FREQUENCY MEASUREMENTS AT RADIO FREQUENCIES

BULLETIN 10

GENERAL RADIO CO.
CAMBRIDGE, MASS.

FREQUENCY MEASUREMENTS AT RADIO FREQUENCIES

A Manual of Measurement and Monitoring Technique

BULLETIN 10

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GENERAL RADIO COMPANY
CAMBRIDGE, MASSACHUSETTS

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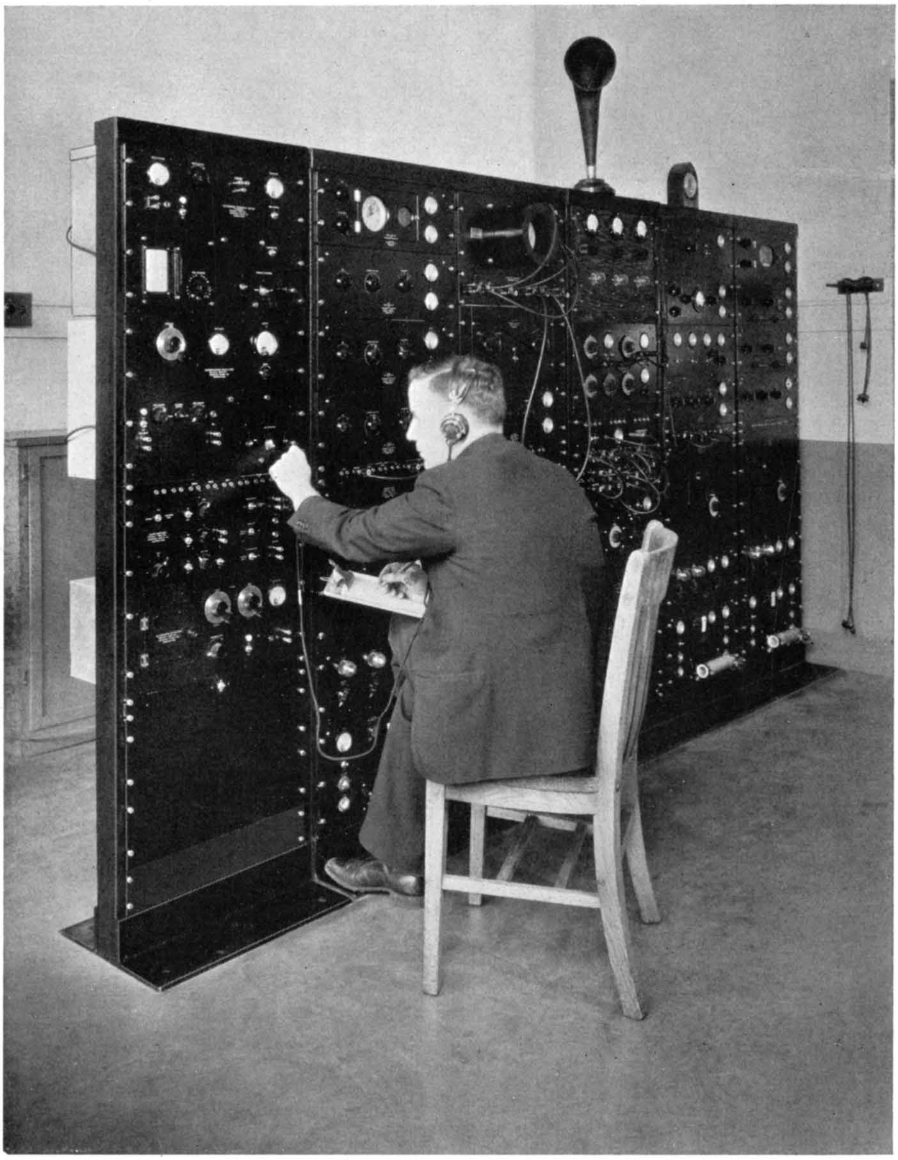


The frequency standards room at the General Radio Company. The standardization equipment consists of four standard-frequency oscillators with means for inter-comparing them and observing frequency drifts. The two racks at the left contain a complete frequency-measuring assembly consisting of a Class C-21-H Standard-Frequency Assembly and interpolation equipment shown in detail on page 33

INTRODUCTION

Modern frequency-measuring methods are not entirely new. The principles involved have been a matter of common knowledge for some years, although little equipment for applying these principles was available until the demand arose for more accurate measurements.

As the number of radio stations has constantly increased and frequency tolerances have grown smaller, the importance of accurate frequency measurement and frequency monitoring has increased accordingly.

These decreased tolerances have brought about a complete change in the equipment used for routine frequency measurement and monitoring. In addition, the larger communication companies are finding it advisable to install central monitoring stations to measure the frequencies of groups of transmitters. Many classes of scientific measurements require an accurate knowledge of frequency, and this has resulted in the installation of primary standards of frequency in the physics and communication laboratories of several colleges and universities. This standard-frequency equipment is also useful in teaching electrical communication students and in demonstrating the principles involved in precise frequency measurements.

A few years ago, the tuned-circuit wavemeter was the universally accepted frequency-measuring device, in fact, it was "the fundamental radio instrument" on which all measurements at radio frequencies were based. It had many advantages. Its frequency was continuously variable over a wide frequency range, it was portable, and its accuracy was sufficient for the uses to which it was put.

The calibration of a standard wavemeter was usually determined either by the calculation of its resonant frequency from the circuit constants or by comparison with the frequency delivered by a high-frequency alternator, which can be calculated from its speed and structural constants. Of these methods, the latter is the more fundamental, since the frequency is determined by comparison with time, as is the frequency of our highly precise primary standards of today. After a standard wavemeter had been calibrated in one of these ways, other wavemeters could be calibrated in turn from it and used as practical frequency-measuring instruments.

The accuracy obtainable with the wavemeter is limited by several factors, the first of which is obviously the inaccuracies in calibration.

As the art developed, however, the error from this source was greatly reduced through the use of piezo-electric oscillators as frequency standards, and the error in calibration reached the point where it became negligible in comparison with other factors. Among these are the change in resonant frequency due to the effects of temperature and aging in the tuned circuit and the reaction on the wavemeter frequency of the circuit under measurement. Superposed on these errors is that due to its rather poor precision of setting, although this factor is not difficult to overcome. As a result of these inherent errors, the best accuracy obtainable from commercial models of wavemeters, when the calibration is relied upon for an extended period of time, is from 0.1 per cent to 0.25 per cent. A comparison of these figures with the allowable frequency tolerances on commercial radio stations shows why the wavemeter has yielded to other instruments and other methods.

The obvious point at which to start improving the accuracy of frequency measurements is in the frequency standard itself. The development of the piezo-electric oscillator as a frequency standard eliminated most of the errors from this source, and this type of standard was long used as a basis for wavemeter calibrations. The precise piezo-electric standards now in use have further reduced these errors to the point where they are negligible for most commercial purposes.

After the development of accurate frequency standards it became necessary to produce methods and equipment for utilizing the standard frequency in the determination of unknown frequencies. The key to this problem lay in the use of heterodyne methods, and these have now been brought to the point where the accuracy obtainable by the intelligent use of a calibrated heterodyne frequency meter is about ten times better than that formerly achieved with the wavemeter.

Expressed in general terms, the problem of frequency measurement does not differ markedly from that of measuring length, weight, or other physical quantities. It is essentially a matter of making a comparison between the unknown and a known standard.

There are, therefore, two parts to any frequency-measuring system, first a means of producing a standard frequency, and second a means of comparing the unknown frequency with that standard.

The Frequency Standard

The various types of frequency standards are discussed later in this bulletin. For the present, it is sufficient to point out that the principal requirement for a standard of frequency is that its frequency be as nearly constant as possible. The selection of a frequency standard for a definite use involves the consideration of a number of factors, but this is the most important one.

Once a source of constant frequency has been established, its absolute value can be easily determined by means which are described later, and it can be used as a standard with which other frequencies may be compared.

Methods of Comparison

1. If the unknown frequency and the standard frequency differ by only a few cycles, the comparison can be made by means of a rectifier and a beat-frequency indicator to show the difference between them. This method is used in most of the frequency monitors in radio broadcasting stations.

2. While this arrangement is suitable for measuring a single frequency, it cannot be used where measurements over a wide frequency range are to be made in terms of a single-frequency standard. Means are available, however, for deriving from the frequency standard several series of harmonically related frequencies, the fundamental frequencies of which are controlled by the standard frequency and bear integral relations to it.*

With a harmonic series of this sort available, any unknown frequency will, in general, lie between two of these harmonics. The problem is then reduced to determining the frequency interval between the unknown frequency and the nearest standard harmonic.

There are two methods of measuring this interval, first by comparison with a calibrated low-frequency oscillator, and second by interpolation on the scale of a linear-scale radio-frequency oscillator. In either case, since the frequency interval is small compared with the absolute value of the frequency under measurement, slight errors in its determination do not seriously affect the result.

3. Where a local frequency standard is not available, the measurement of an unknown frequency can be made by means of a calibrated radio-frequency oscillator, which is periodically checked against some frequency standard and whose calibration is relied upon in the periods between checks. An example of this system is a heterodyne frequency meter whose calibration is checked against standard-frequency radio transmissions. This is the class of measurements formerly made with a wavemeter, but the accuracy has been greatly improved. In addition to the better precision of setting afforded by heterodyne methods, the calibration is relied upon for short periods only, and accurate standards are available for correcting the calibration.

*J. K. Clapp: "Universal Frequency Standardization from a Single Frequency Standard," Journal of the Optical Society of America, July, 1927.

Development of Instruments

Some years ago, the General Radio Company undertook a development program directed toward the design of accurate and commercially acceptable frequency-measuring equipment. Rather than merely to keep pace with demands of the radio industry, an effort has been made to keep ahead of them and to have equipment available for meeting frequency-measurement problems whenever the problems arose. In addition to the line of stock equipment, described in this bulletin, many special units and assemblies of units have been built.

General Radio frequency standards and frequency-measuring instruments are now in use all over the world by both government and private agencies. In England, France, Russia, Italy, Japan, Dutch East Indies, and South America, as well as in Canada and the United States, installations of General Radio apparatus ranging from single instruments to complete frequency monitoring stations are in operation. Photographs of many of these are shown in the following pages.

In addition to a discussion of the principles and methods of frequency measurement, this bulletin contains recommendations of instruments and combinations of instruments for specific purposes. Other combinations can be assembled and the General Radio Company is glad to cooperate in suggesting apparatus to meet the user's needs.

PART I

FREQUENCY STANDARDS

FREQUENCY AND TIME

FREQUENCY may be defined as the rate of recurrence of cyclical phenomena, and the units in which it is measured are those of reciprocal time. Frequency and time are identical phenomena and are both derived from the same source.

The fundamental standard on which all measurements of frequency and time are based is the earth's rotation in space. The duration of one complete revolution of the earth on its axis is our fundamental time interval, the sidereal day, and the rate of rotation, one cycle per sidereal day, is our fundamental standard of frequency.

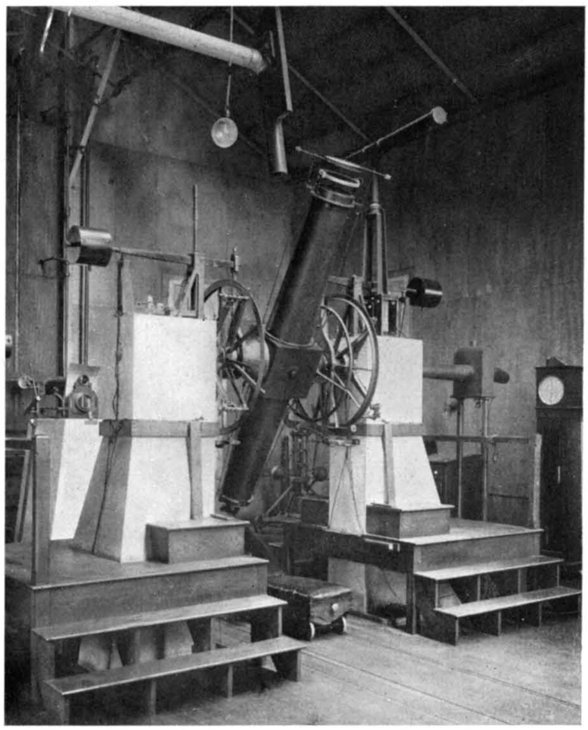


FIGURE 1. The 9-inch transit circle at the U. S. Naval Observatory, Washington, D. C. It is with instruments of this type that the rates of standard clocks are checked with star time

From this it is evident that frequency can be measured in terms of time and conversely that time can be determined from frequency. This principle is used in making standard time available for general use and in establishing a primary standard of frequency.

In the determination of standard time, observations of the passage of certain fixed stars across one of the earth's meridians are made. The interval between two successive transits of one of these stars across the observer's meridian is a sidereal day.

The practical unit of time is the solar day, which is determined by the passage of the sun over a given meridian. Due to the eccentricity of the earth's orbit about the sun and the inclination of the earth's axis in its orbit, the solar day varies in length, and for practical reasons the working standard of time is the mean solar day or the average length of a solar day throughout a year. The mean solar day bears a fixed and known relation to the mean sidereal day.*

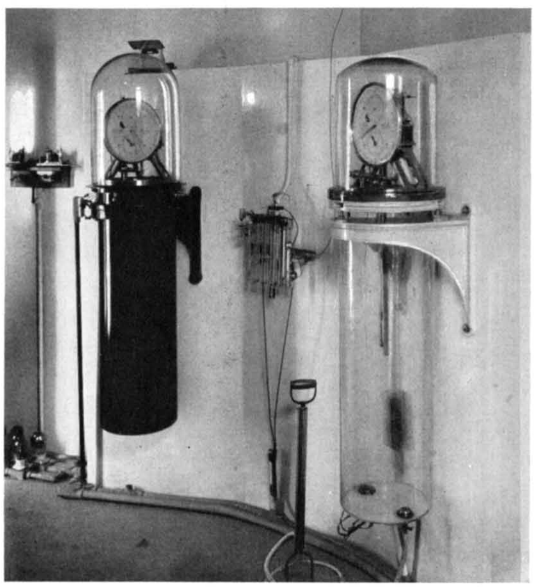


FIGURE 2. Two Riefler standard clocks at the observatory of the Elgin National Watch Company

In practice, the interval between star transits, which determines the sidereal day, is recorded in terms of the readings of precise astronomical clocks which can be regulated to keep either sidereal or mean solar time. Time, as determined by these clocks, is then made generally available by means of time signals over both wire- and radio-communication channels, and standards of both time and frequency can be compared with these signals.

*The length of the sidereal day, sometimes called the apparent equinoctial day, is subject to a slight variation. For this reason, many observatories use mean equinoctial time in computing the rates of precision clocks.

