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H. F. Frequency Measurements

PART II

By the Engineering Department, Aerovox Corporation

HIGH-STABILITY tube oscillators, when carefully maintained, serve very well as secondary radio-frequency standards, since their fundamental or harmonic components may be compared occasionally with some convenient primary standard of frequency. As such, these units frequently take the form of calibration oscillators which may also be referred to as a reliable secondary standard in the absence of a primary.

Calibration oscillators fall into various descriptive categories, depending mainly upon the fundamental frequency value, whether the fundamental frequency or harmonics are normally available for usual measurements, and the type of frequency control employed. The latter factor has been the chief distinguishing characteristic of such oscillators employed in lower-frequency measurements. That is, these instruments have been classified mainly as self-excited or crystal-controlled.

Because of the availability of low temperature coefficient quartz crystals for standard-frequency service, crystal-controlled calibration oscillators have almost totally supplanted the less stable self-excited circuits in frequency measurements at the lower radio frequencies.

Existing standard-frequency equipment in order to be effective over the widest possible range of radio frequencies and in order to embrace certain advantages afforded by low-frequency crystal cuts has had as its basis crystal-controlled oscillators operated at fundamental frequencies of 50 or 100 kilocycles. The output power of these oscillators is maintained relatively low, for the sake of increased stability, with the result that the energy available in high-order harmonics soon becomes too small to be useful for calibration purposes. And, in order to offset this limited utility, there have been incorporated into some standard-frequency sets one or more r. f. amplifier stages which are operated in a distorting manner to increase harmonic energy. Other secondary standards have employed dual-frequency crystals which may be operated at either 100 or 1000 kc., the latter fundamental frequency providing useful output at a more remote harmonic than would the former.

In general, the 50-kc. oscillator, operated at low power output consistent with good stability, will not provide useful energy beyond about 4000 kc., except when detected by extremely sensitive circuits, nor will the 100-kc. oscillator provide strong harmonics beyond about 8000 kc. The 1000-kc. oscillator, however, will deliver useful harmonic voltages into the 40-Mc. region, but at a sacrifice of the finer subdivisions afforded by the lower-frequency fundamentals. The latter unit may be adapted to calibrations at frequencies lower than the 1000-kc. fundamental by synchronizing with it a multivibrator on some submultiple frequency, such as 10 kc. The multivibrator is likewise employed with the 50- or 100-kc. standard-frequency oscillators to provide intermediate spot frequencies between adjacent harmonics of the oscillator frequency.

Use of standard-frequency equipment directly for the testing and calibration of monitors, receivers, oscillators, and transmitters by heterodyne methods at the lower frequencies, and indirectly for calibrating wavemeters and similar non-detecting circuits, is well known. The conventional use in these assemblies of low-frequency oscillators, however, renders such equipment unsatisfactory for similar use at extremely high frequencies.

Calibration oscillators may be arranged, nevertheless, for extremely high-frequency use by adopting some high-frequency for the oscillator fundamental which may be referred directly

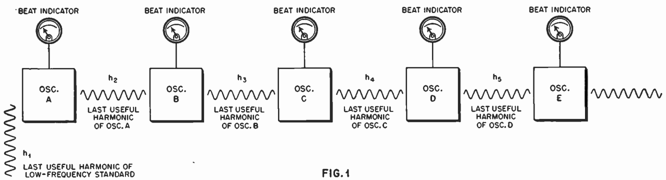

FIG. 1

or indirectly to a reliable lower-frequency standard. These oscillators, like those employed in conventional frequency standards, fall into categories determined by (1) the mode of control, (2) type of circuit, (3) whether fundamental or harmonics are normally to be employed, and (4) whether they are normally operated with fixed or variable-frequency features.

The leading advantage of the oscillator over other methods of high frequency measurement, where detecting equipment is employed, is its use of the highly-accurate beat note principle.

EXTENSION OF STANDARD-FREQUENCY RANGE

The utility of existing lower-frequency primary and secondary standards may be extended into the extremely high frequency region by means of successive oscillators each of which may be synchronized with another operating at a lower frequency and finally with the highest useful harmonic of the low-frequency oscillator fundamental. Each such oscillator will deliver a succession of harmonics, its last useful one being employed to standardize the next oscillator which carries on in the same manner. The complexity of the arrangement will increase as the frequency range to be covered grows wider, or as the highest spot frequency to be reached becomes higher.

