The AEROVOX Research Worker

The Aerovox Research Worker is edited and published by the Aerovox Corporation to bring to the Radio Experimenter and Engineer, authoritative, first hand information on capacitors and resistors for electrical and electronic application.

VOL. 20, NO. 8 AUGUST, 1950 Subscription By Application Only

UHF Frequency Standards

By the Engineering Department, Aerovox Corporation

ACCURATE determination of the frequency of any cyclic phenomenon becomes increasingly difficult as that frequency departs further from the basic standard periodicity; the period of the earth's rotation. For this reason, the measurement of radio frequencies in the ultra high frequency range (300-3000 mc.) necessitates the use of essentially new techniques — just as the original generation and transmission of such frequencies require methods which depart markedly from the conventional. Because of the increasing interest in this portion of the radio frequency spectrum, in connection with UHF television, citizens radio, radar, microwave radio relay, and amateur communication, a review of these techniques is well justified.

At UHF, the usual primary standards employed at low frequencies are not conveniently applied. Signal frequencies derived from temperature-controlled crystal oscillators require an inconvenient number of multiplying stages to provide output in the UHF region and the harmonic content of primary standards employing low-frequency multivibrators is usually insufficient to provide identifiable check-points at such frequencies. In addition, the propagation characteristics in this part of the radio spectrum do not make the use of standard-frequency broadcasting, such as WWV transmissions, practical. Other methods, such as the derivation of microwave primary frequency standards from the spectral absorption lines of gasses[1], exist but are at present quite complicated and generally beyond the means of the individual experimenter or small laboratory.

Primary-Referred Standards

One method of referring a low-frequency primary standard signal to the UHF region has been described in the AEROVOX RESEARCH WORKER for May, 1943. This system utilizes a succession of self-excited oscillators, each synchronized by the zero-beat method with the last useful harmonic of its neighbor. The lowest frequency oscillator in the series is synchronized with a primary standard such as WWV transmissions. Zero-beat or null indicators, consisting of meters or electronic tuning-eyes, are employed with each oscillator stage to give a ready indication of synchronism. Good stability is required of each oscillator in the chain if frequent readjustments are to be avoided. With sufficient care in operation, this system will yield UHF check-points accurate to at least one part in one million.

Another simple system for obtaining UHF check-points against a primary standard has been used.[2] This method produces usable harmonics throughout the lower portion of the UHF spectrum and is capable of excellent accuracy. A conventional crystal-controlled oscillator circuit operating at 5 megacycles is supplied with *unfiltered* d.c. plate voltage. The harmonic content of the crystal oscillator output is greatly increased by the application of this pulsating d.c., with the result that marker frequencies occurring every 5 mc. can be detected on a receiver throughout the 420 mc. amateur band, the citizens radio band, and the UHF television band. An antenna cut for the desired output frequency serves to accentuate the harmonic output in that region. The 5 mc. crystal signal may be compared in a receiver with WWV transmissions on that frequency and may be zero-boat by variation of the crystal holder pressure, or by a small variable capacitance connected across the crystal. Since this method produces harmonics spaced at intervals equal to the crystal oscillator frequency, a secondary frequency standard, such as will be described later, must be used to identify harmonics.

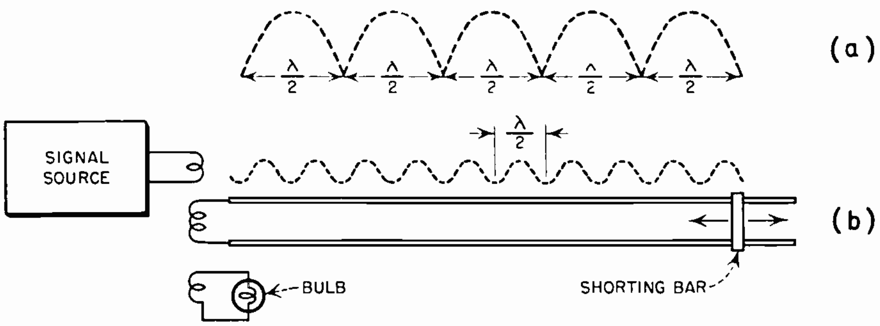
UHF Wavemeters

Of considerably greater utility and convenience for the everyday measurement of ultra high frequencies are the standards based upon high quality resonant circuits. The UHF predecessor of this family of frequency standards is the simple, well-known Lecher wire wavemeter. This instrument, used since the pioneering days of radio, is capable of high accurate wavelength determination in the lower UHF range, when judiciously used. For the purpose of comparison with the more modern systems to be discussed later, a brief description of the Lecher wavemeter will be included here.

