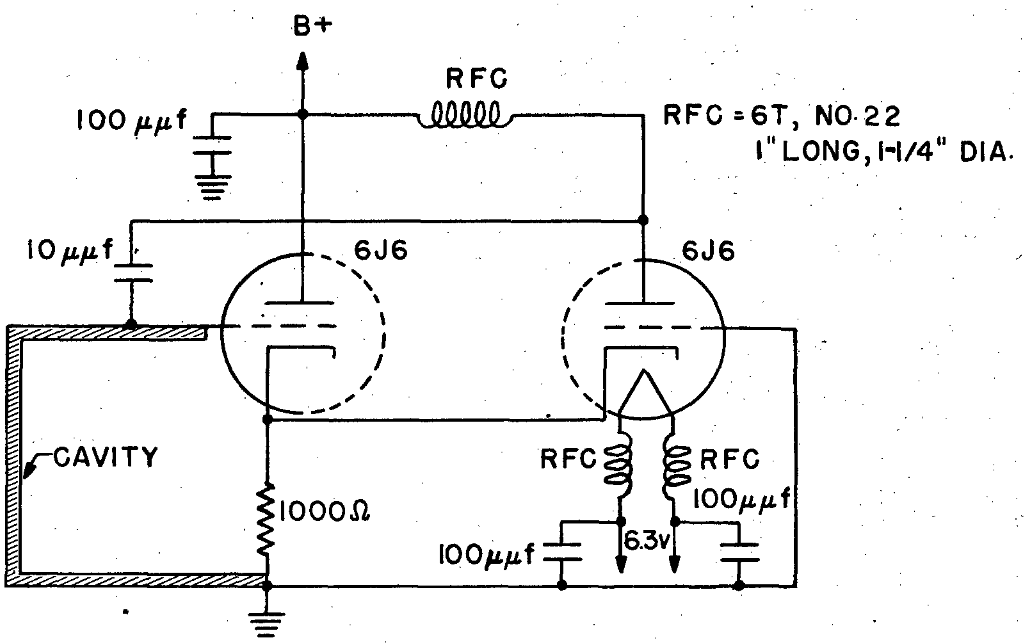

Figure 5 - Cathode-coupled prism cavity oscillator

With the foregoing knowledge and information at hand, a round, copper cavity oscillator (Figure 6) was designed and constructed with the following physical and electrical characteristics: inside diameter, 7 inches; inside depth, 1-3/4 inches; tube type, 6F4; and grid resistor, 22 k ohms. This oscillator was tuned by adjustment of a one-inch-diameter disc near the center of the cavity relative to a one-inch disc mounted on a metal pillar opposite. With this arrangement suitable strength oscillations were generated with a 26-volt plate supply and it exhibited a tuning range of 440 to 570 Mc. When this oscillator was tuned near the low-frequency end of its range, the oscillator was observed to jump frequency at 430 Mc to a higher frequency 605 Mc. Apart from this characteristic, which subsequently will be shown to be avoidable, this type of oscillator showed exceptional promise and it was used as a guide pattern in designing an advanced version.