Figure 1 illustrates in block diagram an arrangement of oscillators for accomplishing this purpose. A, B, C, D, and E are oscillators, each operated at a successively higher fundamental frequency. Each oscillator is set to zero beat with the highest useful harmonic of the preceding oscillator, and delivers a series of harmonics which serve as spot frequencies for calibration purposes. These spot frequencies are separated by a frequency width equal to the oscillator frequency and are available to the highest useful component, designated in the diagram as h_1, h_2, h_3, h_4 and h_5.

For extremely high-frequency applications, these successive oscillator stages will be self-excited and will need to be set exactly to zero beat with the "limit harmonic" of the preceding oscillator and maintained at that point of operation. If the number of oscillators demanded becomes appreciable, as will certainly be the case when the ultra-high and super-high regions are to be reached, the task of maintaining each stage at zero beat is apt to become considerable. Hence, zero-beat indicators are shown as a part of each oscillator unit. For simplicity, this indicator may take the form of a magic-eye tube, operated preferably with a simple amplifier. The operator need only inspect the line of indicators occasionally to spot deviations from original settings, readjusting slightly to suppress any flicker in the eyes.

In any such arrangement as the layout in Figure 1, the frequency error present in any lower-frequency stage will increase with the harmonic order and thus be accumulated in the final stages. Precise settings are consequently required throughout, and the accuracy of the frequency h_1 must be of a high order. Equally important also is the stability of the individual oscillator units, since minute variations along the front of the circuit will result in sizeable frequency deviations in the output circuit.

In the absence of a conventional low-frequency-type standard, the frequency h_1 may be the fundamental or a low-order harmonic of a high-frequency crystal oscillator based upon a low-drift quartz plate. Thus, a 5000- or 10,000-kc. crystal oscillator might be employed to deliver this frequency. And if it is desired to operate the input oscillator, A, at a reasonably high frequency, the crystal oscillator may be followed by one or more frequency multiplier stages, such as triplers or quadruplers which would then deliver the harmonic h_1.

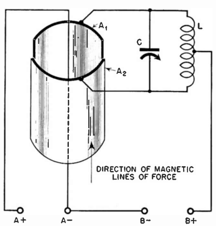

FIG. 2

SPECIAL HIGH-FREQUENCY OSCILLATORS

Oscillator circuits which are to be operated directly at the extremely high frequencies follow several special designs. These arrangements differ from those encountered at lower frequencies in several respects governed by requirements of stability at the very high operating frequencies and, in some cases, by the method of obtaining oscillation.

Whenever the stability of one of these special oscillators is sufficiently high for a given measurement, the instrument may be employed in the conventional manner. The fundamental frequency and its harmonics are available for calibration and reference purposes. The heterodyne method may be employed in testing and calibrating extremely high-frequency devices which employ autodyne, superheterodyne, and ordinary regenerative principles. The oscillators may be modulated *lightly* (large modulation depths impair the stability) for testing super-regenerative and non-regenerative circuits. The oscillator wavelength, and in turn frequency, may be referred to Lecher wire measurements, and vice versa.

Special circuits for extremely high-frequency use are numerous in design, and obtain oscillation both in the conventional and in special manners. Outstanding members of the high-frequency group of oscillators will be described immediately.

Magnetron Oscillator. This circuit, employed for some time in the generation of ultra high frequencies, is based upon the magnetron tube, a special development. The circuit arrangement is shown in Figure 2.

The magnetron tube is a special filamentary diode with cylindrical electrodes arranged coaxially. The two anodes, A_1 and A_2, are portions of the electrode cylinder, and are connected to the external circuit, L-C. Direct A and B voltages are applied, as indicated. The tube is positioned within a magnetic field, generally set up by an electromagnet coil surrounding the tube, so that the lines of force are parallel to the electrode axis. The strength of this field may be controlled by means of a rheostat or potentiometer.

