N R L REPORT NO. R-3082

FIXED AND VARIABLE FREQUENCY OSCILLATORS WITH IMPROVED FREQUENCY STABILITY

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NAVAL RESEARCH LABORATORY

Washington, D.C.

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by

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ABSTRACT

This report discloses new vacuum-tube oscillator systems exhibiting a frequency stability determined substantially by the characteristics of the intended frequency-controlling element. These circuits are capable of satisfactory operation at low and high frequencies and utilize a minimum of circuit components. Fixed and variable versions are given, and application to measuring equipments, primary equipments and frequency standards is indicated. A variation of one circuit offers an excellent means of determining effective resonant element series resistance.

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1. L. A. Meacham, "The Bridge Stabilized Oscillator", Proc. I.R.E. 26, 1278, Oct. 1938.

2. General Radio, "Instructions for Installation and Operation of Class C-21-HLD Primary Frequency Standard", p. 7.

3. J. K. Clapp, "A Bridge-Controlled Oscillator", General Radio Experimenter, 18, 1, April 1944.

4. E. M. Terry, "The Dependence of the Frequency of Quartz Piezo-Electric Oscillators Upon Circuit Constants", Proc. I.R.E., 16, 1486, Nov. 1928.

5. R. A. Heising, "Quartz Crystals for Electrical Circuits", New York, Van Nostrand, 1946, p. 365.

FIXED AND VARIABLE FREQUENCY OSCILLATORS WITH IMPROVED FREQUENCY STABILITY

INTRODUCTION

In the prosecution of problems assigned to the Components Section of Radio Division III, a need was indicated for highly stable, high-frequency oscillators of very small physical size. The oscillator circuits described in this report were devised as a solution to the oscillator portions of these problems. However, their use is not so restricted and these oscillators may be employed in any equipment with similar requirements. A variation of one oscillator circuit is shown to offer an excellent means of determining the effective series resistance of resonating elements over a wide frequency range. This facility is very useful in evaluating crystals since the effective resistance, unlike reactance, is not determined by crystal cut and geometry alone but also depends upon mounting conditions and other mechanical factors.

Within the past two decades a number of vacuum-tube oscillators have been devised which minimize, in varying degree, the effect of both the external impedance shunt upon, and variations in, applied excitation amplitude to the frequency-controlling element. These two factors are the principal contributors to degradation of the frequency-controlling element's inherent stability. Advances in the crystal art, which brought forth quartz resonators so cut and mounted as to exhibit a resonant frequency substantially free from vibration, humidity and temperature, accelerated efforts to perfect circuits which would realize the capabilities of such frequency-controlling elements. The present trend toward more closely spaced radio channels requires that the use of highly stable frequency-determining oscillators be extended to a wider base of equipments. Notable among circuit developments in the above category is the system due to Meacham.[1]

This report discloses a contribution to the oscillator art in the form of a new circuit which embodies the favorable characteristics of the Meacham oscillator, but one which permits operation over a wide frequency range without the use of transformers. At best, transformers of any form factor have an upper frequency limit and at some upper frequency they are inconvenient or difficult to devise with the proper characteristics. The development reported herein presents an extremely simple circuit adaptable to standards in portable equipments, or any equipments where space is in a premium, as well as normal use. In addition to the treatment of fixed-frequency oscillators, a variable-frequency version of the same system is set forth. The latter finds general application, including incorporation into measuring and prime equipments.

BASIC OSCILLATOR CIRCUITS

Oscillator Due to Meacham

Figure 1 represents the basic circuit of Meacham's oscillator. It consists of a linear amplifier with zero phase shift driving a bridge network arranged in a regenerative feedback loop. The bridge network contains a quartz crystal and a current-sensitive resistor (lamp) as two important arms. The crystal is operated in series resonance, with the bridge adjusted so that small unbalance output in proper phase obtains. Were the crystal to attempt oscillation at a parallel resonance frequency, the bridge would exhibit serious unbalance and phase conditions, which would vitiate the conditions for oscillation. The current-sensitive resistance provides amplitude control by swinging the condition of bridge balance in stable equilibrium to provide for variation in feedback loop excitation. If the amplifier has high gain, the crystal is well isolated from variations in circuit and vacuum-tube parameters which would contribute to frequency instability. Perfection in the advantages of this circuit would be achieved with an infinite gain and a perfectly balanced bridge. Although infinite gain is unobtainable, desired performance can be obtained with a specified gain and a predetermined off-balance operation of the bridge.

It is seen that the circuit of Figure 1 requires that the amplifier output and input have no common terminal. Meacham meets this requirement by employing tuned transformers; another system[2] uses a phase splitter to obtain the same result. Both transformer and phase splitter design introduce difficult phase-shift problems at the higher frequencies. In addition, the phase splitter does not lend itself to driving the low impedance bridges inherent with the best crystals.