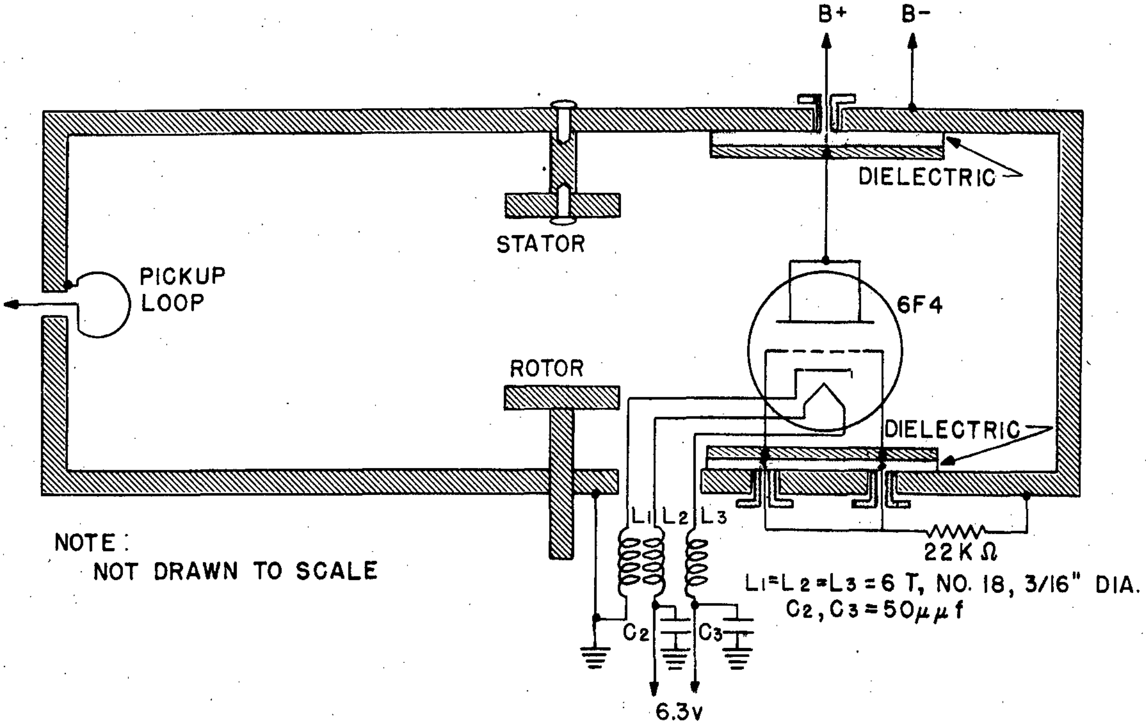

Figure 6 - Circular cavity oscillator with tuning assembly

IMPROVED OSCILLATOR, ITS THEORY, CHARACTERISTICS, AND OPERATION

The improved cavity-type oscillator (Figures 7a, b, and c) to which a degree of temperature compensation was subsequently applied, was constructed of aluminum and tuned by a one-inch-diameter metallic plunger attached to a micrometer head mounted at the center of the cavity. A study of the three figures will disclose the constructional features of this oscillator. The physical characteristics are: inside diameter, 14.6 cm; inside depth, 4.4 cm; tube type, 6F4; and grid leak resistor, 22 k ohms. This cavity oscillator easily covered a frequency range 440 to 560 Mc except that its useful frequency range was limited by an oscillation mode change at the low-frequency end. For example, it was noted that with a 40-volt plate supply the oscillator jumped mode at 460 Mc to a higher frequency, 610 Mc. It was found possible however, after a careful study of this oscillator, to achieve a design which covered the desired frequency range before reaching the point where the jump in mode of oscillation occurred.

The improved cavity oscillator (Figures 7a, b, and c) was finally chosen because theory and experimentation indicated that this form of circuit would be required for good frequency stability and the necessary oscillation efficiency to provide low-voltage operation. This flat cylindrical cavity oscillator operated in the TM_{010} mode. In this mode the maximum capacitive loading effect occurs between the centers of the end-plates.

The diameter of the cylindrical flat-cavity was calculated by using the dimensions of the previously mentioned prism cavity as a guide. The depth being noncritical, within limits, was chosen mainly for convenience in accommodating the tube, tube socket, coupling condensers, and tuning mechanism.