Any standard of time is also a standard of frequency. A familiar example is the pendulum clock. A pendulum which beats seconds is a frequency standard, the frequency of which is one-half cycle per second. By means of the escapement, or other conversion device, the pendulum can be made to operate a clock train which is so geared that, when the pendulum frequency is exactly one-half cycle per second, the clock keeps true time. The clock reading can be checked periodically against star sights, time signals, or an astronomical clock and this can be recorded in terms of the clock indication. The system thus established is

FIGURE 3. The time room at the Naval Observatory. The clock is the apparatus for sending the daily time signals, and, during the period of signaling, controls directly the broadcasting stations at Arlington, Annapolis, Key West, and San Diego, with which it is connected by wire. Connections are made through the switchboard on the right. The seconds as sent by the clock and as received by radio are recorded on the revolving sheet of paper of the chronograph on the right

not only a timekeeper, but is also a means of determining the pendulum frequency. For example, if the clock is gaining two seconds per day, the frequency of the pendulum is

$$\frac{86,402}{86,400} \times 0.5000000 = 0.5000116 \text{ cycles per second,}$$

since there are 86,400 seconds in a mean solar day.

This same method is used in determining the frequency of the primary standard of frequency described in the next section.

THE PRIMARY STANDARD

SINCE radio communication deals with frequencies considerably higher than one-half cycle per second, the pendulum clock just described is hardly a suitable standard for use in measurements at radio frequencies. The useful radio spectrum extends from audio frequencies up to several megacycles and a practical frequency standard should be capable of furnishing standard frequencies over this entire range.

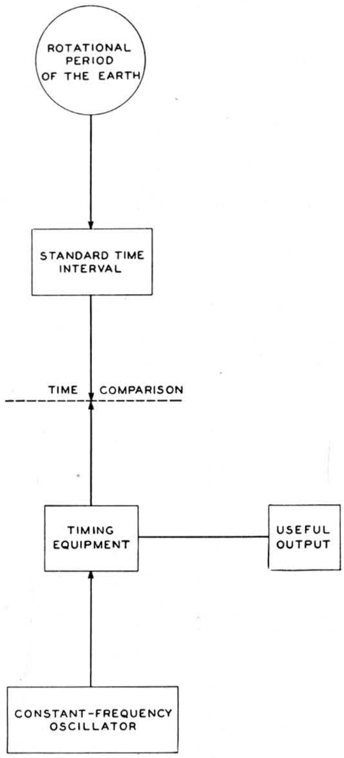


FIGURE 4. Functional diagram for a primary standard of frequency. The frequency of a primary standard is measured by direct comparison with the rotational period of the earth. Hence any primary standard will consist of a constant-frequency oscillator (such as a pendulum, or a crystal) and some means for counting the number of its oscillations in a given standard time interval.
For a detailed example of a practical primary standard, see Figure 6 and Figure 7

For this reason, and also because of certain design considerations, the frequency of the working standard is usually in the low radio-frequency range.

Figure 4 is a block diagram of a primary frequency standard. The working standard is an oscillator whose frequency is extremely stable. Associated with the oscillator is a timing system, which operates as a counter of the number of cycles executed by the oscillator in a given time interval. This counter, which, for convenience, may operate a clock train, can be so geared that, when the frequency of the oscillator has a specified value, the clock indicates true time.

The timing system is the distinguishing characteristic of a primary frequency standard. A stable oscillator does not in itself constitute a primary standard unless a timing means is provided.

Timing

By comparing the reading of this clock with a standard time interval, a measure of the oscillator frequency is obtained. The mean frequency f_0 is given by this expression,

$$f_0 = \frac{\text{Total number of cycles in time interval T}}{\text{Time interval T}}$$

and in terms of the clock indication,

$$f_0 = \frac{\text{Clock reading for time interval T}}{\text{Time interval T}} \times \text{nominal oscillator frequency.}$$

In order to justify the use of a timing system, the frequency of the oscillator must be so nearly constant that the difference between its mean frequency and its instantaneous frequency is negligibly small, since otherwise the mean frequency obtained by means of the time comparison would have no significance.

Frequency Multiplication and Division

Since a single-frequency standard has little value for measurements over a wide frequency range, a practical standard-frequency assembly includes equipment for producing a multiplicity of other frequencies from the standard-frequency oscillator. In the diagram of Figure 4, these frequencies are included in the portion labeled USEFUL OUTPUT. They are usually produced by a process of frequency division and multiplication, which requires comparatively simple equipment.

Reduced to its elements, the system for deriving these frequencies operates as shown in Figure 5. For frequency division, some form of relaxation oscillator is generally used, such as the multivibrator. An oscillator of this type is distinguished by its susceptibility to control by the introduction into its circuit of a voltage whose frequency corresponds approximately to its fundamental or a harmonic. Under this condition, the frequency of the relaxation oscillator locks into step with the controlling voltage and bears an integral relation to it.

If the frequency of the working standard is f_0, a frequency divider controlled by it will have a fundamental frequency $\frac{f_0}{m_1}$, where m_1 is a whole number. This unit can, in turn, control another similar instrument to divide the frequency by another whole number m_2, giving a

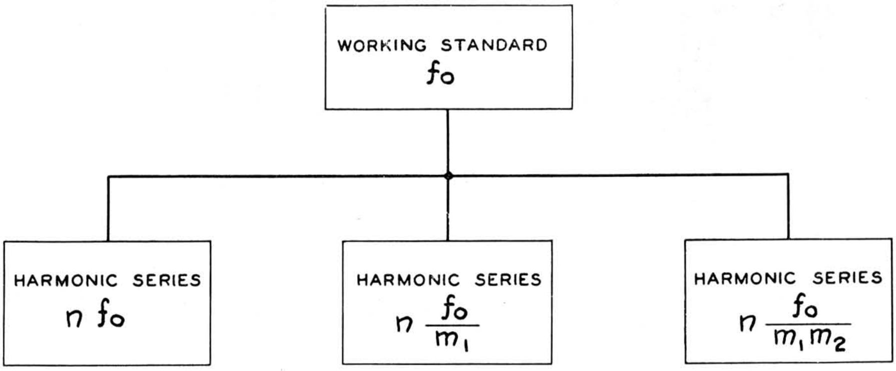


FIGURE 5. Functional diagram of a system for frequency division and multiplication

total reduction in frequency of m_1m_2. This process can, of course, be continued with more stages of frequency division, if desired.

From each of these standard frequencies f_0, $\frac{f_0}{m_1}$, $\frac{f_0}{m_1m_2}$, etc., an infinite series of frequencies can be derived by the generation of harmonics. A relaxation oscillator has an extremely distorted waveform and its output contains hundreds of harmonics. This is, in effect, a process of frequency multiplication.

By means of this process, a great number of standard frequencies, each of which is known with the same accuracy as the source itself, can be produced from a single-frequency source, and, by properly choosing the factors by which the source frequency is divided, these derived frequencies can be made to cover a large part of the communication-frequency spectrum.

CLASS C-21-H STANDARD-FREQUENCY ASSEMBLY

The Class C-21-H Standard-Frequency Assembly is the reduction to practice of the principles just outlined. This assembly is a practical frequency standard system designed for use in laboratory and commercial installations. It supplies hundreds of standard frequencies between one cycle per second and several megacycles, each known to better than one part in a million (0.0001 per cent). Figure 7 shows the functional arrangement of the assembly.

The frequency is determined by comparison with a standard time interval by means of time signals from an astronomical observatory.

The timing device is a 1-kilocycle synchronous-motor-driven clock which, when the driving frequency is exactly 1 kilocycle per second, indicates true mean solar time.

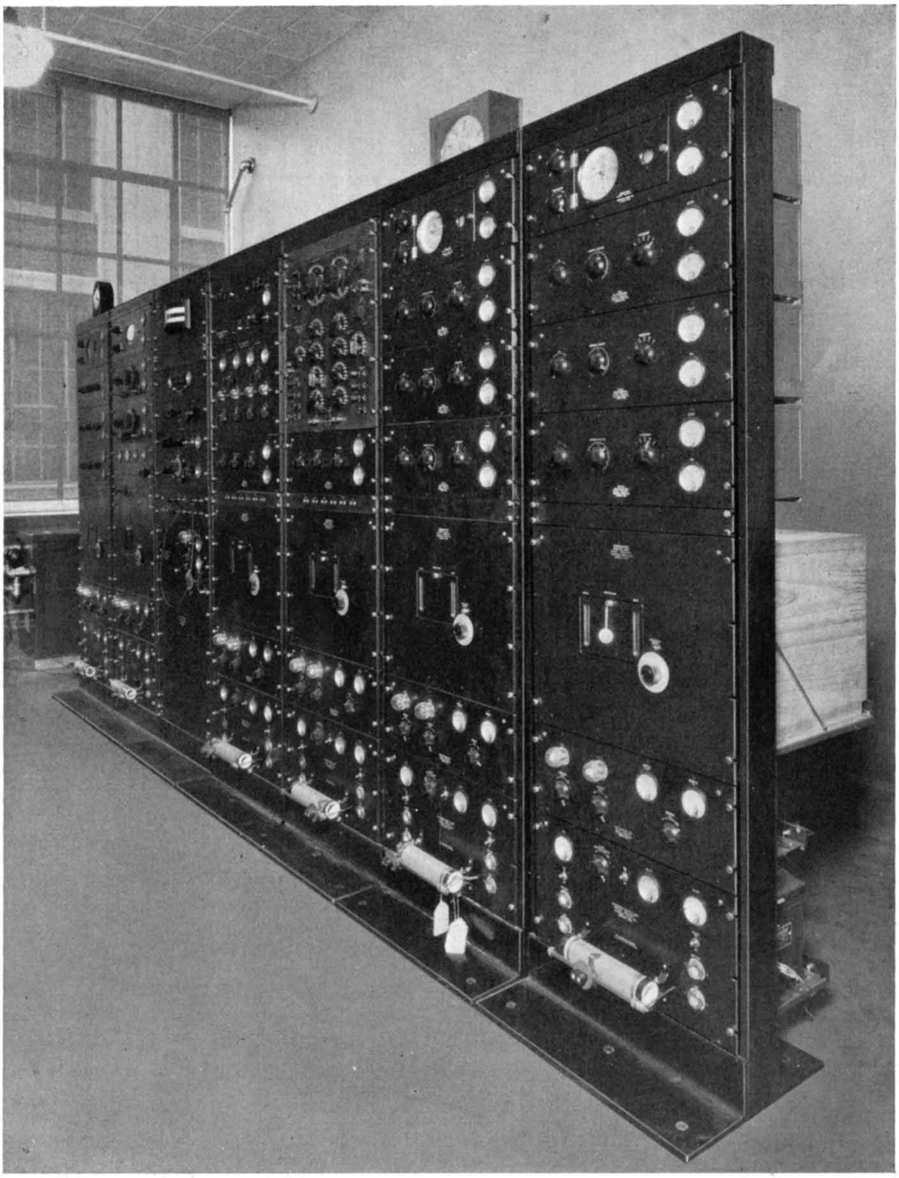


FIGURE 6. A group of experimental primary standards of frequency in one of the General Radio laboratories. Each of the two relay racks at the right contains a Class C-21-H Standard-Frequency Assembly, under test before shipment to a purchaser

The working standard from which the 1-kilocycle frequency is derived is a highly stable piezo-electric oscillator, operating at a frequency of 50 kilocycles. In order to reduce this frequency to 1 kilocycle for driving the clock, two multivibrators are used, one of which divides the standard frequency by a factor of 5, and the second of which further divides it by 10, making a total reduction of 50 to 1.

Each of these multivibrators generates a harmonic series which is indicated in Figure 7. A third multivibrator, operating at the standard frequency, produces harmonics of 50 kilocycles.

The 1-kilocycle harmonics furnish standard-frequency points in the audio-frequency range which can be selected by filter circuits and amplified if necessary.

The 10-kilocycle series is easily usable up to about 4000 kilocycles. At higher frequencies, more elaborate methods of detecting the harmonics may be necessary.

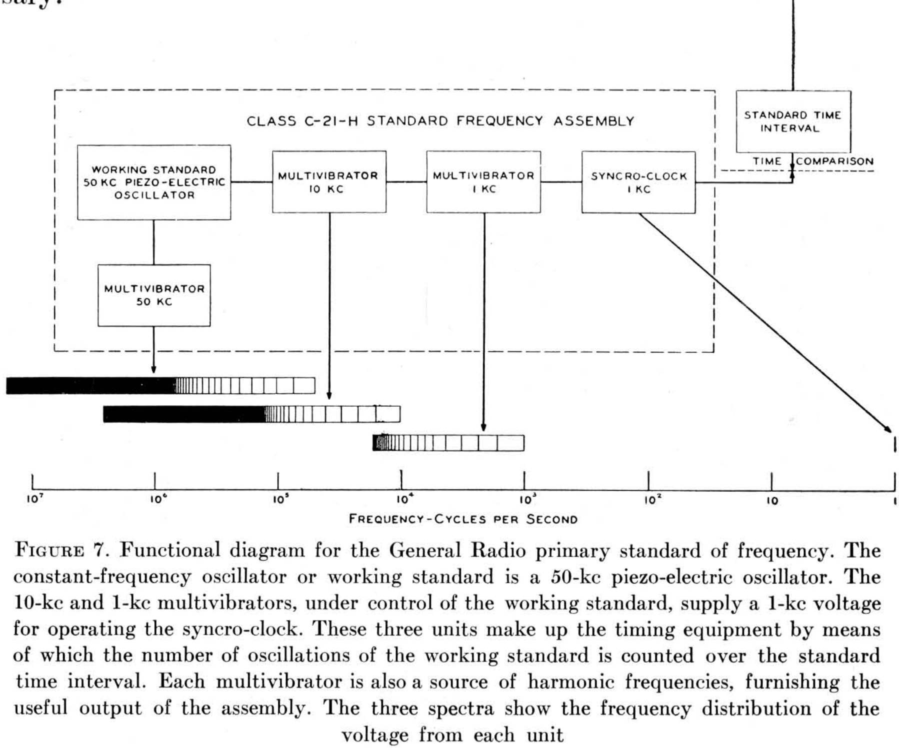
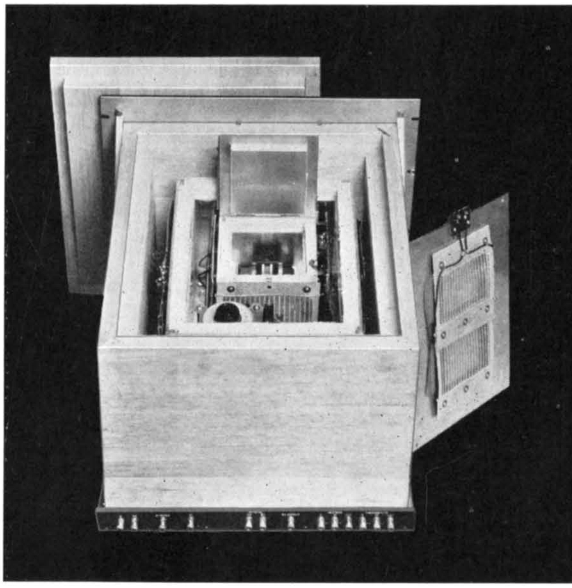


FIGURE 7. Functional diagram for the General Radio primary standard of frequency. The constant-frequency oscillator or working standard is a 50-kc piezo-electric oscillator. The 10-kc and 1-kc multivibrators, under control of the working standard, supply a 1-kc voltage for operating the syncro-clock. These three units make up the timing equipment by means of which the number of oscillations of the working standard is counted over the standard time interval. Each multivibrator is also a source of harmonic frequencies, furnishing the useful output of the assembly. The three spectra show the frequency distribution of the voltage from each unit

Harmonics from the 50-kilocycle multivibrator can be utilized by heterodyne methods up to several megacycles. The exact limit of their useful range depends somewhat on the sensitivity of the apparatus used to detect them. At extremely high radio frequencies an auxiliary oscillator can be used, the fundamental of which is adjusted in terms of the frequency standard at, for instance, 1000 kilocycles. Harmonics of this oscillator at 1000-kilocycle intervals can then be used for frequency standardization at the higher frequencies where the output of the standard cannot be used directly. In addition to the output obtainable from the multivibrators, a contact closing once a second is provided by the synchronous clock unit.