The presence of the strong, uniform magnetic field causes electrons leaving the filament to be deflected away from their normal path and to travel in orbits within the anode enclosure. These orbits will be circular and of less diameter than that of the anode cylinder. Below a certain value of magnetic field strength, however, all electrons may reach the plate.

Deflection of the electrons by the magnetic lines gives rise to a negative resistance which will develop oscillations at, or very closely equal to the frequency of the external L-C combination. In a second method of operation, the oscillation frequency is equal to the frequency of rotation of the electrons around their orbits. This frequency is inversely proportional to the strength of the magnetic field.

Wavelengths of less than 1 centimeter (frequencies higher than 300 Mc.) have been produced by magnetron oscillators in which electron rotation determines frequency of oscillation. While the efficiency of the magnetron oscillator is relatively low, the reduced output it furnishes is adequate for testing purposes.

Concentric-Line Oscillator. The concentric, or coaxial line, used in place of the conventional coil-capacitor tank in extremely-high-frequency oscillators, provides higher Q and stability than might be obtained with common circuits. An open-type, parallel transmission likewise may be employed as a tank. In its action, the "pipe" line performs as a quarter-wave line. An outstanding advantage of the concentric line over the open line, however, is its total elimination of radiation which acts to reduce the resonant-circuit Q in open-line systems operated above 200 Mc. Several circuits embodying concentric linear tank circuits are shown in Figures 3A, 3B and 3C.

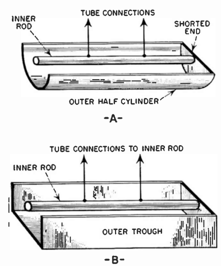

FIG. 4

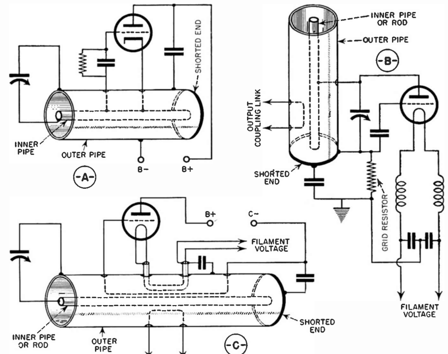

FIG. 3

As is true with open lines, the actual length of the concentric line will be somewhat shorter than the computed value of a quarter wavelength, due to tube loading effects. This may be allowed for by "tapping the tube connections down the line" as shown in Figures 3A and 3B.

For adjustment of resonant frequency, a short-circuiting disc, movable within the tube-conductor system (See Figure 3B) may be arranged. Various mechanical arrangements for sliding this disc in contact with the two pipes may be devised.

The characteristic impedance of the coaxial line system is given as:

$$Z_0 = 138.15 \log_{10} (x/y)$$

Where Z_0 is impedance (ohms),
x is inner diameter of outer pipe
y is outside diameter of inner pipe

x and y may be measured either in inches or centimeters, provided the same unit of measurement is employed in both cases.

The most desirable method of coupling the output circuit to the concentric-line oscillator is the small "hairpin"-type coupling link coil, shown in Figures 3B and 3C. Circuit 3C was designed by RCA for use in broad-band transmitters.

In Figure 3C, a small section of concentric line equivalent to one-half wavelength is used to connect the filament and maintains the proper phase and r. f. voltage relationships along the filament line.

In each of the concentric-line oscillator circuits illustrated, holes must be provided at particular points on the outer cylinder to admit leads for connection at proper points along the inner cylinder or rod. Location of the proper connection points and making of the connection, as well, present somewhat of a mechanical difficulty when it is desired to keep leads rigid and entirely clear of the outer cylinder. The "trough"-type of line, shown in Figure 4, relieves this difficulty.

There are two popular types of trough line. In Figure 4A, half of the outer cylinder has been dispensed with and an inner rod is supported from the trough by means of the half-circle shorted end. The second type of trough construction is illustrated in Figure 4B. The outer conductor in this case takes the shape of a metal box of square cross section.

Since the inner conductor is not fully shielded in trough-type lines, some radiation does occur and this reduces the resonant-circuit Q. However, the Q reduction is still below that experienced with open lines, and the increased facility with which connections may be made to the inner conductor, which is exposed on one side, often recommends this construction.