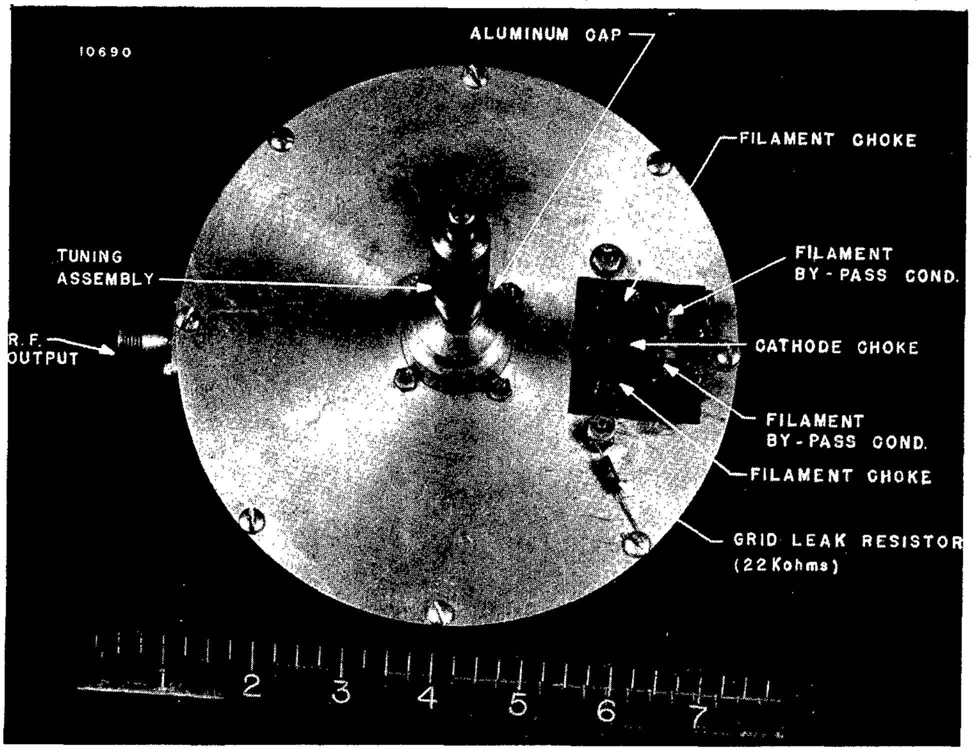

Figure 7a - External view, low-voltage cavity oscillator

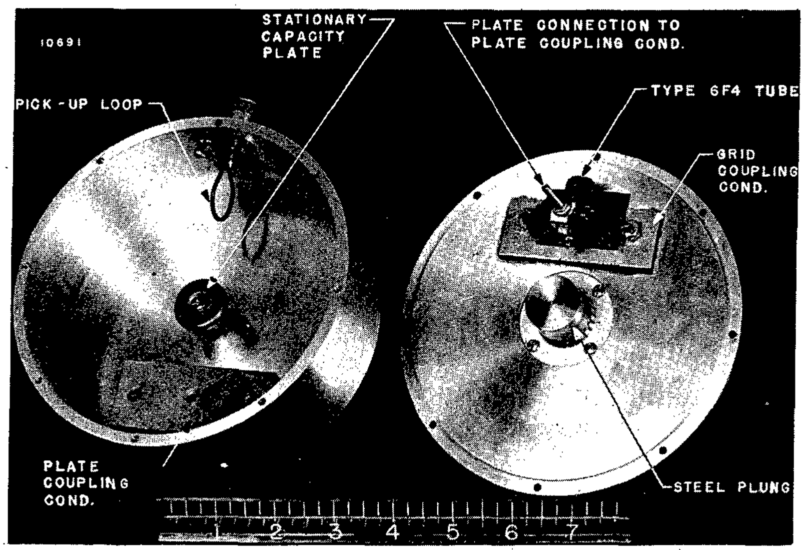

Figure 7b - Internal view, low-voltage cavity oscillator

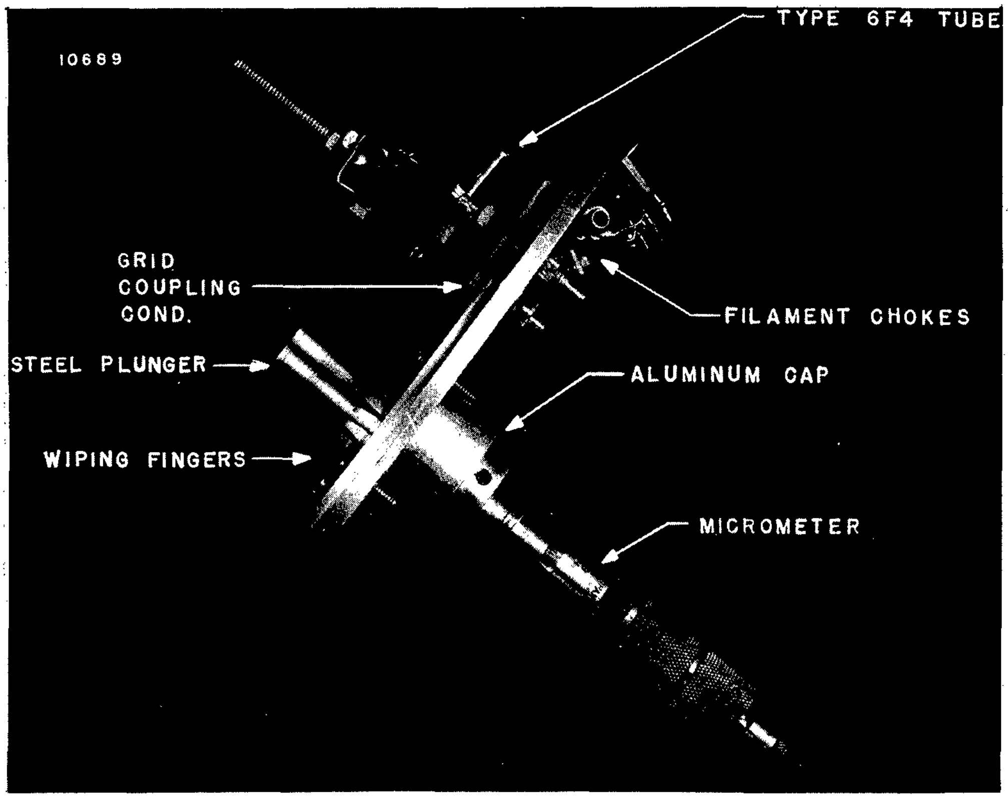

Figure 7c - Side view, low-voltage cavity oscillator

When the tuning capacity at the center of the cavity has a lower reactance than that of the effective transmission line formed by the two end plates and wall, the oscillator will jump frequency to another mode. In all probability beyond this point it acts as a coaxial cavity. As might be expected, changes in grid-circuit resistance, plate voltage, and circuit capacitance affect the frequency at which this mode-change will occur. Since this frequency jump takes place at the low-frequency end of the tuning range, it can be moved and probably suppressed, if troublesome, either by insertion of small chokes in the grid circuit between the coupling capacitor and the grid of the tube, or by changing the inductance in the cathode circuit.