Frequency Stability

The frequency stability of the standard is due entirely to the design and construction of the piezo-electric oscillator. The frequency-determining element of this oscillator is a 50-kilocycle quartz bar, the tem-



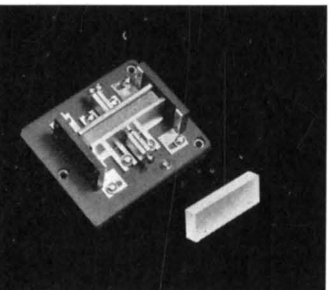


FIG. 9 (*above*). The 50-kc quartz bar and its holder. At the right is shown one of these bars removed from its holder

FIG. 8 (*left*). The two-stage temperature control box with covers removed showing part of the oscillator and the quartz bar. The temperature of the crystal is constant within ±0.01° C. which accounts, in part, for the unusually stable frequency of this primary standard

perature of which is held within 0.01 degree Centigrade. This precise control of temperature is made possible by the use of a two-stage control system, which consists of one temperature-controlled chamber inside another. The outer box controls to about 0.1 degree Centigrade, and the inner, which has to work only against this 0.1-degree variation, holds its temperature to within 0.01 degree. The inner box is considerably smaller than the outer one, and the tube, coil, condenser, and other circuit elements are mounted in the space thus available in the outer box.

The operating parameters are so adjusted that the oscillator is working under optimum operating conditions.

The quartz bar and its mounting are designed to have low decrement and low temperature coefficient. Baffles are provided to minimize the effects of radiated air waves and of changes in atmospheric pressure.

Frequency Dividers

The frequency dividers were described in general terms in the preceding section. A multivibrator is essentially a resistance-capacitance-coupled amplifier with its output fed back to the input. Under this condition, such a device "motor-boats" or oscillates at a frequency determined by the values of resistance and capacitance in its circuit. A small voltage introduced into its circuit from another oscillator can be made to control the frequency of the multivibrator as previously described, provided the frequency of the introduced voltage corresponds approximately to the fundamental or a harmonic of the uncontrolled multivibrator frequency. Actually, for best results, the uncontrolled frequency should be slightly below the controlled value.

Time Comparison

The timing unit consists of an input amplifier, a synchronous-motor clock and an output amplifier. On a shaft rotating once a second is a cam which operates once each revolution. The contact can be made to close at any instant in the one-second interval by rotating the micro-dial in which it is mounted. The micro-dial carries a scale divided into one hundred parts, allowing the instant when the contact is closed to be adjusted to within 0.01 second.

In comparing the time indication of the synchronous clock with radio time signals, the contact is made to short-circuit the loudspeaker of a radio receiver. The contact is of sufficient duration to eliminate the signal from the speaker. The position of this contact is adjusted until only the "nose" of the signal gets through the speaker, the remainder being entirely short-circuited. This condition is reached when (as the micro-dial is rotated in such a direction as to eliminate more of the signal) the signal ceases to be a tone and becomes a "click." This adjustment can be made with very high precision.

The precision with which the oscillator frequency is known depends directly upon the precision with which the time interval can be measured. For instance, if the time interval used is the mean solar day and if the precision with which the time comparison can be made is 0.01 second, the frequency of the standard oscillator is thereby determined to within one part in 8,640,000 since the mean solar day contains 86,400 seconds.

Power Supply

The other units in the assembly are a heat-control panel for regulating the heat supplied to the temperature-control unit and a power-supply panel for trickle charging the batteries from a 110-volt alternating-current line. Storage batteries are used as the power supply in order to assure continuity of service in spite of line voltage interruptions and avoid frequency changes due to supply voltage variations.

Uses of the Standard-Frequency Assembly

The use of the standard-frequency assembly in the measurement of radio frequencies is discussed in Part II of this bulletin. Its use, however, is not restricted to this particular field. In the last measurement of the velocity of light made by the late Dr. Michelson, a Class C-21-H

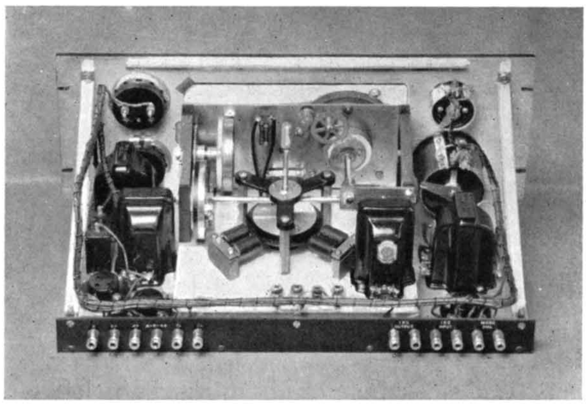


FIGURE 10. The TYPE 593-A Timing Unit contains a synchronous-motor-driven clock geared to keep true time when the frequency is exactly 1 kc. At the left of the clock is the micro-dial mechanism for comparing time kept by the standard-frequency assembly with radio or other time signals

Standard-Frequency Assembly was used in the timing system. Another is now being used in determining the velocity of rifle bullets.

One of these assemblies was provided with a special synchronous clock unit for transmitting a standard sequence of time signals. Another, which was supplied to a large electrical manufacturing company, uses a 60-kilocycle quartz bar and furnishes a 60-cycle output for standardization purposes.

Commercial acceptability, as well as frequency stability, has been kept constantly in mind in the design of this assembly. It need not be installed in a constant-temperature, vibration-proof room, but is intended for industrial, as well as laboratory, installations.

Specifications

Details regarding power supply, tubes, weight, dimensions, etc., will be found in the catalog description in Part IV.

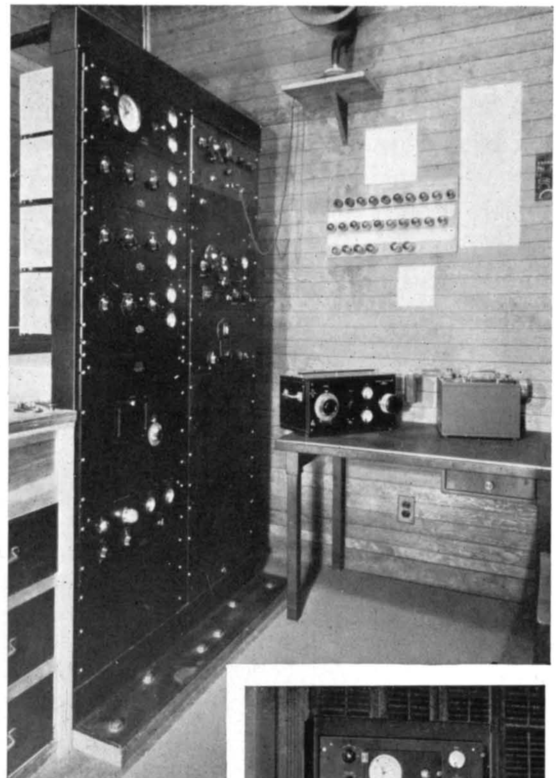
FIGURE 11

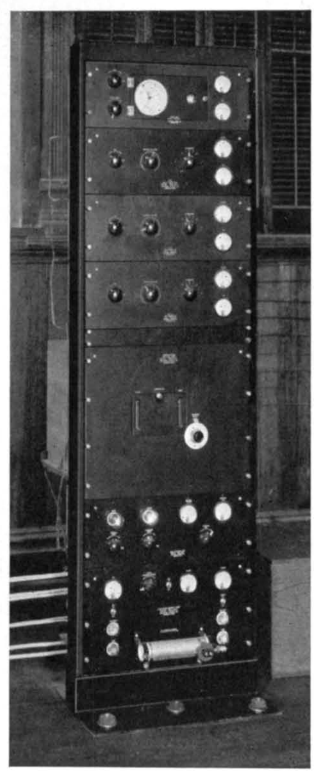
A few installations of the General Radio primary standard of frequency. Other users include the British Royal Air Force • Canadian Department of National Defense • Canadian Department of Marine • • Canadian National Telegraphs • the governments of Russia, Japan, and the Netherlands • U. S. Army • Globe Wireless, Ltd. • Mackay Radio Telegraph Co. • Philadelphia Storage Battery Co. (Philco)

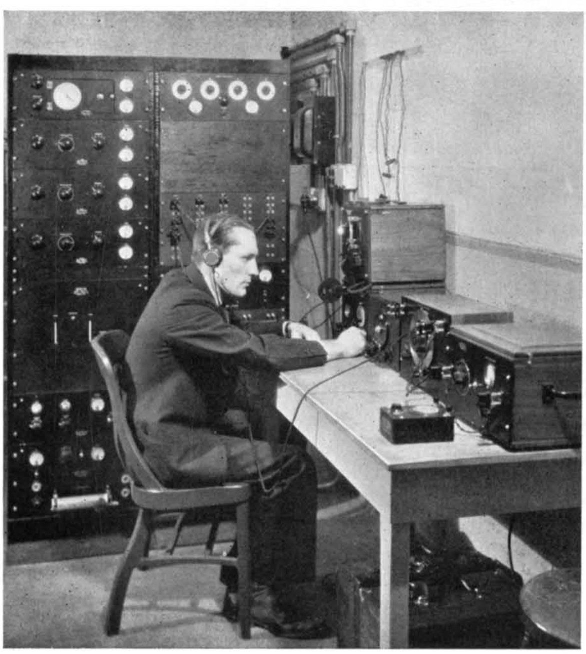
The laboratory of Heintz and Kaufman, Ltd., manufacturers of radio-communication equipment at San Francisco, California (*right*)

The primary standard in the new Physics Building at the University of Texas. Standard frequencies are distributed throughout the building (*lower right*)

The standard-frequency equipment at Cruft Laboratory, Harvard University. The rack at the right carries distribution amplifiers and associated equipment by means of which standard frequencies are made available at other points in the building (*below*)







SECONDARY FREQUENCY STANDARD

A SECONDARY standard of frequency is a calibrated instrument, the frequency of which has been previously determined by comparison with a primary standard. Broadly speaking, the term *secondary standard* can include any calibrated frequency-measuring device, but as here used it refers to a highly stable piezo-electric oscillator.

By dropping the timing unit from the Class C-21-H Standard-Frequency Assembly just described, that assembly becomes a secondary standard. Usually, however, for the purposes for which a secondary standard is used, it is not necessary to set up as elaborate a system as that used in the primary standard.

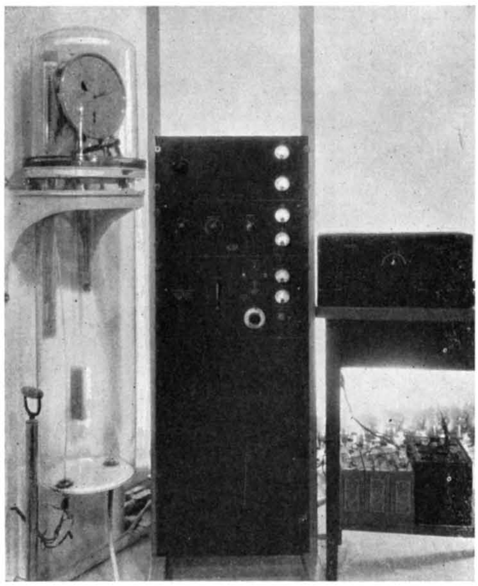


FIGURE 12. A secondary frequency standard of the Class C-10 type in use at the Elgin Observatory. This standard is used as a monitor for standard-frequency radio transmissions

The piezo-electric oscillator can be simplified (and its cost materially reduced) by using a single-stage temperature-control box. This type of secondary standard is widely used as a monitor for radio transmitters and, in conjunction with a multivibrator, as a standard for radio-frequency measurements in either the operating field or in the laboratory.

Its use in monitoring installations is described later (see page 48). For frequency-measurement purposes, the assembly described on the next page has many advantages.

Class C-10 Standard-Frequency Assembly

This standard-frequency assembly consists of a piezo-electric oscillator and a multivibrator. The piezo-electric oscillator operates at a frequency of 100 kilocycles and is capable of maintaining its frequency within a few parts in a million over long periods of time. Its absolute accuracy is guaranteed to within twenty parts per million (0.002 per cent).

The multivibrator can be furnished to operate at 100 kilocycles or any submultiple of 100 up to the fifth (20 kilocycles). While furnished

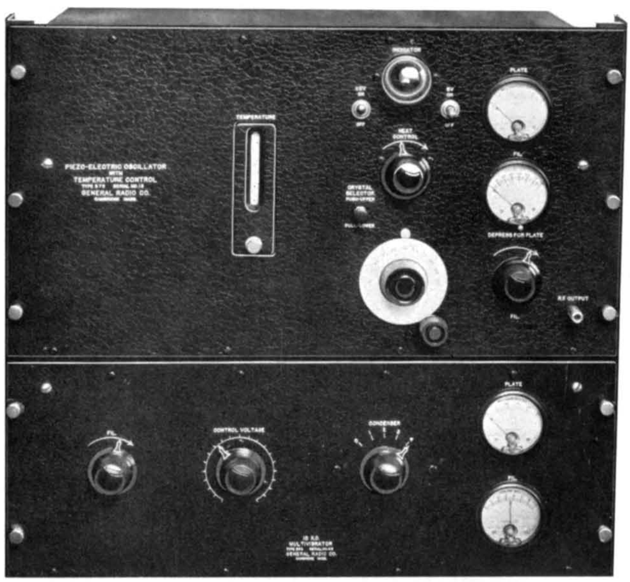


Figure 13. A photograph of the Class C-10 Standard-Frequency Assembly. This assembly is made up of a highly stable piezo-electric oscillator and a multivibrator

for operation at a definite frequency, the multivibrator circuit resistances can be easily changed by the user to obtain other frequencies.

While the frequency range and accuracy of the secondary standard are less than those of the primary standard, the simpler assembly is all that is needed for many classes of work. It is well suited for use as a basis for commercial frequency measurements and routine monitoring. Its uses in these fields are fully described in Part II.

STANDARD-FREQUENCY RADIO TRANSMISSIONS

ANOTHER source of standard frequencies has recently been made available: the 5-megacycle radio transmissions of the U. S. Bureau of Standards. These transmissions are held to an accuracy of better than one cycle by comparison with the Bureau's primary standard of frequency at Washington. Schedules of these transmissions can be obtained from the Bureau. They are also published frequently in the Proceedings of the Institute of Radio Engineers.