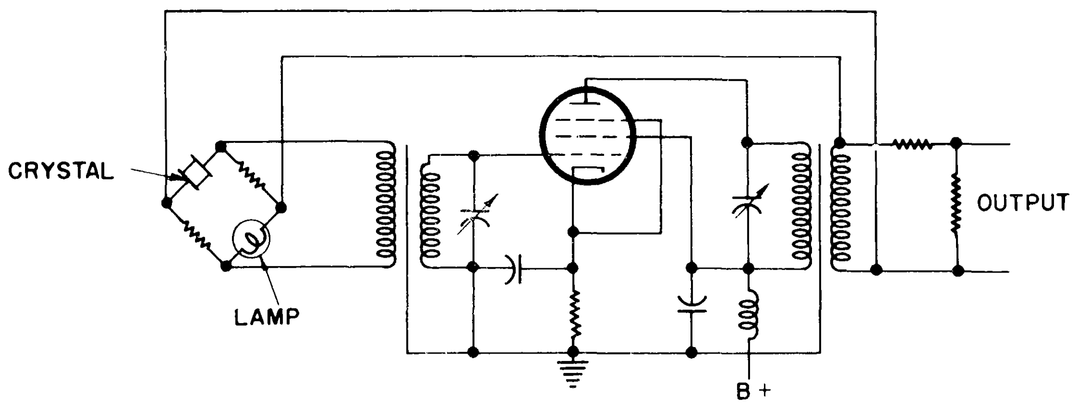

Fig. 1 Bridge-Stabilized Crystal Oscillator.

Bridged Cathode, Cathode-Coupled Oscillators

This oscillator circuit uses to advantage the inherently low bridge element impedance by employing the bridge, in one respect, as a cathode-follower load impedance. The isolation of amplifier input and output terminals or the single-sided, double-sided, bridge-feed problem is solved by quasi cathode-coupling of the amplifier input. Thus, with the necessity for transformers and phase splitters removed and the employment of the high-frequency advantages of a cathode-follower connection and quasi cathode-coupled amplifier input, maximum stability of high-frequency crystals is realizable with a minimum of circuit components.

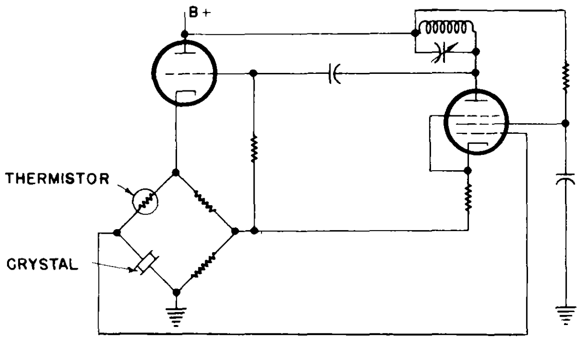

Fig. 2 Basic Circuit of Bridged-Cathode, Cathode-Coupled Crystal Oscillator

Figure 2 shows the basic circuit principles of the new fixed-frequency oscillator. This circuit indicates a single-stage, high-gain, tuned-pentode amplifier, but it is not necessarily so limited. The follower-connected coupling tube and the quasi-coupled amplifier features are self-evident. It is noted that a phase reversal of 180° is employed in both stages. With these conditions the crystal is limited to the position shown in the bridge, or one diametrically opposite, or else a feedback path exists for oscillation not determined by the crystal. Oscillator-amplitude control is obtained by the use of a current-sensitive element having a negative coefficient of resistance (thermistor) in the position shown. The details of biasing the vacuum tubes for intended functions are not exhausted by Figure 2, since any means familiar to those skilled in the art is acceptable. In fact some other method of furnishing bias for the cathode follower will be desirable with certain bridge impedances, and the pentode-cathode resistor may be by-passed in whole or in part to provide increased gain. Since at the oscillation frequency all circuit elements are essentially linear, this is one of the few oscillators whose operation may be analyzed quantitatively. Meacham gives an analysis of linear bridge-coupled oscillators which will not be repeated in this report.

CIRCUIT VARIATIONS AND APPLICATIONS

Circuit Suitable For Checking Crystal Impedance Components

Figure 3 shows shunt feed applied to the bridge circuit of Figure 2 as respects the cathode-follower load. This type of operation allows the placement of components in the bridge to be more flexible by eliminating the cathode-follower dc plate current. It also affords better amplitude control by preventing dc plate-current interaction between the two tubes.

