A Wide Range Microwave Sweeping Oscillator

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(*Manuscript Received July 24, 1950*)

1. Introduction

A SWEPT frequency oscillator is a useful laboratory tool for testing wide-band circuit components. It permits an oscillographic display of a frequency characteristic, avoiding much of the labor of point-by-point testing at discrete frequencies. There was a particular need in the Bell Telephone Laboratories for a sweeping oscillator to cover the communications band between 3700 and 4200 megacycles to facilitate the testing of components for radio relay repeaters.

This paper describes one type of oscillator designed to satisfy this need. It utilizes the BTL 1553 (or the Western Electric 416A) microwave triode. The tuning is accomplished mechanically so that the frequency varies continuously back and forth over the band at a low audio frequency rate. Continuous oscillations have been obtained over a 900 megacycle band from 3600 to 4500 megacycles.

2. Circuit Structure

Basically, the rf circuit consists of a tunable cavity for a grid-anode resonant circuit, a means for feedback to an untuned grid-cathode circuit, and a means for coupling the cavity to a waveguide output. The grid-anode cavity is the only sharply tuned circuit, and it was found that oscillations could be obtained over the entire band by changing the resonant frequency of that cavity alone. In this application, the electronic conductance between the grid and cathode is so high that this portion of the circuit has an inherent broad band such that separate tuning is unnecessary.

The necessity for continuous, rapid tuning virtually requires that there be no sliding contacts in the tuning mechanism. A type of cavity was chosen so that tuning could be accomplished by a simple variable capacitor of the non-contacting type. Reduced to its simplest elements, it consists of a short coaxial line, resonant in the half-wave mode. Actually the line is much shorter than a half wavelength because of excess capacitance at both ends. At one end is the capacitance of the grid-anode gap, and at the other end is the variable capacitor used for tuning.

The actual cavity is illustrated in Fig. 1. This is somewhat more complicated than a half wave line, but the mode of resonance is essentially the same. The variable capacitor utilizes a thin-walled copper cup which is movable vertically. This cup fits rather closely inside, and is coaxial with, a cylindrical hole in the main body of the cavity. It forms the center conductor of a low impedance coaxial line approximately one-fourth wavelength long, so that in this frequency range it is effectively short-circuited to the cavity wall. Vertical motion of the cup is therefore roughly equivalent to moving the end wall, thereby changing the capacitance between the wall and the center conductor of the main cavity. The reso-

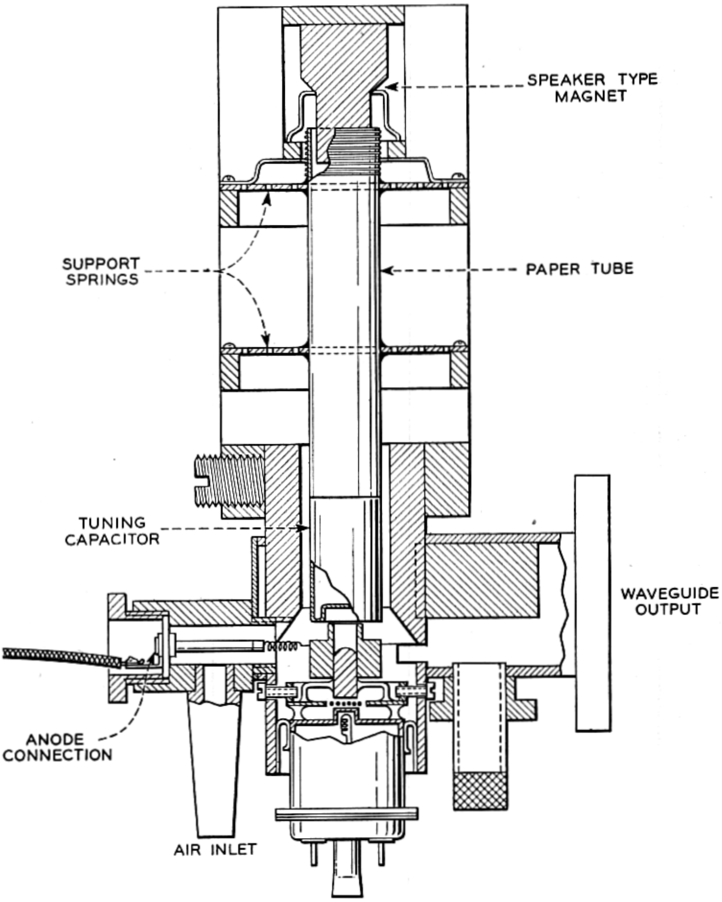

Fig. 1.—Construction of the oscillator.

nant frequency is lowest when the two surfaces are nearly in contact, and highest when the cup is fully extracted.

The recessed end of the cup fits over a protuberance on the center conductor when they are nearly in contact. This special shape was designed to give a reasonably straight curve of frequency vs. displacement. With planar surfaces, the frequency would change more rapidly with displacement at the low than at the high frequency end of the band.