The frequency range of this type of oscillator is materially influenced by the value of inductance inserted in the cathode circuit (Figure 8). This particular oscillator did not oscillate when the cathode was tied directly to the tube socket. A change in total tuning range from 73 Mc to 123 Mc was obtained however, by changing the inductance in the cathode circuit from 0.088 μh to 0.026 μh. Inductance of 0.026 μh was obtained by placing a straight piece of wire in the cathode circuit having a length 1.3 in. and a diameter of 40 mils.

TEMPERATURE CONTROL AND COMPENSATION

Since the specified voltage variations could produce the maximum allowable frequency drift of an oscillator (Figure 7), it follows that these voltage variations must be reduced by regulation. In the case of the cathode heater supply, variations can be reduced by using a current regulator such as a series ballast. If one makes the practical assumption that the filament current can be held rigidly enough to allow only 0.002 percent frequency drift over the specified voltage variation range and further assumes a frequency change of 0.030 percent for plate voltage variation, one then must hold all other frequency changes to approximately 0.004 percent to maintain specifications. Since temperature effects are the principal source of these other frequency changes, temperature control or temperature compensation must be used. Temperature control is standard practice and effective, but weight might be reduced by the use of temperature compensation, so some investigations were carried out with this in mind.

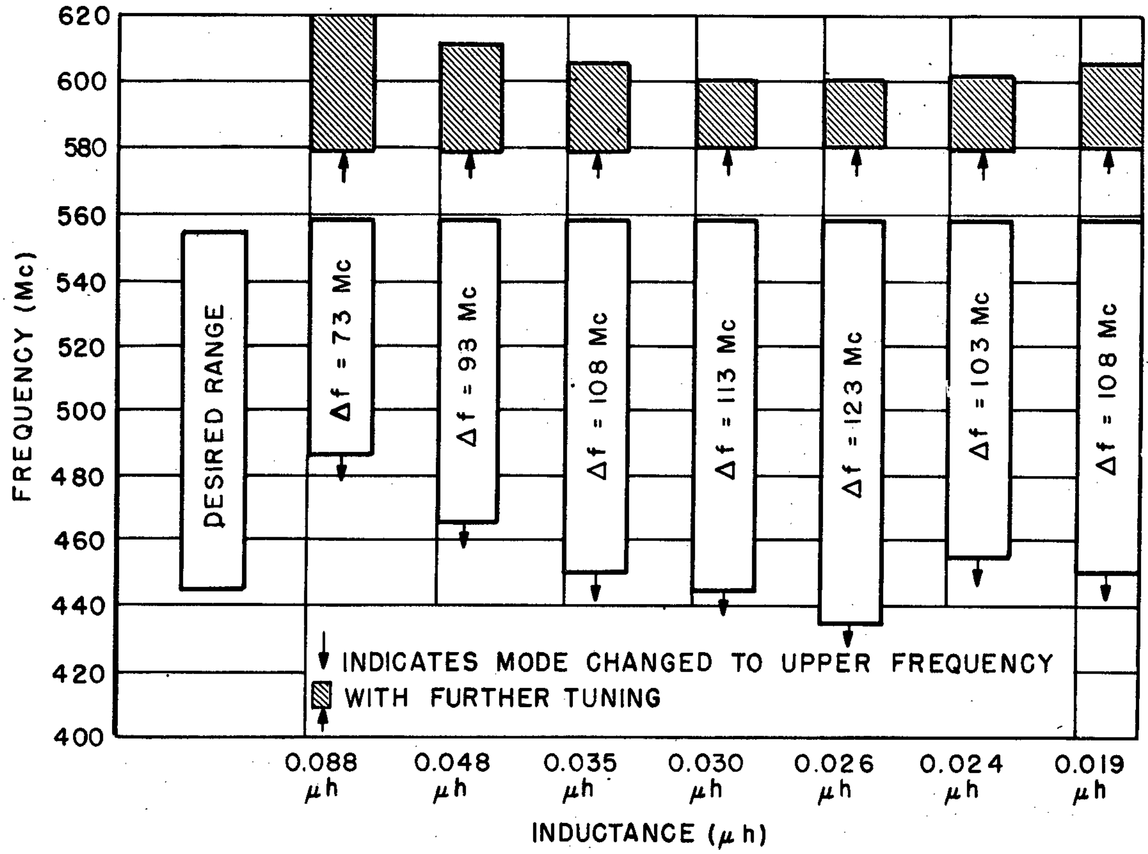

Figure 8 - Frequency range vs. inserted cathode inductance

Because of the nonlinear frequency characteristic of the tuning plunger with penetration and the internal placement of the tube in an oscillator (Figure 7), a mathematical analysis of temperature effects becomes complex. By making certain assumptions, however, comparison values have been calculated for uncompensated aluminum, steel, and invar cavities (Table 1). These calculations of expected frequency drifts, at the tuning-range extremes, show that, to comply with specifications, the temperature of the cavity must be maintained within $\pm\frac{1}{2}^{\circ}$C for aluminum, $\pm 1^{\circ}$C for steel, and $\pm 10^{\circ}$C for invar.