With the above circuit, simple bridge-element voltage measurements allow determination of the effective resistance of the crystal, a factor not easily determined by other means. Although the resonant inductive reactance may be calculated from the dimensions and cut of the crystal, its value may also be determined by use of the oscillator, Figure 3, using the method shown by Clapp[3] The circuit, when correctly designed, may be used from low to high frequencies, requiring only a change of amplifier inductance when large frequency shifts are contemplated.

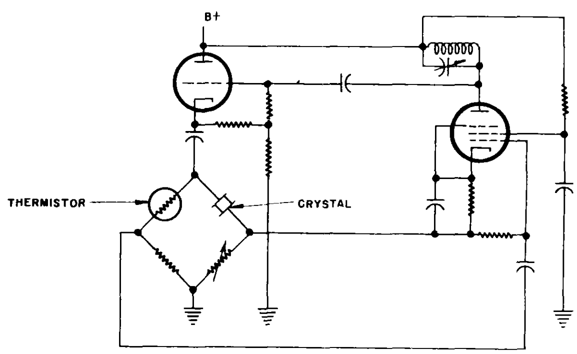

Fig. 3 Bridged-Cathode, Cathode-Coupled Oscillator Suitable for Checking Crystal Characteristics.

Variable-Frequency Oscillator

An adaptation of the circuit shown in Figure 4 is suitable for fixed-or variable-frequency operation, where a series-resonant circuit is arranged as a substitute for the crystal. Although capacity tuning is shown,

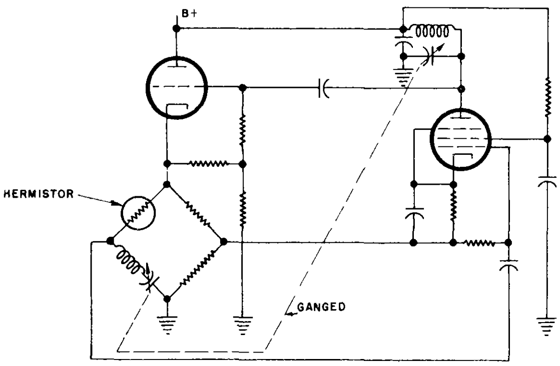

Fig. 4 Bridged-Cathode, Cathode-Coupled Variable Frequency Oscillator.

inductance tuning or a combination of both may be used. If this oscillator is to be operated over a wide frequency range, variations of the equivalent series resistance of the tuned circuit can be compensated for by a ganged control of one of the ordinary resistance elements of the bridge. An examination of this oscillator circuit indicates an extremely good frequency-stability factor, of a magnitude not usually afforded by variable-frequency oscillators, and it is applicable to transmitters, receivers and measuring equipment.

Standard-Frequency Oscillator

Figure 5 shows a circuit used for standard-frequency generation. A positive coefficient resistance element is used for amplitude control, to illustrate a permissible variation from the previous circuits. If the crystal has sufficient stability to warrant further isolation from circuit and vacuum-tube parameters, additional stages of gain may be added. It is pointed out that the preferred positions heretofore mentioned for the crystal and current-sensitive element depend upon whether or not 180° phase reversal is required from the follower-connected stage. If an odd number of high-gain amplifier stages are used, the positions are those herein designated; if, however, the number of stages is even (zero phase reversal), the crystal and current-sensitive element occupy bridge-arm positions adjacent to those previously designated.

The oscillator shown in Figure 5 was subjected to some stability studies in order to demonstrate the relative freedom from change in oscillation frequency when circuit parameters are varied. Figure 6 is a graph showing oscillator frequency as a function of plate-circuit resonant frequency. To facilitate comparison with conventional oscillators, characteristics for the two general types, as has been shown in the literature[4,5], are plotted to the same coordinates. Figure 7 indicates the oscillator's characteristics with plate voltage as the variable. A change of 100 volts in plate voltage, which is certainly more than can be expected for any class of service, causes a deviation of only three parts in 10^8 in oscillator frequency.

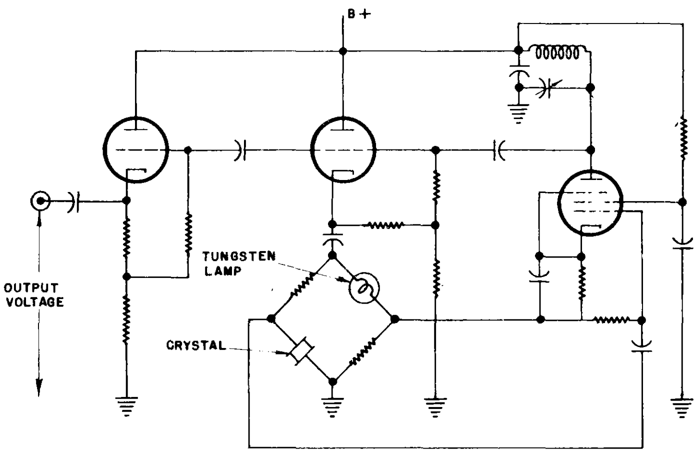

Fig. 5 Oscillator used for Determination of Frequency as a Function of Plate-Circuit Resonant Frequency Plate Voltage