While the 5-megacycle transmissions have an accuracy comparable with that of a primary standard, they do not, for work requiring the continuous use of a primary standard, entirely displace the local standard. They furnish, however, an accurate basis of comparison against which local secondary standards and the frequencies of radio transmitters may be periodically checked.

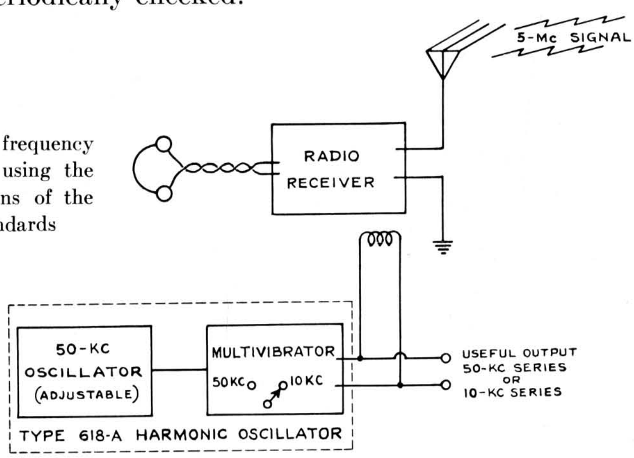


FIGURE 14. Outline of a frequency standardization system using the 5-megacycle transmissions of the U. S. Bureau of Standards

FREQUENCY STANDARDIZATION FROM THE 5-MEGACYCLE TRANSMISSIONS

In order to use these transmissions for frequency standardization and calibration work, it is necessary to produce from the 5-megacycle signal one or more series of harmonically related frequencies similar to those obtainable from a local standard. For this purpose the General Radio TYPE 618-A Harmonic Oscillator has been developed.

This instrument includes a 50-kilocycle oscillator and a multivibrator which operates at either 10 kilocycles or 50 kilocycles, selection being made by means of a switch. The 50-kilocycle oscillator is adjustable over a narrow range of frequency. The multivibrator is controlled by the oscillator, and, as the oscillator frequency is changed, the multivibrator frequency changes correspondingly.

FIGURE 15. Panel view of the TYPE 618-A Harmonic Oscillator. The oscillator frequency is controlled by the dial and knob at the left; the multivibrator switch is at the right

By listening in a radio receiver, the 100th harmonic of 50 kilocycles can be adjusted to zero beat with the 5-megacycle signal. The multivibrator then furnishes a harmonic series of 50 kilocycles or 10 kilocycles identical in character with those obtainable from a standard-frequency assembly. An outline chart of this frequency standard system is shown in Figure 14.

Uses

Frequencies derived in this way from the 5-megacycle transmissions are extremely useful in frequency standardization and calibration work which does not justify the use of a local standard.

Since a harmonic series of 10 kilocycles is available from this system, broadcast station frequencies can be checked directly. A discussion of methods of utilizing these frequencies is given in Part II.

RADIO BROADCASTING STATIONS AS FREQUENCY STANDARDS

THE regulations of the Federal Radio Commission requiring radio broadcasting stations in the United States to hold their frequencies within 50 cycles of their assigned channels have made it possible to use these stations as frequency standards for many classes of work.

A tolerance of 50 cycles at the lowest broadcast frequency (550 kilocycles) is just under 0.01 per cent and at the upper end of the broadcast band (1500 kilocycles) this tolerance is 0.003 per cent. Actually, most of the station frequencies are held to tolerances of 20 cycles or less, so that their accuracy is even greater than these figures.

Assuming an accuracy of 0.01 per cent, however, these stations can be used as standards for calibrating receivers, checking the calibrations of wavemeters and frequency meters, and for many laboratory measurements. An outline of methods of utilizing these frequencies will be found in Part II.

SUMMARY: CLASSIFICATION OF FREQUENCY STANDARDS

The diagram of Figure 16 summarizes the foregoing discussion of the various types of frequency standards. Referring to this diagram, it will be seen that all frequency standards are compared either directly or indirectly with a standard time interval derived from the earth's rotation. The scale at the left of the diagram indicates the accuracy which may be expected from representative standards of the various types. The accuracy of specific standards will, of course, vary somewhat from that shown in the diagram. It should be noted, however, that the accuracy depends on how direct a comparison is made with the standard time interval.

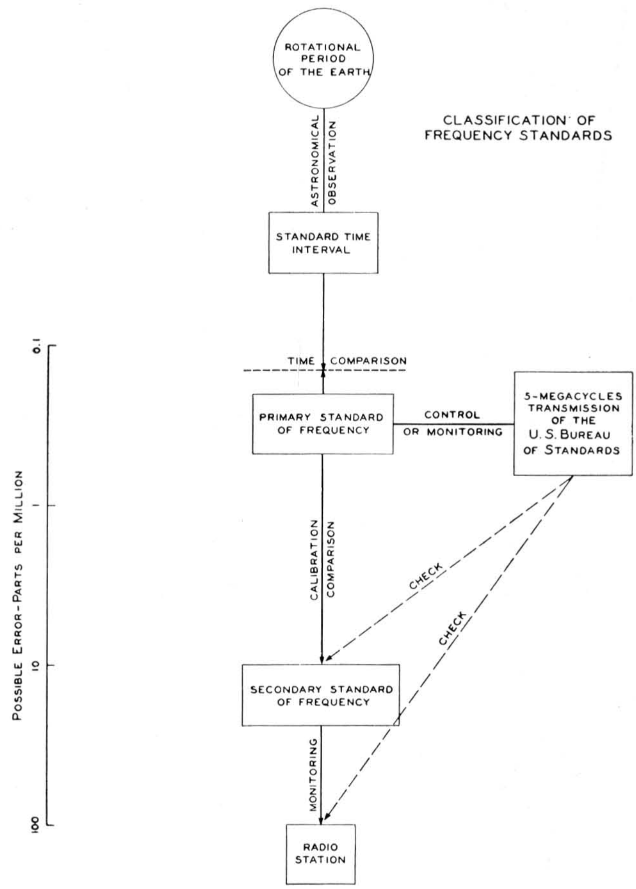
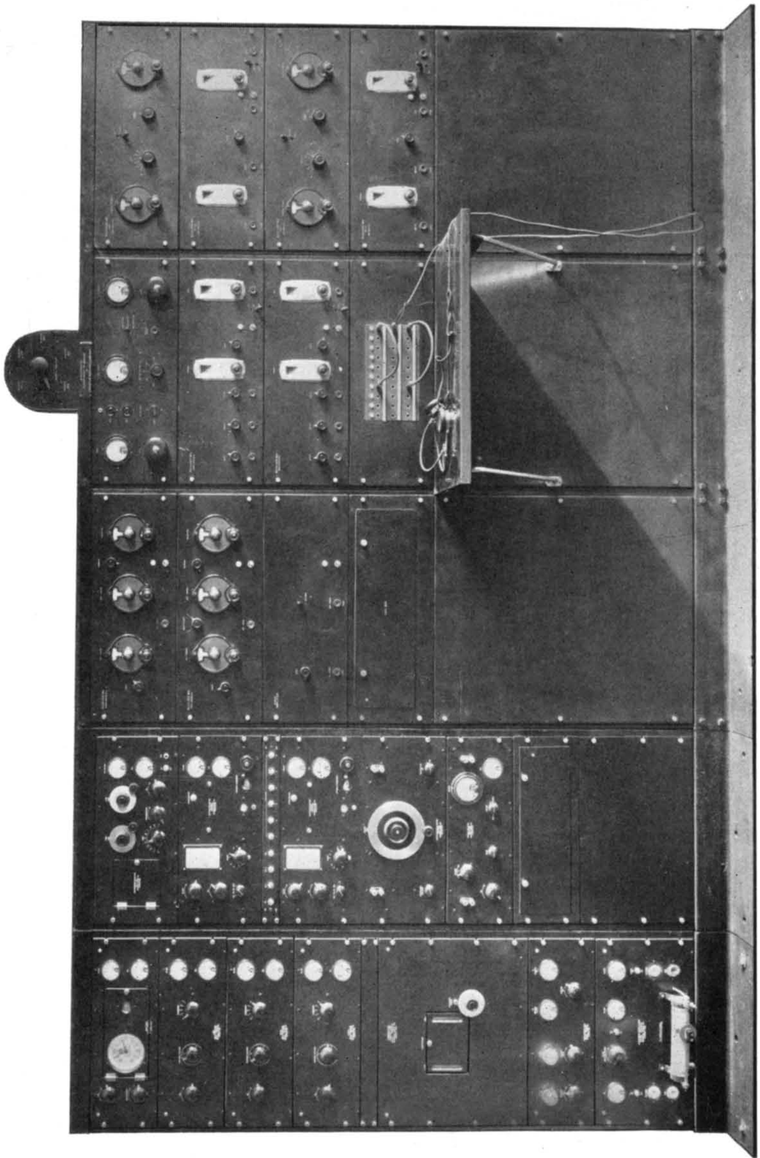


FIGURE 16. A block diagram showing the relations between the various types of frequency standards

PART II

METHODS OF FREQUENCY MEASUREMENT



Photograph, courtesy Department of Marine

FIGURE 17. Frequency monitoring station of the Department of Marine at Ottawa, Canada. The two racks at the left of the photograph carry the primary standard, heterodyne frequency meters, and beat-note measuring equipment built by the General Radio Company. The other three racks contain the receiving apparatus built by the Canadian Marconi Company

METHODS OF FREQUENCY MEASUREMENT

WHILE the frequency standard provides one or more points of reference in terms of which unknown frequencies may be measured, it is necessary to use some auxiliary equipment in order to compare an unknown frequency with the standard frequency.

The amount and type of equipment necessary for this purpose depend on the accuracy with which it is desired to measure frequency and upon the type of standard used.

In this section are discussed the methods of making frequency measurements with reference to the types of standards described in Part I.

FREQUENCY MEASUREMENTS WITH THE CLASS C-21-H STANDARD-FREQUENCY ASSEMBLY

Since the standard-frequency assembly provides harmonic frequencies spaced at equal intervals in the frequency spectrum, any unknown frequency will lie between two of these harmonics.

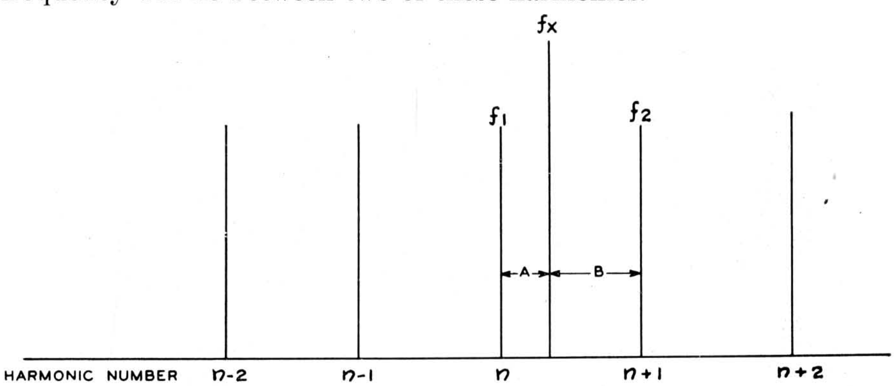


FIGURE 18. This drawing shows an unknown frequency f_x lying between two standard frequency harmonics f_1 and f_2

Figure 18 shows an unknown frequency f_X lying between two standard harmonics which may be designated as f_1 and f_2, where f_1 and f_2 are nth and $(n + 1)$th harmonics of the multivibrator fundamental. The frequencies of the harmonics f_1 and f_2 are known, and the problem is, therefore, to measure one of the frequency intervals A or B in Figure 18. The interval A added to f_1 gives the frequency of f_X. Similarly, B subtracted from f_2 determines f_X.

If the interval between f_1 and f_2, that is, the multivibrator fundamental, is 10 kilocycles, one of the frequency intervals A or B will be 5000 cycles or less, since, if f_X is half way between f_1 and f_2, both A and B will be 5000 cycles.

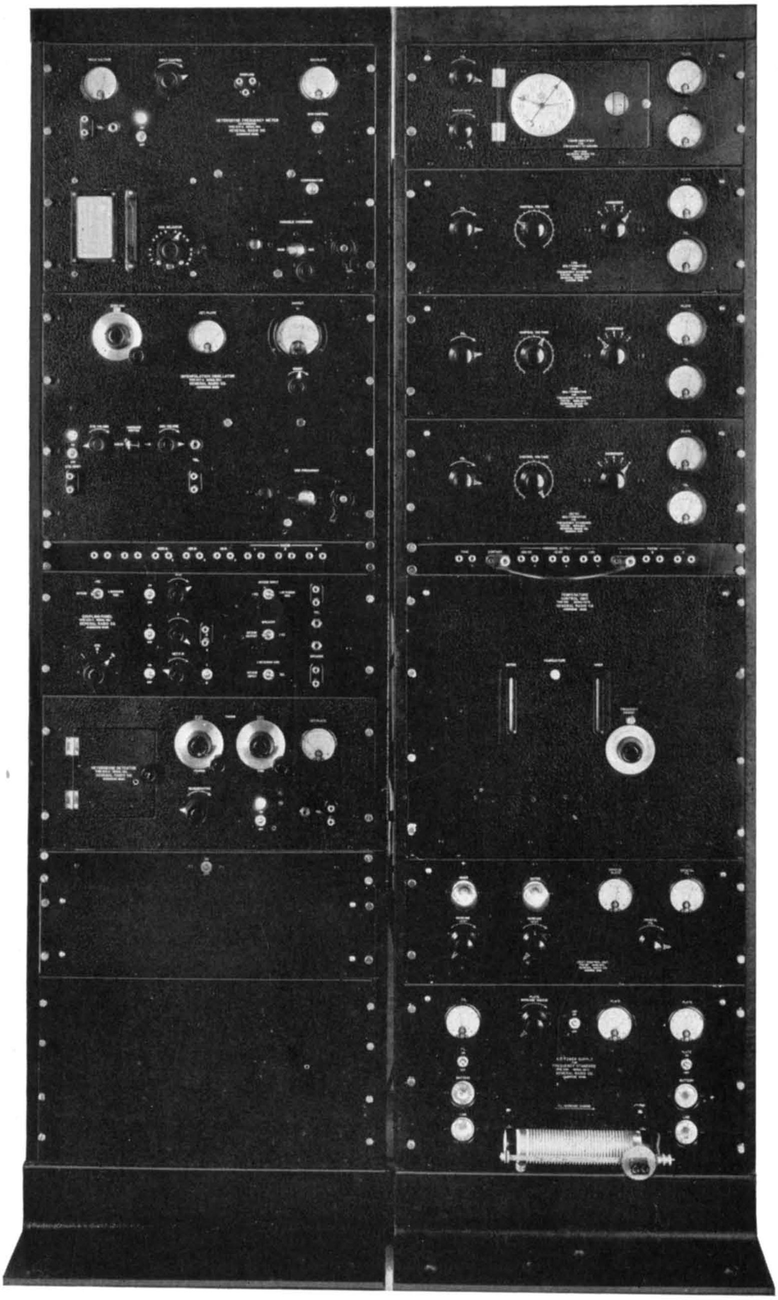


FIGURE 19. A complete frequency-measuring assembly. The right-hand rack is a Class C-21-H Standard-Frequency Assembly; the interpolation and beat-measuring equipment is at the left

In practice, both f_X and the 10-kilocycle harmonic series can be applied to a detector tube and a beat of 5000 cycles or less will be produced in the detector output. This beat can be measured by comparison with a calibrated audio oscillator.