It can be shown both experimentally (Figure 9) and theoretically that almost perfect temperature compensation can be obtained at any single frequency by insuring a differential expansion of the plunger with respect to the cavity proper. This is accomplished by inserting rings of high expansion coefficient into the plunger support (Figure 10). Unfortunately, due both to the nonhomogeneous expansion of the components of the cavity with frequency and the nonlinear nature of the tuning-curve characteristic,[1] the resulting stability at the ends of the frequency range may be negligible.

TABLE 1
Comparison of Cavities with and without Fixed Temperature Compensation
(Computed Values)

Cavity Material	Fixed Compensation	Low End (kc/°C)	High End (kc/°C)
Aluminum	none	-11.7	-16.7
Aluminum	hard rubber compensating ring, 120 mils thick	+16.34	-16.34
Steel	none	- 5.84	- 8.35
Steel	hard rubber compensating ring, 50 mils thick	+ 8.17	- 8.17
Invar	none	- 0.58	- 0.84
Invar	steel compensating ring, 35 mils thick	+ 0.82	- 0.82

The work necessary for providing complete temperature compensation of the oscillator (Figure 7) was not expended in the belief that the problem was too general to warrant it. Nevertheless, sufficient work was done on temperature compensation at a single frequency for an understanding of the problem and a determination of the parameters involved.

It is believed that an oscillator of this type would have size and space requirements dictated by the prime equipment of which it would be a part. Under such circumstances, a cavity, built about the dictated form factor, would have a tuning curve which would not necessarily be that of the oscillator cavity (Figure 7). This tuning curve would be changed by the extreme limits of specified temperature variation, but the whole performance could be experimentally determinable point by point. Armed with this information, complete compensation could be accomplished.

There are several mechanical means for accomplishing the desired result. A suggested method for complete temperature compensation would insert temperature correction automatically as the cavity is tuned. One possible design* embodying this principle would employ a compound cam arrangement (Figure 11). It might also be desirable to first reshape the tuning curve by means of a shaped plunger head (Figure 12) and then design a suitable compensatory mechanism.

* The tuning curve for the experimental cavity (Figure 7) in the range of 440 to 545 Mc is given by

$$f = 550.6 - \frac{784{,}400}{\ell^{2.17}}$$

where f = frequency in megacycles.
ℓ = gap length between plunger and post measured in mils.