The basic Lecher wire wavemeter is illustrated schematically in Fig. 1. It consists of a mechanically rigid length of parallel-wire transmission line, electrically coupled to the source of unknown frequency. Operation is based on the principle that the velocity of wave propagation along such an air-insulated transmission line is essentially equal to the velocity of light and hence the frequency of the source being measured is related to the lengths of the standing waves measured along its length by:

(1) $$f = \frac{30{,}000}{\lambda \text{ (cm.)}} \text{ megacycles}$$

Indication of the lengths of standing waves on a Lecher wire is usually accomplished by sliding a short-circuiting bar along the transmission line and noting the positions at which the line is resonant at the unknown frequency. Resonance will occur at half-wave-length intervals and may be detected by its interaction with the circuit being measured or by an r.f. indicator such as a flashlight bulb or thermo-milliameter coupled to the Lecher circuit. The accuracy of the system depends upon the exactness with which the distance between points of resonance can be determined. Since these points correspond to r.f. voltage minima, they are usually quite sharp if losses are negligible. With considerable precision in construction and use, an accuracy of about .1% can be achieved with a Lecher wavemeter.



TYPICAL LECHER WAVEMETER
FIG. 1

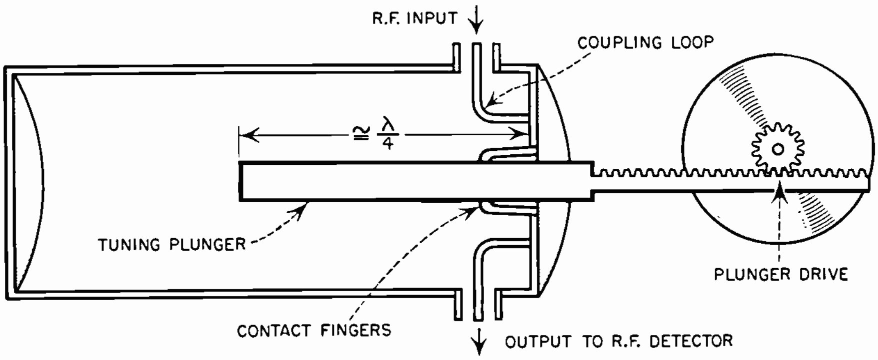
At the higher frequencies of the UHF range, the accuracy of the simple Lecher wire system is limited by radiation losses, which lower the "Q" of the resonant circuit. This has the effect of introducing uncertainties in the positions of voltage minima, since these are no longer sharp as shown at (a) in Fig. 1, but are broader as illustrated at (b) for a lossy line.

These shortcomings of the standard open Lecher line have been overcome by the use of the *coaxial* form of Lecher line shown in Fig. 2. Here the open, parallel-wire transmission line is replaced by a shielded coaxial line which is tuned by a sliding shorting plunger. The unknown frequency is coupled to the coaxial wavemeter by means of an inductive coupling loop and concentric cable. Resonance is indicated by interaction with the circuit being measured, or by a suitable r.f. indicator coupled to the wavemeter by a second coupling loop. This indicator usually takes the form of a crystal detector and microammeter. As in the basic Lecher system, wavelength is determined by measuring the distance between resonance points which occur each half-wavelength. These points give maximum indications on the meter. Because of the fact that no radiation takes place from the coaxial circuit, very sharp resonances are obtained since the "Q" of the wavemeter can be made quite high, especially if the r.f. conducting surfaces are silver-plated and the coupling to the circuit is light.

The accuracy of the coaxial wavemeter is determined by the precision of the mechanical drive mechanism which measures the position of the shortening plunger. In a high quality instrument of this type, the distance between half-wave resonance points can be determined to within about .001 centimeter. At 3000 mc., this represents a realizable accuracy of .01%. Wavemeters of the coaxial variety are widely used as UHF standards since they are self-calibrating and are not greatly effected by temperature changes. The measuring accuracy of Lecher systems is increased if the line is long enough to permit the distance between several successive responses to be measured and averaged.

Secondary Standards

Another form of coaxial wavemeter[3], which makes a convenient secondary standard when calibrated by one of the foregoing systems, is depicted in