The grid disk of the tube is separated from the wall of the cavity by a narrow annular space, and contact is made across the gap by a number of small screws. These screws act as an inductive reactance in series with the circulating currents of the resonant cavity. The voltage developed across this reactance is applied between the grid and the main envelope of the tube, and in this way energy is fed into the grid-cathode space to provide feedback.

The mechanical tuning device was adapted from an inexpensive permanent magnet loudspeaker of the type used in small home radios. The construction is shown in Figs. 1 and 5. The speaker cone was removed and the voice coil was attached to a thin-walled paper cylinder which supports the tuning cup inside the cavity. Two sheet fiber springs support the paper cylinder and maintain the axial alignment in the magnet and cavity. These springs are cut with a number of incomplete circular slits to reduce the stiffness for axial motion. With the voice coil actuated from a small filament transformer, peak to peak motion $\frac{1}{4}$ of inch is obtainable.

The heater and cathode connections are made at the base of the tube which protrudes from the cavity. The grid is internally connected to the main body of the cavity. The anode lead is brought out through a quarter-wave choke and mica button condenser.

To prevent overheating of the anode of the tube, air must be blown through the cavity. This is done by connecting a low pressure air hose to the air inlet shown in Fig. 1. Excessive air flow must be avoided, as it will cause erratic vibrations of the tuning plunger.

3. Adjustment and Operation

The degree of feedback is adjustable by changing the number and relative positions of the feedback screws which connect the cavity to the grid ring of the tube. There are 16 possible screw positions, but only about 5 or 6 are needed to obtain optimum feedback. Reducing the number of screws increases the amount of feedback.

Care should be taken that the spring which contacts the anode for dc connection is not of such a length to have resonances within the band. When such resonances exist, "holes" or other irregularities will be found in the output spectrum. This spring can act as a helical line, and when it is too long, resonances will occur which can absorb power and otherwise affect the cavity impedance.

When properly adjusted and sweeping, the output is continuous and the frequency varies approximately sinusoidally back and forth over the band of interest. The width of the sweeping band depends upon the ac current in the voice coil of the speaker drive, and the center frequency depends upon the mean position of the tuning plunger. The latter can be adjusted mechanically by loosening the clamping screw and raising or lowering the sweeping mechanism by hand. It is also possible to make small adjustments of the center frequency electrically by adding a dc component to the voice coil driving current.

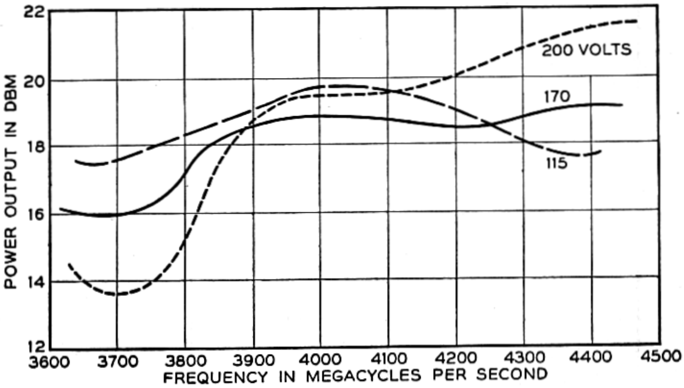

Fig. 2.—Power output curves at 115, 170, and 200 Volts on the anode, for a mean anode current of 25 ma.

Typical curves of power output vs. frequency, taken at different anode voltages, are shown in Fig. 2. The flattest curve requires a voltage considerably lower than the tube rating. The feedback phase is not optimum for best power output, a larger phase shift being desirable in this oscillator. The lowered voltage helps in this regard, increasing the electron transit time in the tube and thereby increasing the phase shift. Efficiency was sacrificed in this design to increase the tuning band. A longer feedback path would increase the power output, but would tend to narrow the band over which oscillation could be obtained by a single tuning adjustment.

The anode power supply should be variable between 100 and 250 volts, but need not be regulated because this voltage is not critical. A rheostat is used for cathode self-bias. The cathode heater and the sweeping mechanism are supplied from a single 6.3 volt filament transformer, with a potentiometer control to vary the sweep range.

A crystal detector and an oscilloscope are used to view the output. It is convenient to use a sinusoidal horizontal sweep on the oscilloscope, driven from the same 6.3 volt transformer as the mechanical sweeping mechanism. In this case, a phase shifter is needed to synchronize the oscilloscope sweep with the motion of the tuning plunger, because there is an appreciable mechanical phase shift in the loudspeaker mechanism.

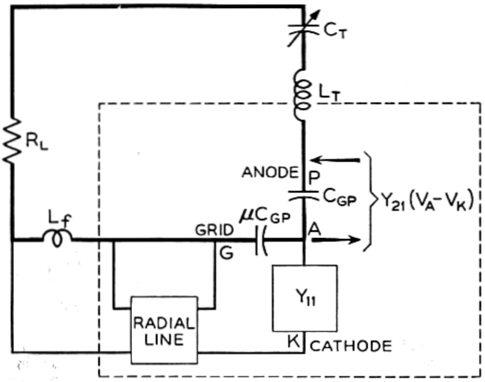

Fig. 3.—Simplified equivalent circuit of the oscillator.