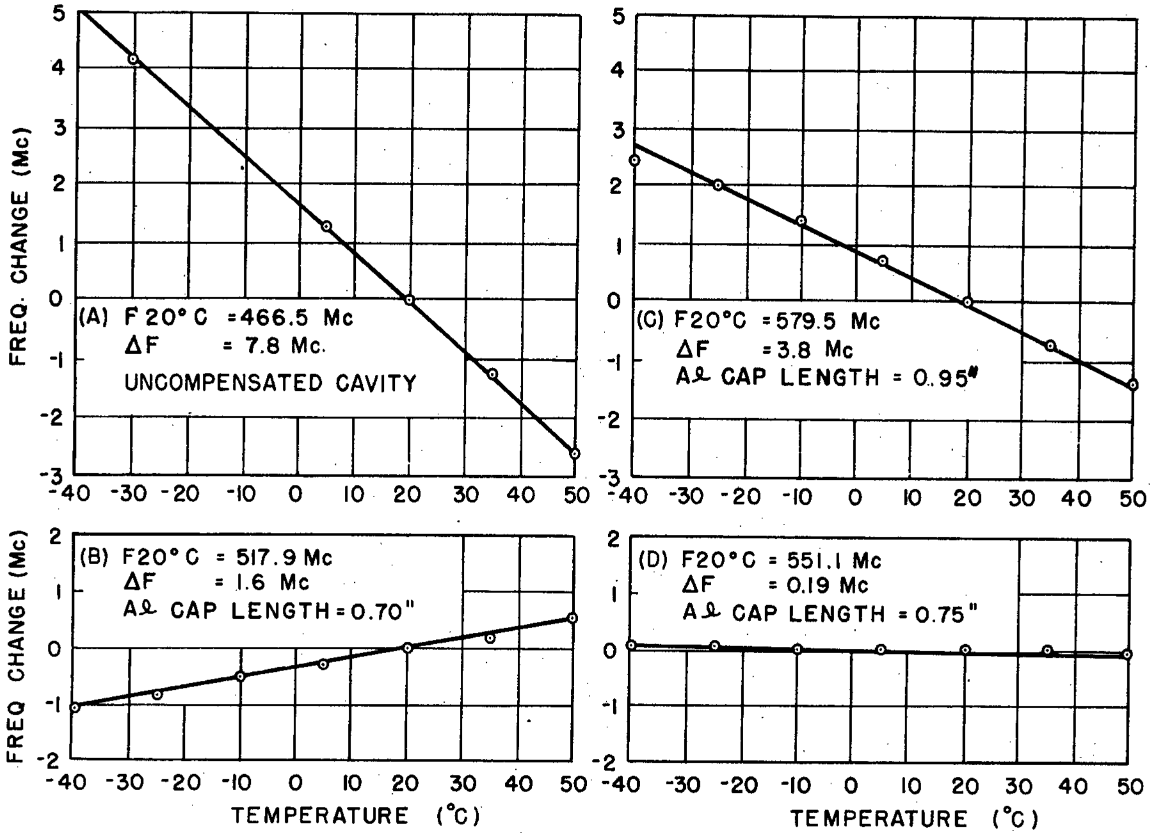

Figure 9 - Frequency change vs. temperature

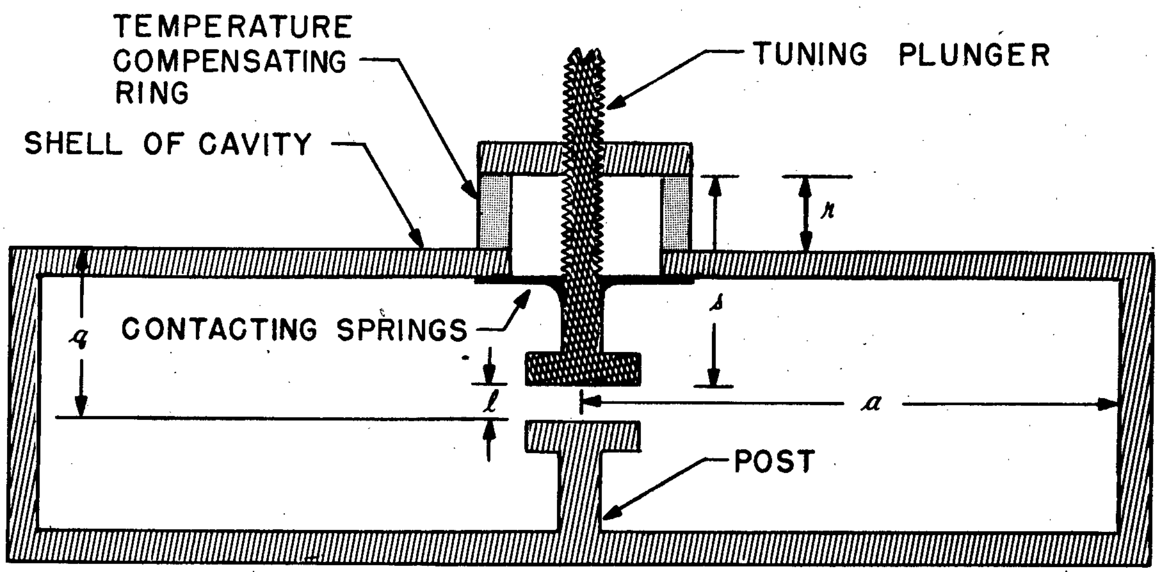

Figure 10 - Geometric configuration of cavity
(cross-section view with critical dimensions noted)

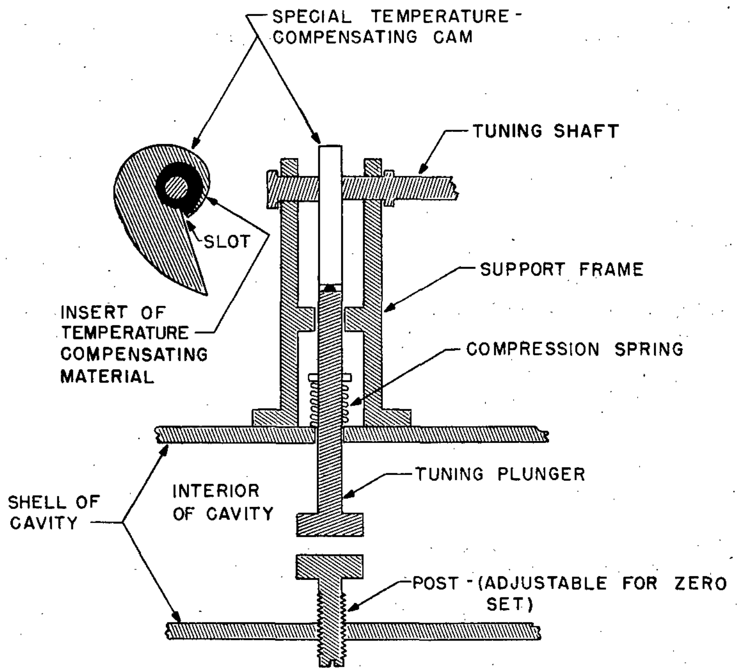

Figure 11 - Suggested tuning arrangement to provide temperature compensation by means of a cam with special insert