QUARTER WAVELENGTH COAXIAL WAVEMETER
FIG. 3

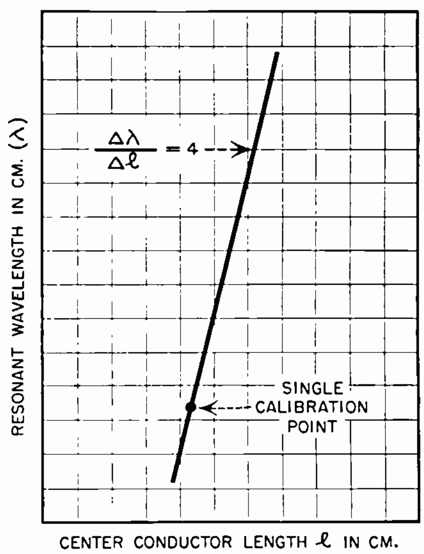
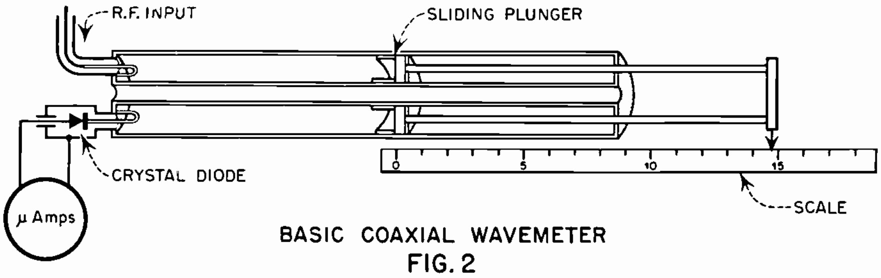


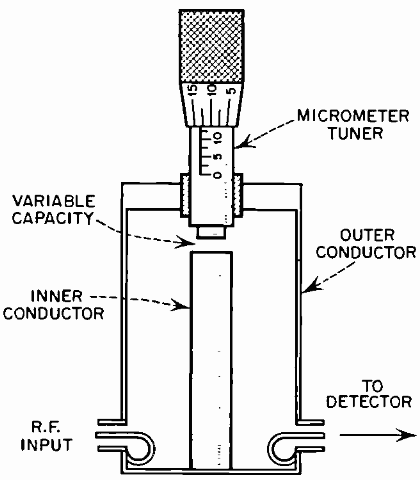
FIG. 4



BASIC COAXIAL WAVEMETER
FIG. 2

Fig. 3. This type is called a *quarter-wavelength coaxial* wavemeter since it is resonant at the frequency for which the open-circuited center conductor is an electrical quarter-wavelength long. This length may differ considerably from a physical quarter-wavelength because of foreshortening capacity between the outer conductor and the end of the inner conductor. However, the important characteristic of this type is the fact that the resonant wavelength is essentially a linear function of the center conductor length. Therefore, if mechanical arrangements are made to vary the length of the center conductor, the resonant wavelength will change 4 centimeters for each centimeter change in the length of the center conductor. This 4:1 relationship is accurate within about 1% in a well-designed instrument. The curve of wavelength versus center conductor length is thus linear and has a constant slope of 4. For this reason, the wavemeter may be calibrated roughly by comparison with a primary standard at a single check-point, as is illustrated for a hypothetical wavemeter in Fig. 4.

To avoid erratic readings, the center conductor of a resonator of the quarter-wavelength type must make good electrical contact to the end plate. A set of spring contact-fingers may be used as in Fig. 3, or a special non-contacting choke joint is sometimes employed as a refinement. The center conductor drive may be a rack-and-pinion arrangement for a "search" wavemeter in which extreme accuracy is secondary to wide tuning and convenience. For greater precision over a smaller range, a micrometer head drive is usually provided for the center conductor.



CAPACITANCE TUNED COAXIAL WAVEMETER
FIG. 5

At the lower frequencies in the UHF range, wavemeters of the Lecher and quarter-wave coaxial types are somewhat bulky and inconvenient. For this reason, a capacity-tuned coaxial resonator as shown in Fig. 5. is sometimes preferable. This type is electrically similar to the quarter-wavelength variety of Fig. 3, but is tuned by a variable capacitance at the end of the center conductor, rather than by varying the center conductor length. The tuning characteristic of this type is not linear, so that it must be carefully calibrated against another standard at a sufficient number of points to allow a curve of frequency (or wavelength) versus tuner setting to be plotted.

Although the "lumped" tuning capacity of this type of wavemeter makes it somewhat more compact than the types previously described, it is considerably more susceptable to errors due to thermal expansion. By careful design, this effect may be compensated in most wavemeters by the use of special low-expansion materials such as "Invar", or by making the outer conductor of a material having a temperature coefficient sufficiently greater than that of the center conductor that capacitance changes due to expansion are corrected. An alternative design,[4] makes use of a small temperature compensating fixed capacitor connected between the outer conductor and the end of the inner conductor.