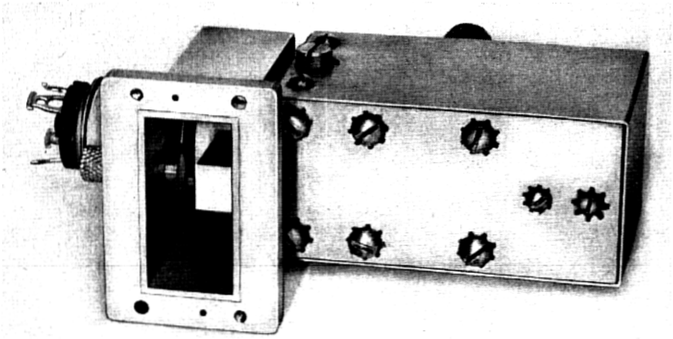

Fig. 4.—The complete oscillator, showing the output coupling window and the ridged waveguide coupling transformer.

When properly phased, the output spectrum will be displayed across the oscilloscope screen with the minimum and maximum frequencies at opposite ends of the trace. In addition, a vibrating relay (such as the Western Electric 275 B Mercury Relay) is used to short out the input to the oscilloscope during half of each cycle. This converts the return trace into a zero-signal reference line, so that the complete picture is a closed loop with a flat bottom. The separation of the active from the reference trace is a direct indication of signal strength, displayed as a function of frequency.

The results reported here were obtained using the BTL 1553 tube, which is a laboratory model. Samples of the production model, Western Electric 416A, have also been used in this oscillator with quite similar results. To adapt the oscillator for the 416A, the grid ring should be threaded on the inside to fit the threads on the grid disk of that tube.

4. AN EQUIVALENT CIRCUIT

The field configuration in the cavity of the oscillator is quite complex, and cannot be readily described in any quantitative fashion. The formulation of an equivalent circuit would require many approximations and judicious guesses if values are to be specified for the various circuit parameters. The circuit of Fig. 3 is believed to be equivalent in a qualitative sense.

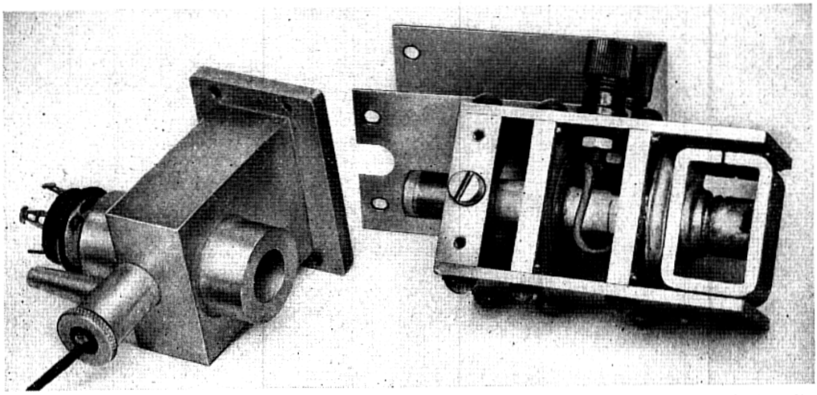

Fig. 5.—The complete oscillator, showing the sweeping mechanism partially dismantled.

A portion of the circuit is within the tube itself. This is the region enclosed by the dotted line in Fig. 3. The T of elements which include Y_{11}, C_{gp}, μC_{gp} and the injected currents, is the equivalent circuit of Llewellyn and Peterson[1] for the active region of a triode. Experimentally determined values for these quantities are reported by Robertson[2]. Y_{11} is the admittance of an equivalent diode between the grid and cathode, and the injected currents indicated by the arrows are the electronic transfer currents associated with the grid voltage and the transadmittance. At high

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[1] Llewellyn and Peterson, "Vacuum Tube Networks," *I.R.E. Proc.*, Vol. 32, pp. 144–166 (March 1944).

[2] S. D. Robertson, "Electronic Admittances of Parallel-Plane Electron Tubes at 4000 Megacycles," *B. S. T. J.*, Vol. 28, p. 619, Oct. 1949.

frequencies, both the admittance Y_{11} and the transadmittance Y_{21}, are complex quantities which vary with frequency as shown by Llewellyn and Peterson. The 4-pole box shown represents the passive radial line between the glass seal at the edge of the tube and the cathode-grid gap. This line is heavily loaded with dielectrics and is believed to be electrically about a quarter wavelength long at 4000 Mc. The inductance connected to the anode is that of the anode pin itself and the coaxial center-conductor attached to it. A series resistor R_L is added to include the effects of cavity losses and loading by the output coupling window. C_t is the tuning capacitor which varies with tuning plunger position. The inductance L_f is the feedback reactance introduced by the screws connected to the grid disk.

5. ACKNOWLEDGMENTS

I wish to acknowledge the assistance of Messrs. J. A. Morton, R. M. Ryder, and the late A. E. Bowen for many helpful suggestions in the design of this oscillator.