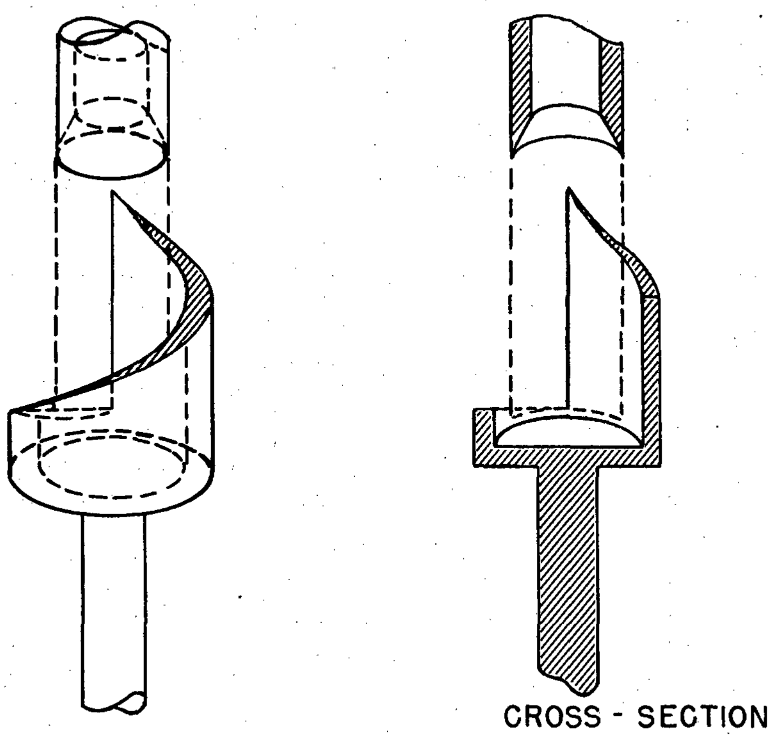

Figure 12 - Cylindrical cam-type plunger (shaped to present the desired tuning curve)

LOW-VOLTAGE CAVITY OSCILLATOR CHARACTERISTICS

Frequency Range

The tuning of the oscillator can be adjusted to cover the range 440 to 545 Mc.

Harmonic Content

A panoramic adapter was used to determine the harmonic content of the oscillator. Visual observation showed the second harmonic to be less than 5 percent. The beat note, as observed aurally on a receiver and on an LM frequency meter, sounded satisfactory even with alternating-current filament supply.

Frequency vs. Filament and Plate Voltage

From the plot of frequency change vs. filament voltage (Figure 13), it can be seen that a 20 percent change in filament voltage results in a change of only 0.012 percent in frequency. From the graph of frequency change vs. plate voltage (Figure 14), it can be seen that a change of 20 percent in plate voltage results in a frequency change of only 0.03 percent of the total frequency of 500 Mc.

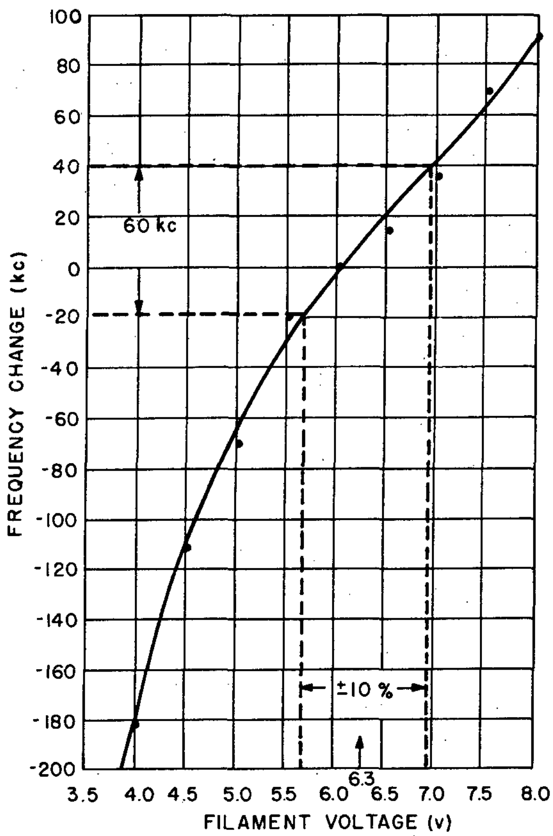

Figure 13 - Δf vs. heater voltage

Size and Weight

The size of the final oscillator was: inside diameter 14.6 cm, inside depth 4.4 cm, and wall thickness 0.63 cm. It weighed 2-1/2 pounds.

During the course of experimentation several cavity oscillators were built and the following information shows the weight of some of these oscillators. A copper cavity 3/32 inch thick weighed 2 pounds, an aluminum cavity 1/4 inch thick weighed 2-1/2 pounds, and an aluminum cavity 1/16 inch thick weighed one pound. The minimum weight of this type of oscillator then is approximately one pound. Using thinner aluminum than 1/16 inch might cause the cavity to buckle during temperature changes thus causing the oscillator to jump in frequency or defeat attempts at temperature compensation.