This is the method recommended for use with the Class C-21-H Standard-Frequency Assembly.

Auxiliary Apparatus

For use with the Class C-21-H Standard-Frequency Assembly in frequency measurement, the following apparatus is necessary:

Type 616-A Heterodyne Frequency Meter
Type 617-A Interpolation Oscillator
Type 619-A Heterodyne Detector
Type 612-A Control Panel.

The heterodyne frequency meter is a highly stable radio-frequency oscillator with a linear scale. Its frequency range is continuously variable from 100 to 5000 kilocycles in sixteen bands, controlled by a switch.

The interpolation oscillator is an audio-frequency oscillator of the beat-frequency type. It has a linear scale (one cycle per scale division) and covers a range of from zero to 5000 cycles. It contains an audio amplifier and beat indicator. Provision is made for checking the calibration in terms of the audio-frequency output of the standard-frequency assembly.

The heterodyne detector is a tuned regenerative detector and audio amplifier. Its frequency range extends from 100 kilocycles to 6000 kilocycles, using twelve plug-in coils.

The control panel carries the necessary volume controls and switches for operating the assembly.

Procedure

The procedure to be followed in making frequency measurements with this equipment will be easily understood by reference to the diagram of Figure 20. In this diagram it is assumed that the frequency under measurement is a radio signal from a distant transmitter. The procedure consists of setting a local oscillator to zero beat with the received signal and measuring the audio-frequency beat between the local oscillator and the nearest 10-kilocycle harmonic. Since the frequency range of the local oscillator, and also the range over which the 10-kilocycle harmonics are usable, is limited, harmonic methods must be used at the high and low ends of the radio-frequency spectrum. For this reason the upper part of the diagram of Figure 20 is divided into three parts, each covering a definite portion of the spectrum.

Measurement of a Frequency Between 100 and 3500 Kilocycles

1. The signal f_X is first picked up in a radio receiver. Usually an oscillating receiver should be used. If the signal is modulated, however, the receiver can be used in the non-oscillating condition.

2. The heterodyne frequency meter is adjusted to zero beat with the signal. This adjustment can be made to within one cycle per second if the three-oscillator method described on page 47 is used. This transfers the signal frequency f_X to the heterodyne frequency meter, whose frequency f_L is equal to f_X, and effectively gets rid of such factors as interference, fading, and failure of signal.

3. The telephones are transferred to the heterodyne detector (this is done by merely throwing a switch on the control panel), and the signal from the heterodyne frequency meter is picked up in the heterodyne detector. A 10-kilocycle harmonic series is introduced into the heterodyne detector.

4. An audio-frequency beat f_A will then be heard in the heterodyne detector output and this beat is introduced into the interpolation oscillator.

5. The interpolation oscillator is adjusted until its frequency beats zero with the audio frequency f_A and the frequency is then read directly from the dial.

6. In order to determine whether the beat is to be added to or subtracted from the standard harmonic, the heterodyne frequency meter setting is varied slightly.

If, for instance, the frequency of the heterodyne frequency meter is increased slightly, the audio frequency f_A will increase if the beat is between f_X and f_1 and will decrease if between f_X and f_2.

7. The frequency of the standard harmonic f_1 or f_2 can be determined from the calibration of the heterodyne frequency meter, or the heterodyne detector.

Harmonic Methods

In using this method directly, the range over which measurements can be made is limited at the low end by the fact that the lowest frequency obtainable from the heterodyne frequency meter is about 100 kilocycles, and at the upper end by the 10-kilocycle harmonics which are too weak for reliable use above 3500 kilocycles. The frequency range over which this method is useful when using the fundamental frequency of the heterodyne frequency meter is approximately 100 to 3500 kilocycles. Above and below these frequencies, measurements are made by harmonic methods.

Measurement of a Frequency Above 3500 Kilocycles

In order to measure frequencies above 3500 kilocycles, a *harmonic* of the heterodyne frequency meter is adjusted to zero beat with the unknown frequency. The fundamental is then measured as described previously, and the result is multiplied by the harmonic number. For

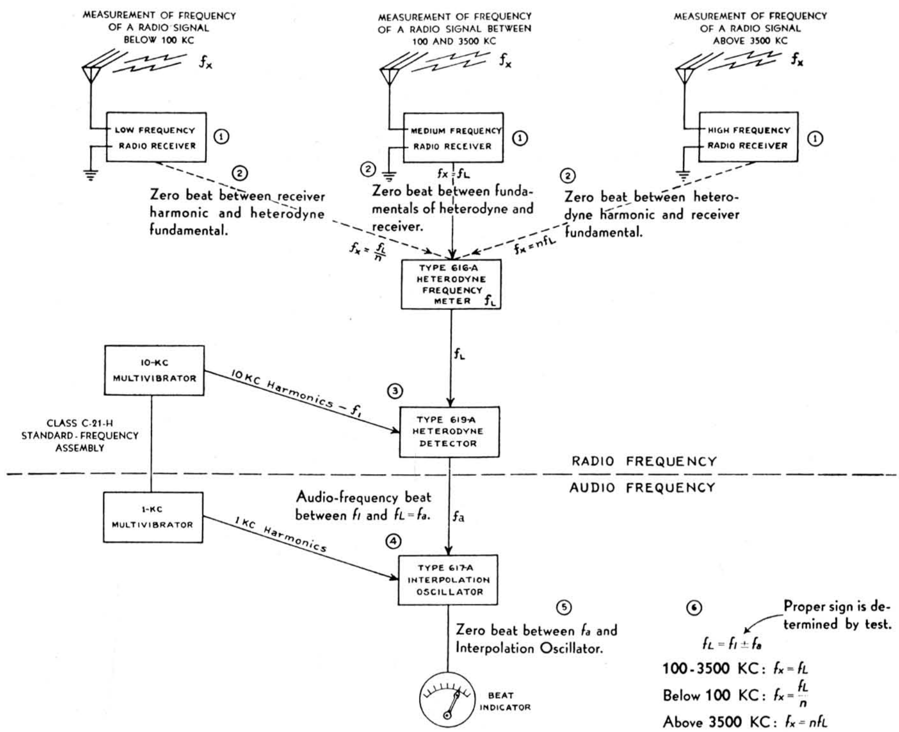


FIGURE 20. Functional diagram showing the operation of the frequency-measuring assembly. The basic method of measurement is the same for all frequencies but the top of the diagram is divided into three parts, each covering a portion of the radio-frequency spectrum

instance, if the nth harmonic corresponds to the signal frequency, the fundamental frequency f_L is multiplied by n to find f_X. This procedure is shown starting at the upper right of Figure 20.

Measurement of a Frequency Below 100 Kilocycles

For low frequencies the process is the reverse of that used at high frequencies. The low-frequency signal f_X is picked up on a suitable *oscillating* receiver, and the receiver is made to oscillate strongly enough to generate harmonics. One of these harmonics is picked up in the heterodyne detector, and the heterodyne frequency meter fundamental f_L is adjusted to zero beat with it. The fundamental of the heterodyne frequency meter is then measured as before, and the result is divided by the number of the receiver harmonic used. Refer to the upper left of Figure 20 for this case.

Controls

In order to make the diagram as simple as possible, the Type 612-A Control Panel is not shown. Its use greatly reduces the time required to measure a frequency and simplifies the operation of the equipment.

Advantages of Method

It will be noted from the foregoing explanations of the method that the frequency actually measured is in each case the fundamental of the heterodyne frequency meter. This is a considerable advantage in the routine measurement of frequencies, since the mechanics of making the measurement are the same regardless of the frequency.

Restricting the frequency range in which measurements are made results in a considerable saving in equipment and also allows the measurement to be made at frequencies where several factors, harmonic amplitude, stability of oscillator, and selectivity, combine to produce optimum measuring conditions.

Strong Signals

The foregoing discussion has assumed that the unknown frequency is a distant radio signal. When f_X is a strong local oscillator, simplifications in the general method can be made.

In the range between 100 and 3500 kilocycles, for instance, the receiver can be dispensed with and the signal can be picked up in the heterodyne detector and beat directly with the nearest 10-kilocycle harmonic. The heterodyne frequency meter is used in this case for identifying the 10-kilocycle harmonic and for making the test to determine the algebraic sign of the beat.

In the high-frequency range the signal from a strong oscillator can be picked up in the heterodyne detector by listening at a frequency which is a submultiple of the oscillator frequency. If the heterodyne detector is oscillating strongly, one of its harmonics will produce a beat with the oscillator.

At low frequencies, a strong oscillator will usually produce harmonics of sufficient strength so that one of them may be measured directly.

Specific Examples

1. Let us consider first the measurement of a received signal whose frequency is 2853 kilocycles. This signal is picked up on an oscillating

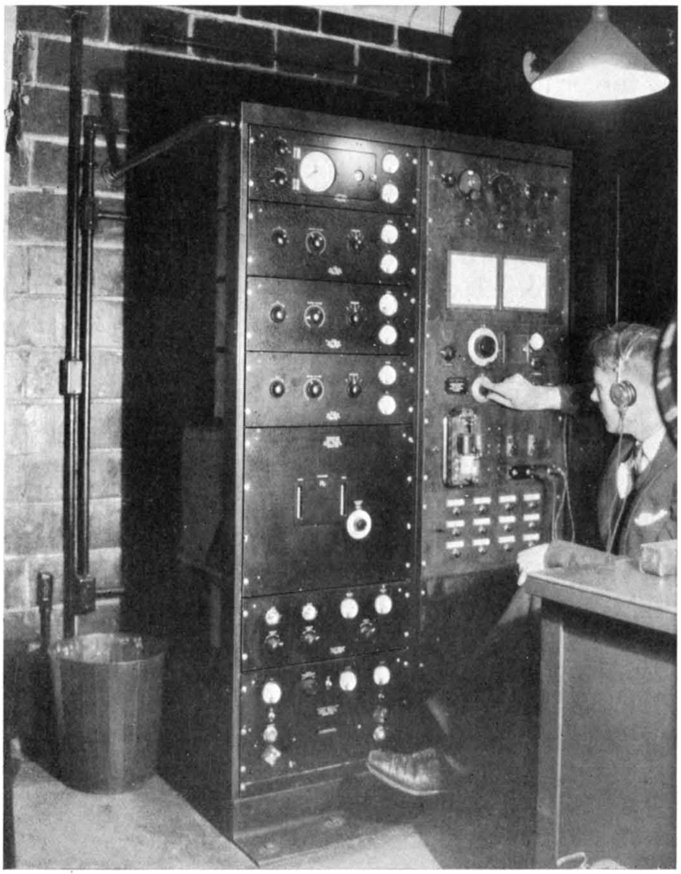


FIGURE 21. Frequency monitoring installation in a Pacific coast radio station. At the left is shown the Class C-21-H Standard-Frequency Assembly

radio receiver, and the receiver is set to zero audible beat with the signal. Still listening in the receiver, the heterodyne frequency meter (TYPE 616-A) is adjusted to zero beat with the signal. Through the use of the "three-oscillator" method, this adjustment can be made to a small fraction of a cycle. After transferring the telephones or loudspeaker from the radio receiver to the heterodyne detector, the detector is made to oscillate and is tuned to zero beat with the 2853-kilocycle signal from the heterodyne frequency meter. This regeneration is then reduced until oscillation ceases, and a series of 10-kilocycle harmonics from a standard-frequency source is introduced. An audio-frequency beat is heard in the output of the heterodyne detector. The frequency of this tone is measured by comparison with a TYPE 617-A Interpolation Oscillator which has previously been calibrated in terms of the audio-frequency output of the standard-frequency assembly. The dial reading of the interpolation oscillator is 3000 divisions, indicating that the beat is 3000 cycles. From the calibration of the heterodyne frequency meter, it is noted that the 10-kilocycle harmonic most nearly corresponding to the dial reading is 2850 kilocycles. The frequency of the heterodyne frequency meter is increased slightly and the audio-frequency beat increases when this is done. This indicates that f_X lies *above* the standard harmonic. From these considerations, f_X is the sum of 2850 kilocycles and 3 kilocycles or 2853 kilocycles.

2. When the signal to be measured is considerably higher, as, for instance, 22,824 kilocycles, the problem is nearly as simple as before. In this case, an oscillating receiver is again set to zero beat with the signal. A *harmonic* of the heterodyne frequency meter is next adjusted to zero beat with the signal. Let us suppose this is the 8th harmonic (the harmonic number is easily determined from the calibrations of the receiver and the heterodyne frequency meter). The fundamental is then measured as before and found to be 2853 kilocycles. This value is then multiplied by 8 (the harmonic number) to obtain the unknown frequency, 22,824 kilocycles.

3. The third problem is that of a frequency below 100 kilocycles. Let the signal frequency be 28.53 kilocycles. As in previous examples, an oscillating receiver is set to zero beat with the signal. The regeneration of the receiver is then increased until it oscillates strongly in order to generate harmonics. The tenth harmonic is then picked up on the heterodyne detector and the heterodyne frequency meter is brought into zero beat with it. The fundamental of the heterodyne frequency meter is then measured as before and found to be 285.3 kilocycles. Division by 10 (the harmonic number) then gives the signal frequency.

*Alternative Method**

Another method of measurement which can be used with the primary standard is the direct interpolation method which is described on

*A discussion of the principles involved in both methods will be found in a paper published in the Proceedings of the Institute of Radio Engineers for September, 1930, entitled "Interpolation Methods for Use with Harmonic Frequency Standards" by J. K. Clapp.

pages 38 to 42. It is not, however, as accurate as the direct-beating method just described.

Accuracy

This equipment is sufficiently accurate for use as a central monitoring station for commercial or governmental use.

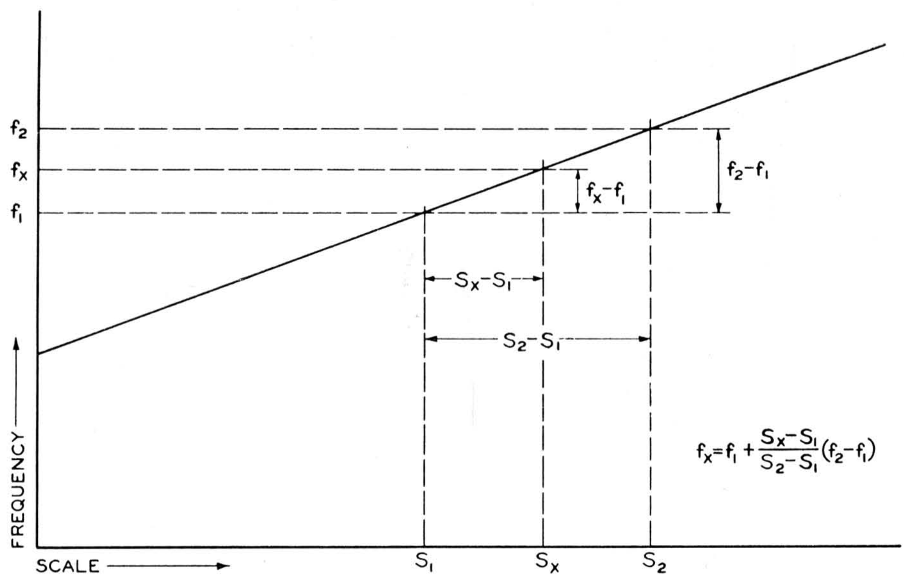
The frequency standard is accurate to better than one part in a million. The only other errors are those due to zero-beat settings and to inaccuracies in the interpolation oscillator. Each zero-beat setting can be made to better than one cycle per second, and the interpolation oscillator can be relied upon to one or two cycles.