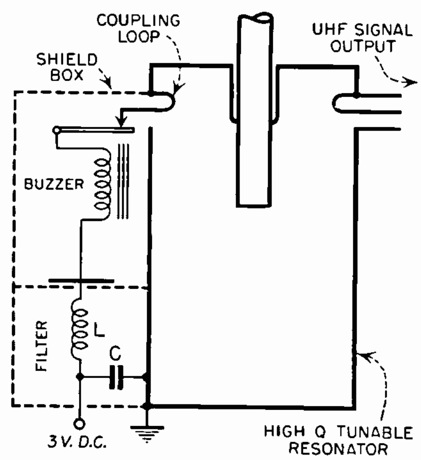
Standard Signal Generators

Calibrated signal sources for experimental work with UHF receivers, antennas, and other components may be produced by utilizing high quality resonant circuits of the type described above for the frequency determining elements of self-excited oscillators. In general, the accuracy and stability of such devices is much inferior to that of the same circuits used as wavemeters because of the loading and thermal instability introduced by the vacuum tube.

An important exception is the *buzzer signal generator*[5] shown in Fig. 6. In this extremely simple and useful device a high "Q" cavity wavemeter, usually of the quarter-wavelength type, is excited by the noise "hash" generated by the interrupter contacts of a buzzer. The wavemeter circuit acts as a very selective band-pass filter which passes only the frequency component to which it is tuned. Since the short pulses generated by the buzzer are very rich in high frequency content, the signal generator will provide useful output throughout the entire tuning range of the resonant cavity circuit. The output signal is tone modulated at the buzzer frequency. To prevent spurious radiation, the buzzer and its d.c. leads must be well shielded and filtered. The ferquency stability and accuracy of the buzzer signal generator is essentially equal to that of the wavemeter circuit used since no vacuum tube is used to contribute electronic loading and little heat is generated. Such devices have been used as standard signal sources to at least 10,000 mc.

REFERENCES

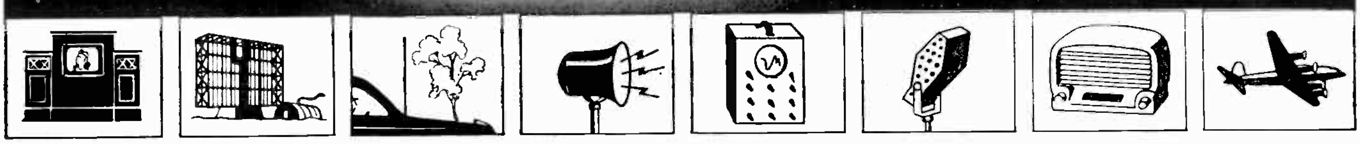
1—Electronics, April 1949.
2—Radio & Television News, January 1950.
3—Electronics, March 1948.
4—Electronics, September 1949.
5—Electronics, July 1950.



BUZZER SIGNAL GENERATOR
FIG. 6

The Star Performer—

in assemblies that must stand the gaff . . . day-in-and-day-out . . . for months and years to come:



TELEVISION
Minimizes costly service calls. Shows greater profit on usual maintenance deals.

MILITARY
Roughest handling without failure. Withstands climatic conditions without flinching.

AUTO RADIO
Unaffected by temperatures from sub-zero to 212° F. Nothing to melt. Humidity-proof.

SOUND SYSTEMS
No "noise" troubles due to moisture penetration and electrical leakage. Dependable.

INSTRUMENTS
No shelf deterioration. Can be stocked well ahead of use, yet remain "fresh" and reliable.

BROADCASTING
Greatest freedom from component-breakdown troubles and "off-the-air" spells.

HOME RADIO
Smaller than usual paper capacitors. Contribute to more compact chassis. Build good will.

AIRCRAFT
Withstand wide temperature ranges, varying air pressures, vibration, shock.

● Component-breakdown *insurance. That's precisely* why assemblies that must stand up—regardless of humidity, heat, cold, mechanical or electrical abuse—are featuring Duranite capacitors.

Duranite means *different*. Not just another plastic tubular. Not just an improvement over previous paper tubulars. Duranite stands for an *entirely new* concept of the capacitor art—*new* impregnant, Aerolene, doing the work of both wax and oil; *new* casing material, Duranite, providing rock-hard, non-varying, impervious sealing throughout; *new* processing methods insuring quality with economy. You will never know how dependable radio-electronic components can be until you have tried Duranite capacitors.

● ***Write on your business letterhead for samples. Detailed literature on request. Let us quote on your requirements.***

CAPACITORS • VIBRATORS • TEST INSTRUMENTS

AEROVOX capacitors

For Radio-Electronic and Industrial Applications

AEROVOX CORPORATION, NEW BEDFORD, MASS., U. S. A. • Sales Offices in All Principal Cities
Export: 41 E. 42nd St., New York 17, N. Y. • Cable: AEROCAP, N. Y. • In Canada: AEROVOX CANADA LTD., Hamilton, Ont.