Compensation

The group of graphs (Figure 9) illustrates the effect of compensation on the frequency stability of the oscillator operating at a single frequency. An uncompensated cavity (Figure 9a) has a frequency change of 7.8 Mc for a temperature change of 90°C. A compensated cavity (Figure 9b) with a steel shaft and an aluminum cap length of 0.70 inch exhibited a frequency change of 1.6 Mc with a temperature change of 90°C. Over compensation (Figure 9c) is shown by increasing the cap length from 0.70 inch to 0.95 inch. A compensated cavity (Figure 9d) with a nearly correct cap length of 0.73 inch gave a frequency ohange of 190 kc for a change in temperature of 90°C.

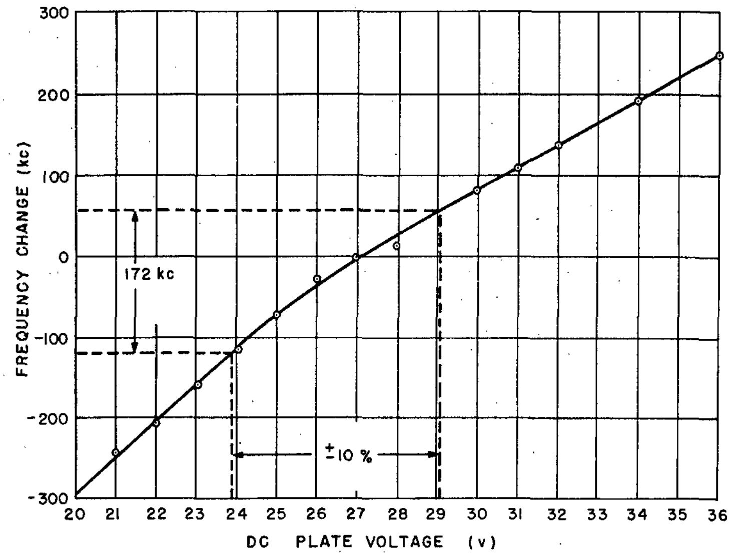

Figure 14 - Frequency change vs. plate voltage when operated at 500 Mc

Power Output

The oscillator delivers between one and two milliwatts output which is sufficient for use as a local oscillator.

RECOMMENDATIONS

1. In connection with the frequency stability of this oscillator it would be desirable to develop a 28-v voltage regulator which would keep the anode voltage constant and prohibit the 0.03 percent frequency change which accompanies a 20 percent variation in plate voltage.

2. Information was not obtained on the effect of humidity on the oscillator frequency. However, it is recommended that any undesirable frequency change from this cause can be remedied by sealing the oscillator. This could be accomplished by placing a cap over the tube socket and a bellows around the tuning plunger.

3. Sufficient stability for this type of oscillator under variable ambient temperature conditions may be obtained by controlling the temperature of the unit within ±1/2°C using an aluminum cavity, ±1°C using a steel cavity, or ±10°C using an invar cavity. For the case of the aluminum or steel cavity, a thermostatically controlled "oven" would be required. For the case of the invar cavity, a less elaborate insulated box might suffice.

4. Where weight reduction is paramount, the oscillator should be temperature compensated. A possible method of built-in compensation is through mechanical linkage to the tuning shaft through a specially constructed cam (Figures 11, 12).

5. Apart from the type of temperature compensation employed, the oscillator should be mounted with sufficient insulation lagging to remove the effects of sudden changes in temperature to either a portion or all of the oscillator.

6. Cast cavities are preferable and should be structurally ribbed along the direction of desired linear expansion. This feature should make compensation problems more simple and allow reasonable altitude change without frequency change due to atmospheric pressure.

ACKNOWLEDGMENTS

The authors express their appreciation for the work of R. C. Peck, and R. O. Parker who prepared the oscillator circuit review and preliminary cavity oscillator design.

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2. Microwave oscillators
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cavity oscillator; and various models of the cathode-coupled cavity type oscillator. The final cavity type local oscillator is continuously tunable, covers the frequency range 440 to 545 Mc, operates on a nominal anode supply of 28 v, and has a second harmonic of less than 5 percent. The final oscillator, which weighs $2\frac{1}{2}$ lb, has an inside diameter of 14.6 cm, an inside depth of 4.4 cm, and a wall thickness of 0.63 cm. Temperature control and compensation were determined which should provide a frequency stability of ±0.02 percent with an ambient temperature change of 90°C.

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OFFICE OF NAVAL RESEARCH, NAVAL RESEARCH LAB., WASH., D.C.
(NRL REPORT 3913)

A FREQUENCY-STABLE VHF OSCILLATOR FOR LOW-VOLTAGE OPERATION

BRYANT, H.M.; SPITLER, R.H. 2 JAN'52 14PP PHOTOS, TABLE,
DIAGRS, GRAPHS, DRWGS

OSCILLATORS, HIGH FREQUENCY	ELECTRONICS (3)
FREQUENCIES, VERY HIGH	COMPONENTS (10)

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