It is possible to make routine measurements with an over-all accuracy of a very few cycles, the exact magnitude of the error depending on the number of steps in the measurement and the order of magnitude of the signal frequency.

FREQUENCY MEASUREMENTS WITH THE CLASS C-10 STANDARD-FREQUENCY ASSEMBLY

THE lower accuracy of the secondary standard and its low cost as compared with that of the primary standard do not justify the use of as much auxiliary apparatus as is used with the primary standard.

A convenient and simple method to use with this standard is that of linear interpolation. In addition to the standard and the receiver necessary if distant transmitters are to be measured, only two instruments are needed: TYPE 616-A Heterodyne Frequency Meter and TYPE 619-A Heterodyne Detector.



$$f_x = f_1 + \frac{S_x - S_1}{S_2 - S_1}(f_2 - f_1)$$

FIGURE 22. Frequency *vs.* scale-reading characteristic of the heterodyne frequency meter

The process of linear interpolation depends upon the straight-line-frequency property of the heterodyne frequency meter. The statement that the instrument is straight-line-frequency means that frequency intervals are proportional to corresponding intervals in scale reading.

Figure 22 shows a plot of frequency against scale reading for the heterodyne frequency meter. If this instrument is successively adjusted to zero beat with an unknown frequency f_X, the standard harmonic f_1, and the standard harmonic f_2, three corresponding scale readings S_X, S_1, and S_2 are obtained.

Since the plot is a straight line,

$$\frac{f_X - f_1}{f_2 - f_1} = \frac{S_X - S_1}{S_2 - S_1}$$

and

$$f_X - f_1 = \frac{S_X - S_1}{S_2 - S_1}(f_2 - f_1)$$

where
$f_X - f_1$ is the frequency interval A, and $f_2 - f_1$ is the interval between standard harmonics.

The intervals $S_2 - S_1$ and $S_X - S_1$ can be determined from the scale readings.

The frequency interval $f_X - f_1$, therefore, may be easily calculated and added to f_1 to determine the frequency f_X.

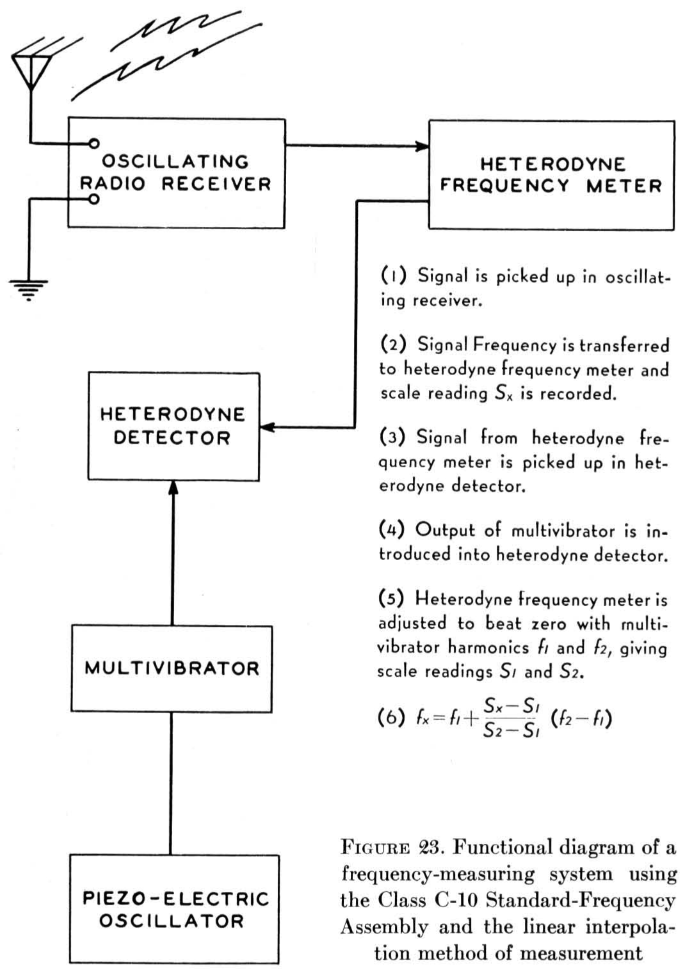


FIGURE 23. Functional diagram of a frequency-measuring system using the Class C-10 Standard-Frequency Assembly and the linear interpolation method of measurement

Outline of Procedure

The various steps in the measurement are as follows (refer to Figure 23):

1. The signal which it is desired to measure is picked up in an oscillating radio receiver.
2. The heterodyne frequency meter is adjusted to zero beat with the signal, using the three-oscillator method (page 47).
3. The telephones are transferred to the heterodyne detector which is then tuned to the heterodyne frequency meter. The detector is oscillating.
4. The output of the multivibrator is introduced into the heterodyne detector.
5. The heterodyne frequency meter is then adjusted to zero beat with the multivibrator harmonic f_1 next below f_X and the corresponding scale reading S_1 is recorded. Similarly, the scale reading S_2 corresponding to f_2 is obtained. In making these adjustments, the three-oscillator method is used.
6. The frequency of f_X is determined from

$$f_X = f_1 + \frac{S_X - S_1}{S_2 - S_1}(f_2 - f_1).$$

Example

As an example of this method, let us consider the measurement of a received signal of approximately 2834 kilocycles. This signal is picked up in a receiver and the heterodyne frequency meter is set to zero with the signal by means of the three-oscillator method. The scale reading S_X is found to be 1496 divisions on Coil 14. The telephones are transferred to the heterodyne detector. A 100-kilocycle harmonic series from the multivibrator is introduced, and the heterodyne detector is set to zero beat with the harmonic next below the signal f_X. The heterodyne frequency meter is then set to zero beat with this harmonic, and its scale reading S_1 is found to be 1406.3 divisions. Similarly, S_2 is 1672.2 divisions. From these readings, we find that

$$S_X - S_1 = 89.7 \text{ divisions}$$

and

$$S_2 - S_1 = 265.9 \text{ divisions.}$$

From the calibration of the heterodyne frequency meter it is determined that S_1 corresponds to 2800 kilocycles. The unknown frequency is then

$$f_X = 2800 + \frac{89.7}{265.9}(100) \text{ kilocycles}$$
$$= 2833.73 \text{ kilocycles.}$$

Harmonic Methods

When the unknown frequency lies above or below the range of the heterodyne frequency meter, use may be made of harmonic methods as previously described.

For frequencies above about 5000 kilocycles, a harmonic of the heterodyne frequency meter is set to zero beat with the signal. Below 100 kilocycles, the heterodyne frequency meter is set to zero beat with a harmonic of the receiver in which the signal is picked up.

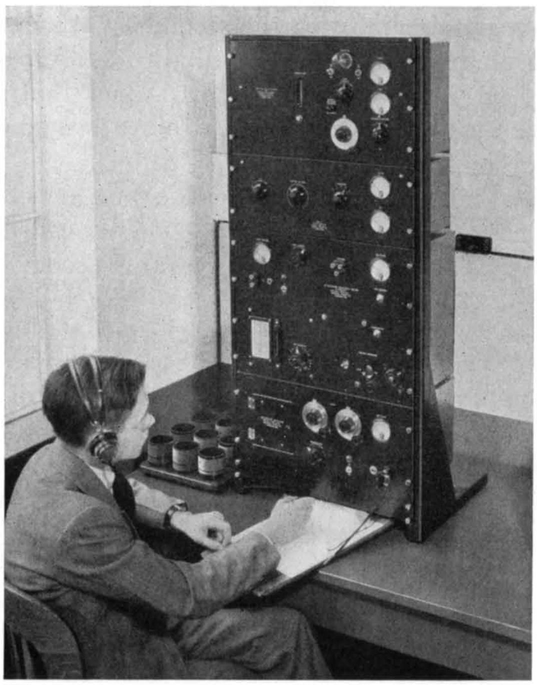


FIGURE 24. A frequency-measuring assembly consisting of a Class C-10 Standard-Frequency Assembly, a TYPE 616-A Heterodyne Frequency Meter, and a TYPE 619-A Heterodyne Detector

Simplifications–Auxiliary Dial

The TYPE 616-A Heterodyne Frequency Meter is fitted with an auxiliary dial which allows the intervals $S_X - S_1$ and $S_2 - S_1$ to be read directly from the scale. This does away with the necessity for subtracting scale readings in order to obtain these quantities.

The determination of the frequency f_X from the scale intervals can also be carried out by means of a chart.

Reduction of Number of Units

When the signals to be measured are reliable and fairly strong and lie between 100 and 5000 kilocycles, it is possible to omit the heterodyne detector from the assembly and to do all the listening directly in the radio receiver. The upper limit of frequency is not fixed, since it depends on the characteristics of the receiver, that is, whether its selectivity and sensitivity are sufficiently good to pick up the weak multivibrator harmonics and to separate them on the dial.

Accuracy

The accuracy obtainable with the secondary standard is, of course, less than that of the primary standard. In addition to this, there is some error in the interpolation due to the fact that the heterodyne frequency meter may deviate slightly from a straight-line-frequency characteristic.

The over-all accuracy of measurement is 0.01 per cent or better. If care is taken, accuracies of better than 0.005 per cent can be reached, particularly if a small interpolation interval is used.

Uses

This assembly is particularly recommended for use by small communication companies engaged in a limited class of service as, for instance, air transport companies.

It is also well suited to the needs of the college laboratory where it is desired to instruct students in the principles of frequency measurement and to standardize laboratory measurements.

USE OF 5-MEGACYCLE TRANSMISSIONS IN FREQUENCY MEASUREMENT

Interpolation

Since the Type 618-A Harmonic Oscillator, described on page 24, produces from the 5-megacycle transmissions a harmonic series like that obtainable from a standard-frequency assembly, the direct interpolation method of utilizing these harmonics can be used. For this purpose a Type 615-A or Type 616-A Heterodyne Frequency Meter can be used in exactly the same way as with the secondary standard just described.

Calibration

The output of the Type 618-A Harmonic Oscillator can be used to supply a series of calibration points for the calibration of oscillators and radio receivers at fixed intervals in frequency. For this purpose it is only necessary to bring the oscillator or receiver undergoing calibration into zero beat with the points of the harmonic series and to record the frequency and the dial reading of the instrument which is being calibrated.

Measurement of the Frequency of a Radio Transmitter

The frequencies of radio stations whose assigned channels are multiples of 10 kilocycles or 50 kilocycles can be compared directly with the 5-megacycle transmissions. Radio broadcasting stations can in this way obtain accurate checks of their frequencies whenever the 5-megacycle signal is on the air.

After the Type 618-A Harmonic Oscillator has been synchronized with the standard-frequency signal, the multivibrator can be operated at 10 kilocycles, supplying a standard frequency for every broadcast channel. For those stations which are multiples of 50 kilocycles, the multivibrator may be operated at 50 kilocycles.

The procedure for making this comparison is quite simple. The oscillator harmonic and the station frequency can be picked up on a radio receiver and, if the station is within a few cycles of its assigned channel, a slow beat will be heard which can be counted and checked against a watch or, if the beat is too fast to be counted, the dial of the Type 618-A Harmonic Oscillator can be changed until the oscillator is brought into zero beat with the station frequency, after which the difference in the two frequencies can be determined from the change in dial reading.

Figure 25 shows this method diagrammatically. If measurements are made in or near the station, the antenna shown on the broadcast receiver is not necessary.

Checking the Frequency of a Secondary Standard

These transmissions provide a convenient means of checking the

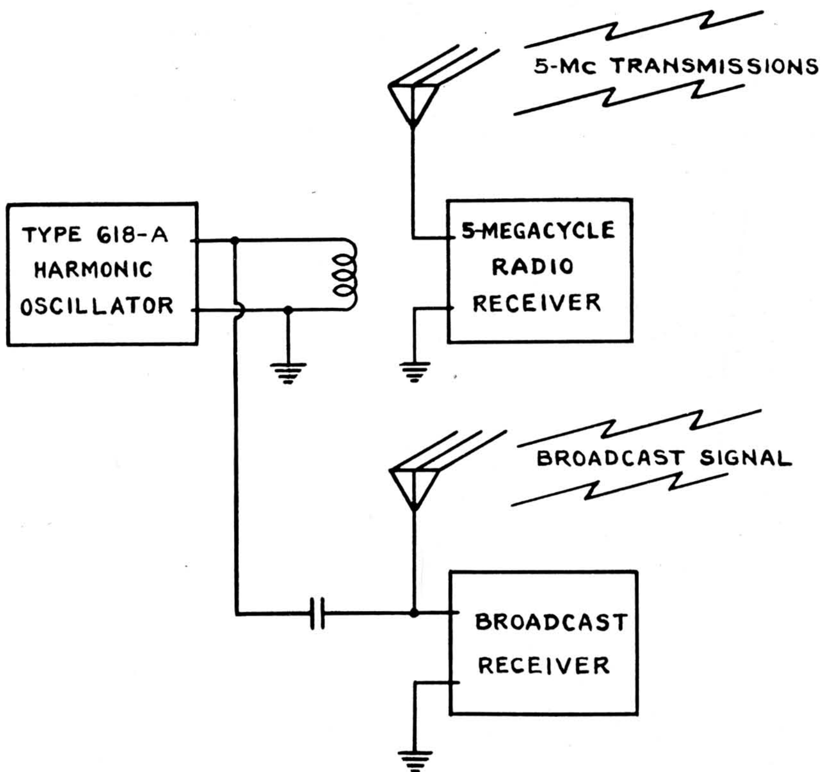


FIGURE 25. Functional diagram showing how the frequency of a radio broadcasting station may be checked against the 5-megacycle transmissions of the U. S. Bureau of Standards

frequency of a secondary standard, such as the Class C-10 Standard-Frequency Assembly. Comparison can be made in the manner just described for use with a radio transmitter. If the error in the secondary standard is determined in this way, due allowance can be made for it when the standard is used to measure frequency and a better accuracy of measurement can be obtained.

FREQUENCY MEASUREMENTS WITH THE HETERODYNE FREQUENCY METER

THE heterodyne frequency meter is one of the most useful instruments in a frequency-measuring system. It has several advantages over the absorption type of wavemeter. By using heterodyne methods, settings can be made with much better precision and measurements can be made at frequencies above and below the fundamental range through the use of harmonics.

