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H. F. Frequency Measurements

PART IV

By the Engineering Department, Aerovox Corporation

USE OF CRYSTAL OSCILLATORS

HARMONICS generated by lower-frequency crystal oscillators may be employed in the calibration of extremely-high-frequency apparatus, provided the crystal fundamental frequency is located reasonably near the high-frequency region. The harmonic spot frequencies from such oscillators are spaced apart by a number of kilocycles equal to the crystal frequency. The highest useful harmonic order is governed by the oscillator power output and the sensitivity of the receiving or monitoring device. When sensitive pickup equipment is employed, a large number of accurate calibration points may thus be obtained.

If the inherent stability of the high-frequency monitor or receiver is high and if this device is regenerative or is used in combination with an extremely-high-frequency heterodyne oscillator, good accuracy may be obtained by beating against the crystal harmonics. If the monitor device is non-regenerative or super-regenerative, it will be necessary to apply audio-frequency modulation to the crystal oscillator, and the obtainable accuracy of measurement will not be so high as in the previous case.

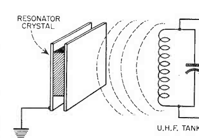

FIG. 1

Crystals suitable for the generation of harmonic frequencies in the extremely-high-frequency region will have fundamental frequencies between 5 and 30 megacycles. Several different crystal cuts having various distinguishing characteristics are included within this frequency range, individual demands of accuracy and stability dictating choice of type.

Perhaps the most significant of crystal characteristics, with respect to extremely-high-frequency harmonic generation, is frequency-temperature coefficient. This characteristic is important, since the frequency drift due to temperature is multiplied by the order of the harmonic employed, a slight drift at the fundamental frequency amounting to an appreciable frequency change at a high-order harmonic.

First-grade general communication crystals are supplied in the 5-30-Mc. range with frequency-temperature coefficients sufficiently low to permit their use for high-frequency harmonic generation. Typical ratings of such crystals are: 5-11 Mc., plus 2 cycles per megacycle per Centigrade degree; 11-18 Mc., plus 2 cycles; 18-23 Mc., plus 20 cycles; and 23-30 Mc., plus 43 cycles. A constant-temperature oven, capable of maintaining the crystal temperature within 1 degree or better of its calibration temperature will greatly improve the stability of harmonic points. The use of an oven is imperative in the case of the higher-frequency crystals, because of their increased coefficients, and it is recommended that this oven control the

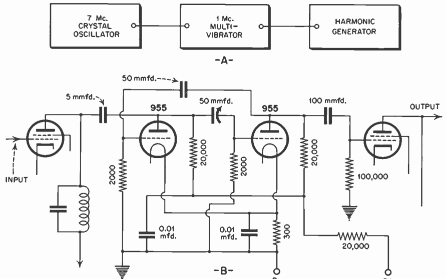

FIG. 2

crystal temperature within one-tenth or one-hundredth degree.

A particular advantage of employing a crystal fundamental frequency of 5, 10, or 15 megacycles is the opportunity to compare these frequencies with standard-frequency emissions from WWV. For correction against standard-frequency signals, several means are available: at frequencies up to 5 Mc. a small variable capacitor may be shunted across the crystal holder; at frequencies above 5 Mc. a variable-air-gap holder may be employed for the purpose; and very small variations of crystal frequency may be obtained by changing the operating temperature of a closely-regulated oven.

The crystal manufacturer is able to calibrate within 0.01 percent of the indicated frequency. The guaranteed accuracy of 0.025 percent includes this figure and an additional 0.015 percent which represents deviation in frequency as the crystal is operated in oscillators other than that in which it was calibrated. The last figure may be eliminated by having the crystal calibrated in the actual oscillator in which it is to be employed.

The high-frequency crystal oscillator must be designed in such a manner as to keep shunting capacitances low. The by-passing effect of tube capacitances increases at high frequencies, often becoming more predominant at some harmonic than at the crystal fundamental. Tube choice is accordingly of importance. In high-frequency crystal oscillators, it is advisable to employ only triodes with low values of input capacitance.

The higher-frequency crystals are harmonic-cut types, since conventional cuts would be impractically thin at these frequencies. These crystals actually oscillate at a harmonic of the frequency which would correspond to their thicknesses, and they may be made to oscillate as readily at their fundamental frequencies simply by resonating the plate tank to the lower value. Since all crystals oscillate at their fundamental frequencies in the Pierce circuit, the latter is not suitable for operation with harmonic-cut crystals.

Harmonic output voltage from the crystal oscillator may be increased by employing high values of grid bias voltage, low-C tank circuits, and, whenever practicable, introducing a small amount of regeneration. Best results will be obtained by employing tubes which have been designed especially for ultra-high-frequency operation.

USE OF RESONATOR CRYSTALS

High-frequency receivers, monitors, and oscillators may be calibrated by means of resonator crystals by employing the ability of these crystals to resonate in the manner of a wavemeter when they are electrostatically coupled to tank circuits of the devices under test. In operation, one electrode of the crystal is grounded (see Figure 1) and the other electrode is placed within the field of the coil or connected to an electrostatic pickup coil which in turn is placed near the coil or an active electrode of the tube.

As the high-frequency circuit is tuned through its range, oscillation or regeneration is reduced sharply as harmonics of the crystal frequency are passed through. In a straight oscillator, these resonant points, separated by the fundamental frequency, may be detected by deflections of a grid- or plate-circuit milliammeter or by reduction of beat-note intensity as delivered by an auxiliary monitor. In an oscillating or strongly regenerating receiver, there will be a reduction in beat-note intensity or in tube or circuit noise as these resonant points are passed through. In a super-regenerative receiver, the characteristic super-regenerative rush or hiss will be reduced or completely blocked as the points are passed through. In each of these applications, response of the resonator crystal is comparable to that of an absorption wavemeter, except that the crystal will furnish a succession of standard-frequency spot frequencies instead of the single frequency characteristic of the wavemeter. Intensity of the crystal action will depend upon the harmonic order, tightness of electrostatic coupling, and activity of the crystal.