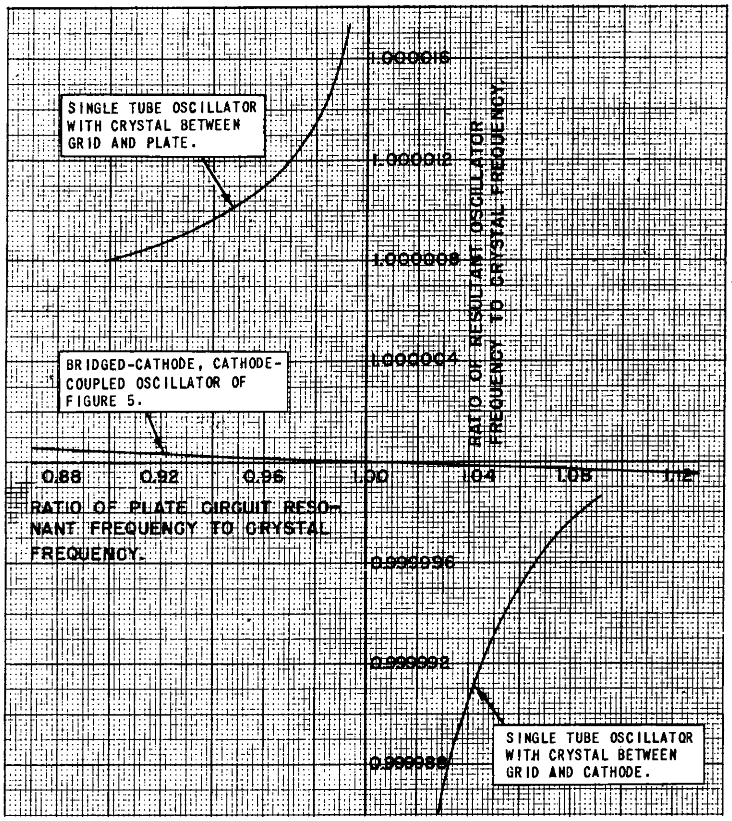

Fig. 6 Resultant Oscillator Frequency as a Function of Plate-Circuit Resonant Frequency for Various Oscillators.

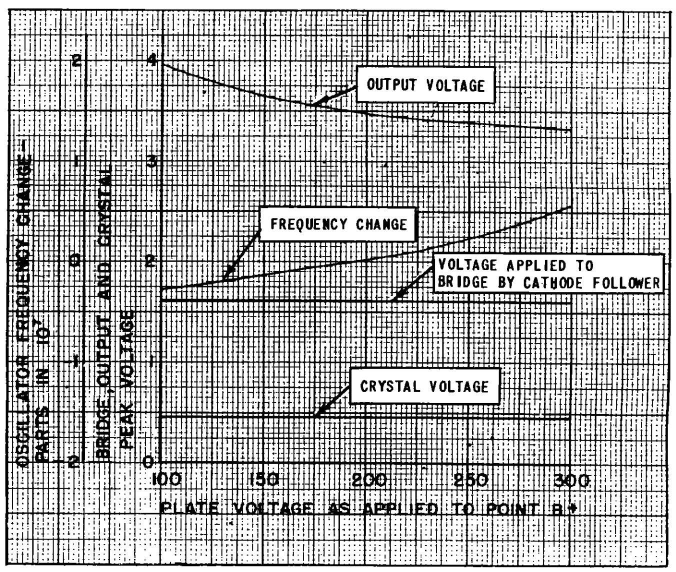

Fig. 7 Frequency Change, Crystal Voltage, Bridge Voltage and Output Voltage as a Function of Applied Plate Voltage for Oscillator Shown in Fig. 5. Base Frequency 100 KC.

CONCLUSIONS

A study of the characteristics of the oscillators disclosed in this report indicates their useful application to frequency standards and to prime and measuring equipment. When used as components of the latter two equipments, such oscillators will afford a constancy of frequency generation not heretofore realized, and present a solution to the ever present problem of attaining greater frequency stability. Use of the subject oscillator circuits makes it possible to utilize fully, in any class of service, the improved frequency stability furnished by various new crystal types. For example, by installing a temperature-corrective network in one oscillator bridge arm and using a GT-cut crystal as the frequency-determining element, a frequency stability of 1 part in 10^6 may be attained over an ambient temperature range of 100° C without requiring a regulated power supply or a temperature-controlled oven.

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