The General Radio Company manufactures two models of this instrument. One is a portable model, battery operated, and covers a frequency range of from 275 to 5000 kilocycles, and the other is designed for relay-rack mounting and a–c operation with a range of from 100 to 5000 kilocycles. Both these instruments have straight-line-frequency condensers and tapped coils controlled by switches. The circuit is a modified form of the familiar Colpitts circuit. A screen-grid tube is used for the oscillator and a stabilization system is included which greatly reduces the effect on the frequency of changes in voltage and tubes.* The result is a highly stable oscillator, capable of holding its calibration within narrow limits over a long period of time. In the portable model (TYPE 615-A), a detector is included for listening to beats and in the relay-rack model (TYPE 616-A), a detector and an audio amplifier.

The use of the heterodyne frequency meter in conjunction with a local frequency standard has been described in previous pages. This, however, is by no means the limit of its use. When it is used as a calibrated instrument, extremely good accuracy can be reached provided the means available for checking the calibration are used.

As pointed out in the preceding section, radio broadcasting stations provide a ready means of checking and standardizing calibrated apparatus. Since the broadcast stations are required to stay within 50 cycles of their assigned frequencies, the least accurate any one of them can be is just under 0.01 per cent (50 cycles at 550 kilocycles is 0.0091 per cent). Actually broadcast stations are usually much closer than this figure, and 10 cycles would be a better value.

Both the TYPE 615-A and the TYPE 616-A Heterodyne Frequency Meters cover the entire broadcast band so that several calibration points between 550 and 1500 kilocycles can be obtained. This is done by tuning in the broadcast station on a receiver (an oscillating receiver is preferable) and setting the heterodyne frequency meter to zero beat with it. If the receiver can be made to oscillate (the older types of re-

*J. B. Dow, "A Recent Development in Vacuum-Tube Oscillator Circuits," Proc. IRE, Dec., 1931.

ceivers will all do this), the zero-beat adjustment can be made to within one cycle by using the three-oscillator method described on page 47. If the receiver is of the non-oscillating type, the exact setting can still be made by listening to the noise in the output as it is modulated by the beat between the broadcast station and the heterodyne frequency meter.

Harmonic methods must be used to calibrate those portions of the frequency range which lie outside the broadcast band.

Below the broadcast frequencies, harmonics of the heterodyne frequency meter can be made to beat with the broadcast station. For example, if the broadcast receiver is set to a 1000-kilocycle station and the frequency meter is tuned through 500 kilocycles, the second harmonic of the frequency meter will beat with the station in the broadcast receiver. Similarly the third harmonic of 333.3 kilocycles can be used, the fourth of 250 kilocycles, etc. Using only a few stations, a number of points can be obtained.

Above the broadcast band, it is necessary to use either an oscillating receiver* or an auxiliary oscillator. If the receiver or oscillator is adjusted to zero beat with the station, its harmonics can be made to beat with the fundamental of the heterodyne frequency meter. These beats can be detected at low orders of harmonics by listening in the detector circuit of the heterodyne frequency meter. For high harmonics, it may be necessary to use a receiver at the harmonic frequency.

This procedure is not restricted to the use of broadcast stations. Any radio signal *known to be accurate* may be used. When the 5-megacycle signals of the U. S. Bureau of Standards are on the air, these may be used. In checking against 5 megacycles, the frequency of the heterodyne frequency meter is progressively reduced, allowing its harmonics to beat against the 5 megacycles exactly as when using broadcast stations as described above.

If the heterodyne frequency meter is calibrated when used, a fairly high accuracy can be obtained. Directly after checking the calibration against a broadcasting station, the accuracy at the calibration points is probably 0.005 per cent or better, this being the error in the source of calibration.

A further error of about 0.005 per cent may occur, due to curvature in the frequency *vs.* scale-reading characteristic, since the heterodyne frequency meter cannot be made exactly straight-line frequency. For short-scale intervals this deviation is very small.

Over-all accuracies of 0.02 per cent or 0.03 per cent are easily obtained with careful use and an accuracy of 0.01 per cent is possible.

*Care should be taken to prevent the oscillating receiver from radiating and causing interference.

THE THREE-OSCILLATOR METHOD OF MAKING ZERO-BEAT ADJUSTMENTS

THE three-oscillator method has been in use for a number of years, yet there are still numbers of people engaged in making frequency measurements who are not acquainted with it. It allows two oscillators to be set to zero beat within one cycle without any auxiliary equipment except an oscillating detector.

Suppose a continuous wave signal is picked up in an oscillating receiver, and it is desired to bring a heterodyne frequency meter into zero beat with the signal. The receiver is adjusted to give zero audible beat and the heterodyne frequency meter is brought into zero audible beat also. The precision of the zero-beat setting is limited by the fact that the range of zero audibility is several cycles wide.

If, however, the frequency of the oscillating receiver is then moved away from the zero audible beat setting until an audible beat tone of, say, 1000 cycles is heard, the difference frequency between the signal and the heterodyne frequency meter will be heard in the form of a waxing and waning of the audio-frequency tone. If the frequency of the receiver is varied slightly, thereby changing the audio frequency, no change in the rate of waxing and waning occurs, showing that the beat is between the signal and the heterodyne frequency meter. If the waxing and waning rate *does change* when the receiver frequency is varied, the beat is between the wrong pair of oscillators and the adjustments should be made again with more care.

After the waxing and waning beat is heard, the heterodyne frequency meter may be readjusted to bring the rate of waxing and waning to one, or less, cycles per second after which the two frequencies will be matched to within a cycle.

The example of the radio signal and the heterodyne frequency meter is given merely for purposes of illustration. Obviously, any two oscillators can be set to zero beat by this method, if a third oscillator and a detector are available.

FREQUENCY MONITORING EQUIPMENT

FREQUENCY monitoring, while employing methods and equipment as used in frequency standardization and measurement, is specialized, in that monitoring deals with the maintenance of frequencies of radio stations, rather than their measurement. The apparatus and methods, consequently, are modified to emphasize automatic or direct-reading features, or to shorten to a minimum the time required to make an observation.

U. S. radio broadcasting stations are required by law to use frequency monitors. In order to maintain properly the frequencies of police and

FIGURE 26. The indicating element of the General Radio frequency monitor for radio broadcasting stations

fire department transmitters, a monitor is practically a necessity. Many communication companies using a large number of transmitters, the frequencies of which are measured periodically at central frequency-measuring stations, have found it advisable to install monitors in the transmitting station.

A FREQUENCY MONITOR FOR BROADCASTING STATIONS

To meet the rigid requirements now imposed on U. S. broadcasting stations, the General Radio Company has developed a new frequency-monitor which indicates directly in the operating room the deviation from channel frequency. Its *guaranteed* accuracy is in excess of that now demanded by the Federal Radio Commission, and a considerably better accuracy can be obtained by careful operation. Nearly two hundred of these monitors are now in use in broadcasting stations and are enabling these stations to maintain their frequencies to within a few cycles of their assigned values.

This monitor has been approved by the Federal Radio Commission (Approval No. 1452).

The essential element in the new monitor is a highly stable secondary frequency standard which operates at a frequency differing from the assigned channel by exactly 1000 cycles per second. Voltages from this standard and from the unmodulated master oscillator of the transmitter are supplied to a new type of audio-frequency meter which

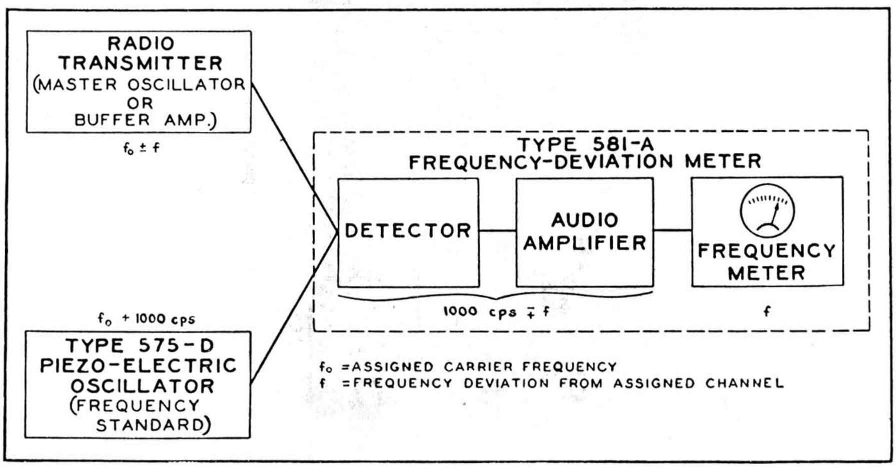


FIGURE 27. Functional diagram of the broadcast monitor

indicates directly and continuously the deviation of the resulting audio-frequency beat tone from 1000 cycles per second.

For example, if the transmitter is off-channel by 40 cycles per second on the high side, the beat-tone frequency is 960 cycles per second; if off-channel 40 cycles per second on the low side, the beat-tone frequency is 1040 cycles per second. Actually, the large meter dial is marked in CYCLES PER SECOND so that it reads "40 cycles high" or "40 cycles low," as the case may be. No calculations are required; the device is direct reading.

The monitor consists of the following standard items, all of which are listed on pages 61 to 78:

TYPE 575-D Piezo-Electric Oscillator
TYPE 376-J Quartz Plate
TYPE 581-A Frequency-Deviation Meter.

Accuracy

The frequency of the Type 575-D Piezo-Electric Oscillator when used with a Type 376-J Quartz Plate is guaranteed to be within 0.002 per cent of its specified frequency and can be expected to hold that frequency to within 5 cycles in a million, 0.0005 per cent, under service conditions if operated in accordance with furnished instructions. When installed by the user, the oscillator frequency is usually found to be much closer to its assigned frequency than the guarantee indicates. The guaranteed accuracy is set as a conservative figure to allow for extreme cases.

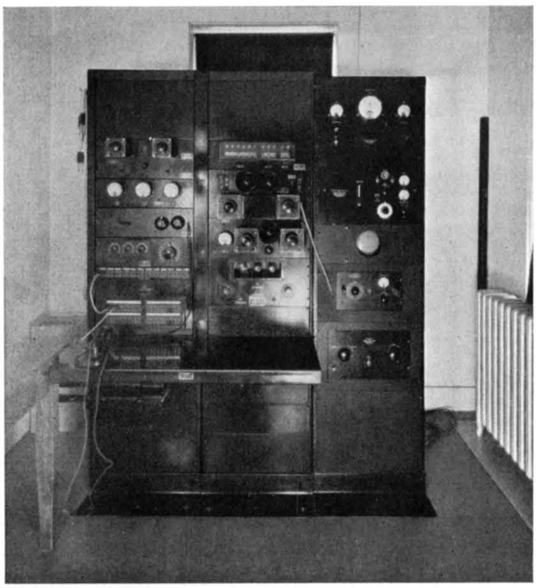


Figure 28. A General Radio frequency monitor installed at station WCSH, Portland, Maine. The monitor is shown at the top of the right-hand bay

The Type 581-A Frequency-Deviation Meter is guaranteed to indicate the 1000-cycle beat between the transmitter and the piezo-electric oscillator to ±5 cycles per second for deviations below 50 cycles per second. The 1000-cycle difference does not appear on the scale of the instrument. The instrument indicates the transmitter deviation in cycles per second directly.

Expressed in terms of channel frequency, these accuracy considerations mean that, if the transmitter is adjusted until the indicator reads zero,* the transmitter will be within 50 cycles of its assigned channel.

*Provided, of course, the apparatus is operated with due care and in accordance with the furnished instructions.

Adjustment of Frequency

An adjustment is provided on the frequency-deviation meter to allow the user to adjust the indication to compensate for the above errors and to bring the monitor into agreement with the measurements of the Supervisor of Radio.

Summarizing the foregoing, this means that,

1. If the transmitter is adjusted in terms of the apparatus as received, the station, regardless of channel frequency, will be within 50 cycles.
2. By minor adjustments, the system can be brought into exact agreement with government measurements.

Police and Fire Department Broadcasting Stations

Since the allowable frequency tolerance on police and fire department radio stations is much greater than that prescribed for other radio broadcasting stations, the frequency difference between the transmitter and the frequency standard need not be determined as accurately as is possible with the Type 581-A Frequency-Deviation Meter.

For this class of service, the Type 575-D Piezo-Electric Oscillator may be used as a frequency standard and the station adjusted to zero audible beat with the standard. The frequency of the quartz plate is the same as the station channel frequency.

Voltages from the transmitter and the piezo-electric oscillator are impressed on the receiver or detector unit. An audio frequency corresponding to the difference of their frequencies will appear in the detector output. The transmitter is then adjusted until the beat is below audibility, under which condition the transmitter frequency will be well within the allowable frequency tolerance.

If the monitor is operated continuously, a beat tone heard in the loudspeaker will attract the attention of the operator and indicate to him that the transmitter frequency has changed.

The receiver can be an ordinary police broadcast receiver or any receiver capable of tuning to the desired frequency. If no receiver is available, a detector or detector-amplifier unit can be easily assembled.

The units required for the monitor, exclusive of the receiver, are:

Type 575-D Piezo-Electric Oscillator

Type 376-J Quartz Plate.

Monitoring Equipment for Other Radio Stations

For other types of service, particularly with transmitters in which the master oscillator is keyed, an audible-beat method of monitoring is the most satisfactory. The General Radio Company builds two types of monitors for this purpose, one for high-frequency transmitters and the other for low frequencies.

The Type GR-P-198-A High-Frequency Monitor is designed for use at frequencies up to 25,000 kilocycles. For monitoring a given channel,

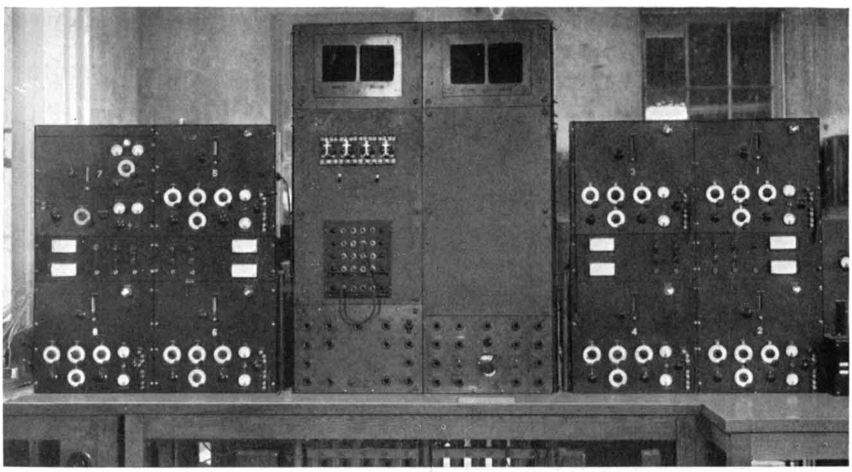


Figure 29. General Radio frequency monitor panels installed in a radio transmitting station

a quartz plate is used whose frequency is a submultiple of the channel frequency. By means of tuned circuits, the crystal harmonic which corresponds to the channel frequency is selected and impressed on the detector, together with a voltage from the transmitter. The beat between these two frequencies can then be heard in the audio-amplifier output.