The spot-frequency points afforded by a resonator crystal, like those set up by a standard-frequency oscillator, cannot readily be identified as to actual frequency unless some standard reference frequency is available. However, such points are invaluable when it is desired to subdivide the region between known frequencies into equal subdivisions.

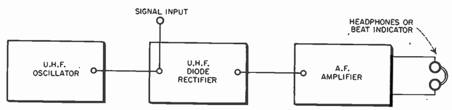

FIG. 3

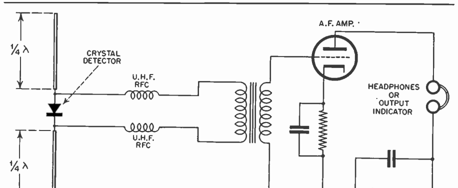

FIG. 4

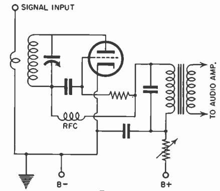

FIG. 5

U. H. F. FREQUENCY STANDARD

A very familiar arrangement of standard-frequency calibrator assembly for low-frequency application is the 100-kc. oscillator and 10-kc. multivibrator circuit. The utility of the harmonic-generating crystal oscillators, just described, may be increased by the addition of a suitable high-frequency multivibrator to subdivide the extremely-high-frequency regions delineated by the crystal harmonics into equal portions. Such an arrangement has been developed by Sabaroff[1] and is illustrated in functional block diagram in Figure 2-A.

In this arrangement, the crystal oscillator operates on a fundamental frequency of 7 Mc. and controls a 1-Mc. multivibrator, the latter delivering signal voltage to a harmonic generator in the usual fashion. Calibration points as high as 250 megacycles have been obtained by the designer.

The high-frequency multivibrator is adjustable to frequencies between 800 and 1800 kilocycles and is readily synchronized by oscillator voltages at frequencies of ten times the multivibrator fundamental. Constants in the multivibrator circuit are of particular interest, since these circuits are ordinarily set up for audio-frequency and very-low radio-frequency response and must be specially arranged for high-frequency synchronization and ultra-high-frequency harmonic transmission. The multivibrator circuit and constants given by Sabaroff for 1-Mc. operation are shown in Figure 2-B. Acorn tubes and ultra-high-frequency-style wiring are recommended.

U. H. F. SIGNAL GENERATORS

Various signal generators for the ultra-high-frequency range afford continuously-variable-frequency output at fundamentals extending well into the very high frequency spectrum. Additional calibration frequencies are also available by employing harmonics of the fundamental frequencies.

Such equipments are manufactured by General Radio Co. to reach a fundamental frequency of 330 megacycles, by Weston Electrical Instrument Corporation for fundamental coverage up to 150 megacycles, and by Ferris Instrument Corporation for fundamental coverage up to 100 megacycles.

MONITORS

For the comparison or identification of extremely-high-frequency signals, monitors of various types may be constructed in accordance with the high-frequency techniques previously outlined.

For unmodulated signals, a regenerative or oscillating detector circuit with either conventional or linear tank circuit may be employed. The monitor may be calibrated by means of a Lecher frame, calibrated wavemeter, or standard oscillator. Since there is an upper limit of oscillation for each tube type, the experimenter must select regenerator tubes which are capable of reaching the frequencies to be monitored.

An alternative arrangement for checking extremely-high frequencies embraces a high-frequency oscillator of one of the types described earlier in this series together with an ultra-high-frequency diode detector, as shown in block diagram in Figure 3. Standard oscillator signal and unknown signal are mixed in the diode detector, the beat note being delivered to headphones, audio amplifier, or beat indicator. Signal frequencies may be measured very accurately by the beat-note method with such an arrangement.

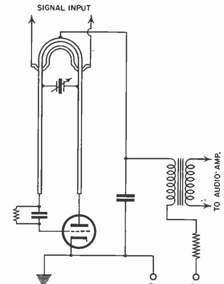

FIG. 6

Other monitor circuits for modulated signals are shown in Figures 4 to 7. Figure 4 illustrates a simple crystal detector circuit fixed-tuned to a given frequency by a dipole antenna, each leg of which is one-quarter wavelength long at the measurement frequency. Figure 5 is a super-regenerative detector employing conventional coil-capacitor tuning. Figure 6 shows a super-regenerative detector with "hair-pin" line tank circuit. And Figure 7 shows a Barkhausen-Kurz-Gill-Morrel detector utilizing an electron orbit oscillator. The circuit is after Uda.[2] This circuit is relatively unstable and suitable only for modulated signals.

[1] An Ultra-High-Frequency Measuring Assembly. Samuel Sabaroff. *Proc. I. R. E.* Mar. 1939, p. 208.

[2] Radiotelegraphy and Radiotelephony on Half-Meter Waves. Uda. *Proc. I. R. E.* June 1930.

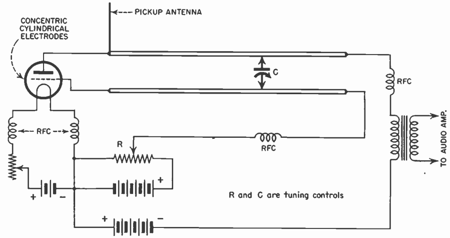

FIG. 7