Positions for eleven crystals are provided and any one can be selected by means of a switch. This permits one monitor to be used for eleven transmitting channels.

The Type GR-P-307 Low-Frequency Monitor is suitable for channels whose frequencies are as low as 30 kilocycles.

A voltage from the transmitter is applied to an amplifier tube which delivers a highly distorted output. A harmonic of the transmitter frequency is thus obtained which is compared with a crystal whose frequency is a multiple of the channel frequency.

PART III

CHOICE OF EQUIPMENT FOR SPECIFIC PURPOSES

CHOICE OF EQUIPMENT FOR SPECIFIC PURPOSES

Two factors influence the selection of frequency-measuring equipment, the desired accuracy and the cost. In choosing apparatus to fill a particular need, accuracy is the main consideration and cost is secondary, since the accuracy requirements must be met or the equipment is useless for the purpose.

After the minimum price has been fixed by the accuracy desired, a further question arises, whether it is justified economically to increase the cost slightly to obtain a greater accuracy in order to assure a margin of safety and to provide for future needs. If the frequency of a radio transmitter must be held within a given tolerance, the equipment used to measure the frequency should be capable of an accuracy several times better than the frequency tolerance. For instance, if the station frequency tolerance is 0.04 per cent, the frequency measurement should be made to, say, 0.01 per cent or better. A measurement accuracy four or five times better than the allowable error is the least margin of safety that should be considered, since it is desirable to operate as near the assigned transmitter channel as possible.

Two complete frequency-measuring assemblies have been described, one using a primary standard and an audio-beat method of interpolation; the other including a secondary standard and a less accurate interpolation means.

PRIMARY STANDARD SYSTEM

The price of the first assembly including the primary standard is $3215.00. Its accuracy of measurement is, in general, within a few cycles and it is capable of measuring frequencies between 10 kilocycles and 20 or 30 megacycles.

The possible errors in the results obtained with this equipment may be analyzed as follows:

1. Error in Standard

The error in the frequency standard will be less than ± 1 part in a million.

2. Error in Interpolation

The interpolation oscillator can measure the beat between the standard and unknown frequencies to within one cycle per second.

3. Errors in Zero-Beat Adjustment

Matching the frequency of the heterodyne frequency meter to the signal under measurement can be accomplished with a precision of better than one cycle. Usually only one zero-beat setting enters the radio-frequency part of the measurement. There is no appreciable error in matching the interpolation oscillator to the audio beat.

4. Total Error

The net result is that all errors are extremely small and the total for any one measurement may be about two or three cycles between 100 and 5000 kilocycles and perhaps 10 cycles at 20 megacycles. Whenever the unknown frequency is near enough to a standard harmonic to allow the beat to be counted, the total error is, of course, no greater than that in the frequency standard itself.

SECONDARY STANDARD SYSTEM

The second assembly, that which includes a secondary standard and employs the linear interpolation method, is subject to a larger error. Its over-all accuracy varies from about 0.01 per cent to 0.005 per cent. Its cost, however, is only $1215.00. The errors are distributed as follows:

1. Error in Standard

The guaranteed accuracy of the piezo-electric oscillator is ±0.002 per cent.

2. Error in Interpolation

Since the scale of the heterodyne frequency meter is not absolutely linear, a slight error of interpolation occurs, due to curvature. When interpolating over a 100-kilocycle interval, this error may amount to as much as 0.008 per cent. If a 20-kilocycle interval is used, this error can be reduced to about 0.004 per cent. A 10-kilocycle interval reduces it still further.

3. Zero-Beat Errors

In comparison with the errors in the standard and interpolation, the errors in making zero-beat settings are negligible.

Methods of Improving Accuracy with a Secondary Standard

1. One way in which the accuracy of measurements made with the secondary standard can be improved is by checking the frequency of the standard periodically against standard-frequency radio transmission, such as the 5-megacycle transmissions of the U. S. Bureau of Standards. If the standard is checked weekly and its error either corrected or allowed for in determining the results of measurements, this factor can be made extremely small. It can be further reduced by using a 50-kilocycle quartz bar instead of the 100-kilocycle quartz plate. The

50-kilocycle bar used in the primary standard (TYPE 576-A) is considerably more stable than the TYPE 376-J Quartz Plate. If this bar is used and the frequency is periodically checked in terms of a highly accurate standard, such as the 5-megacycle transmissions, the error in the standard can be made almost negligible. The 50-kilocycle bar should *not* be used, however, unless facilities for checking its frequency are available. It is sold without a frequency guarantee because it can be adjusted by the customer. With a frequency standard or a standard-frequency signal available for checking purposes, the bar can be adjusted to its true frequency. Actually, the bar is adjusted to frequency at the factory, but no guarantee of frequency can be made since adjustments are not sealed.

The use of the TYPE 576-A Quartz Bar instead of the TYPE 376-J Quartz Plate increases the price of the assembly by only $55.00.

2. Another method of improving the accuracy of measurements is to use the audio-beat method of interpolation. This, together with the improvement in the standard outlined above, allows an accuracy to be obtained which approaches that possible with the primary standard. The use of the beat-tone method of interpolation is not justified economically, however, unless the standard is accurate.

This further increases the price by $515.00. The additional $15.00 is the price of a second relay rack.

SUMMARY

The units which make up the frequency-measuring systems just described, together with their prices, are listed here.

	Price	Accuracy of Measurement
1. *Primary Standard Assembly*		
Class C-21-H Standard-Frequency Assembly	$1860.00	
TYPE 612-A Control Panel	65.00	
TYPE 616-A Heterodyne Frequency Meter	500.00	
TYPE 617-A Interpolation Oscillator	500.00	
TYPE 619-A Heterodyne Detector	250.00	
TYPE 480-A Relay Rack	40.00	
TOTAL	$3215.00	See page 54
2. *Secondary Standard Assembly*		
Class C-10 Standard-Frequency Assembly	$465.00	
TYPE 616-A Heterodyne Frequency Meter	500.00	
TYPE 619-A Heterodyne Detector	250.00	
TOTAL	$1215.00	0.006% to 0.01%

	Price	Accuracy of Measurement
3. *Secondary Standard Assembly with* TYPE 576-A *Quartz Bar*	$1270.00	0.002% to 0.005%
4. *Secondary Standard Assembly with* TYPE 576-A *Quartz Bar and* TYPE 617-A *Interpolation Oscillator* (including extra TYPE 480-B Relay Rack)	1785.00	about 0.001%

FURTHER MODIFICATIONS

Power-Supply Considerations

The TYPE 616-A Heterodyne Frequency Meter and the TYPE 619-A Heterodyne Detector are designed for a–c operation. Battery-operated models are available, TYPE 615-A Heterodyne Frequency Meter (portable) and TYPE 619-B Heterodyne Detector. These can, of course, be substituted for the a–c models listed above, with a consequent reduction in the price of the complete assembly.

The use of the portable heterodyne frequency meter is often an advantage since, for field work, it can be calibrated in terms of the standard and then used for measurements at points remote from the standard.

USE OF A CALIBRATED INSTRUMENT

When it is not feasible to purchase a frequency standard, the calibrated heterodyne frequency meter is useful for many purposes. Its calibration can be checked against standard-frequency or other radio transmissions, and it is capable of producing quite accurate results if properly used. If the necessary receivers are available, it is necessary to purchase only the heterodyne frequency meter. Two models are offered: one is a–c operated and priced at $500.00; the other is portable, battery-operated, and is priced at $375.00. The accuracy of measurement is between 0.01 and 0.05 per cent.

MONITORING

Stations transmitting on a single frequency and engaged in a limited class of service, such as, for example, broadcasting stations, use monitoring equipment. In addition, many of the large communication companies have found it desirable to use monitors in the transmitting station as well as to maintain central frequency-measuring stations for measuring the frequencies of groups of transmitters.

Monitors for all these purposes are described on pages 48 to 52.

Use of Standard-Frequency Radio Transmission to Check Monitors

Standard-frequency radio transmissions, such as the 5-megacycle signals sent out by the U. S. Bureau of Standards, can be used to check station frequencies and monitors. When the frequency to be checked is a multiple of 10 kilocycles, the Type 618-A Harmonic Oscillator is a simple and convenient transfer device for this purpose.

SUMMARY

1. Wherever possible, the primary standard should be used. It provides a system independent of external standards (except time) and is the most reliable system available. If the accuracy desired does not justify the expense involved, then some form of secondary standard will probably be satisfactory.

2. If, on grounds of both accuracy and cost, a local standard is out of the question, the use of a calibrated heterodyne frequency meter should be considered.

3. For frequency monitoring at the transmitter, one of the several types of frequency monitors described in Part II will be found useful.

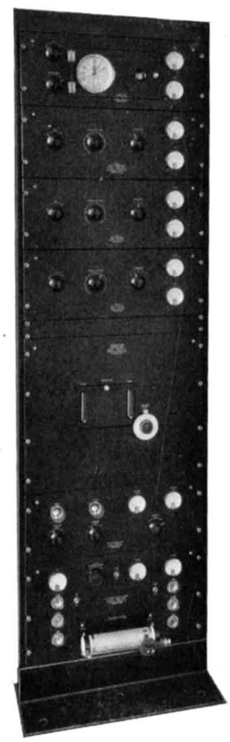
PART IV

CATALOG

CLASS C-21-H STANDARD-FREQUENCY ASSEMBLY

This assembly is a high-precision primary standard of frequency, supplying hundreds of standard frequencies between one cycle per second and several megacycles. The frequency is determined by comparison with standard time without reference to any other frequency standard. A complete description will be found in Part I, page 15.

The assembly consists of the following units, each of which is described in detail on the page indicated.



Unit	*Page*
1—Type 590-A Piezo-Electric Oscillator	61
1—Type 576-A Quartz Bar	62
1—Type 591-A Temperature-Control Unit	63
3—Type 592-A Multivibrators	64
1—Type 594-A Heat-Control Unit	64
1—Type 593-A Timing Unit	65
1—Type 595-A Power-Supply Unit	66
1—Type 480-A Relay Rack	78

SPECIFICATIONS

Frequency Range: Standard frequencies between one cycle per second and several megacycles can be obtained from this assembly.

The output obtainable is as follows:

From the 50-kilocycle multivibrator:

50 kilocycles and its harmonics up to several megacycles. The upper limit depends on the method used to detect and utilize them.

From the 10-kilocycle multivibrator:

10 kilocycles and its harmonics up to about 4000 kilocycles. Above 4000 kilocycles the amplitudes of the harmonics are small and it is difficult to discriminate between them by heterodyne methods.

From the 1-kilocycle multivibrator:

1 kilocycle and its harmonics in the audio-frequency range. The harmonics can be filtered and amplified for particular uses.

From the timing unit:

One-second pulses, the time of which is adjustable over a range of one second.

Output Amplitude: The multivibrator output voltage is of the order of one or two volts. Harmonic amplitudes are sufficient for heterodyne measurement over the ranges indicated under *Frequency Range* at left.

Frequency Calibration: The Type 576-A Quartz Bar is adjusted in our laboratories to within one part in a million of its specified frequency. Since the adjustments are not sealed, some changes may occur in shipment, and, after the assembly is installed, the frequency must be determined by a time comparison. Complete operating instructions are supplied.

Frequency Stability: When the assembly is properly operated, the frequency will remain within one part in a million over long periods of time. Since time comparisons are made daily, the frequency is known to within a few parts in ten million at all times.

Output Terminals: The various output frequencies are supplied through terminals at the rear of the assembly. Cables for power supply and interconnections between units are furnished.

Tubes: The following tubes (not supplied) are required:

2—171-A type (RCA or equivalent)
1—280 type (RCA or equivalent)
16—112-A type (RCA or equivalent) or
15—112-A type and 1 Western Electric Type 101-D

Wherever possible, the use of a Western Electric Type 101-D Vacuum Tube is recommended for the piezo-electric oscillator.

Tubes are *not* supplied with the assembly.

Power Supply: Batteries, which are continuously trickle charged, are used for power supply. These are *not* supplied with the assembly.

The following lead-type storage batteries are required:

2—6-volt, 125-ampere-hour capacity
3—48-volt, 6000-milliampere-hour capacity

The Type 595-A Power-Supply Unit provides the necessary equipment for maintaining a continuous trickle charge.

In addition, the following block-type dry batteries are needed:

2—45-volt batteries for the Type 590-A Piezo-Electric Oscillator Plate
1—22½-volt grid-bias battery tapped at 4½-volt steps

Power Input: In normal operation, the power input from the 110-volt, 60-cycle line is about 225 watts. This includes the power supplied to the heaters in the temperature-control box and the power taken by the battery chargers.

Accessories: The only accessories necessary to operate the assembly are the tubes and batteries previously listed.

Mounting: All units are mounted on standard 19-inch relay-rack panels. A relay rack for mounting the panels is included in the assembly.

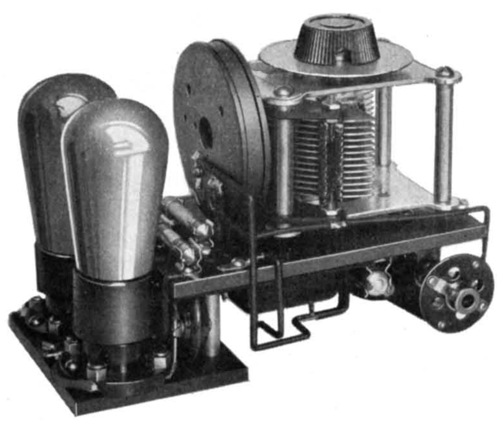
Dimensions: The over-all dimensions are (height) 69⅛ x (width) 20 x (depth) 24 inches.

Net Weight: 319 pounds.

	Price
Class C-21-H Standard-Frequency Assembly...........................	**$1860.00**

Price does not include batteries or tubes

TYPE 590-A PIEZO-ELECTRIC OSCILLATOR



This oscillator was designed especially for use in the Type 591-A Temperature-Control Unit to serve as a precision-frequency standard. When sold with the Type 591-A Temperature-Control Unit, the oscillator is mounted in the temperature box at the factory. The oscillator circuit is designed for the maximum stability consistent with simplicity, and the circuit constants have been so chosen that the oscillator is operating under optimum conditions.

Small changes in frequency may be obtained by adjustment of a variable air condenser connected across the crystal. The total frequency change obtainable in this way is of the order of fifty parts per million, which is sufficient to compensate for any frequency shifts due to aging.

An output amplifier is provided to isolate the oscillator from the load circuit.

With the oscillator is furnished an inductor suitable for operation with a crystal of the frequency specified (usually 50 kilocycles).

SPECIFICATIONS

Frequency: Although this oscillator is designed for use at 50 kilocycles in a Class C-21-H Standard-Frequency Assembly, other frequencies can be supplied on special order.

Tubes: Two vacuum tubes are necessary. The output amplifier uses a 112-A type tube. For the oscillator, either a Western Electric Type 101-D or a 112-A type may be used. The use of the Western Electric tube is recommended because of its long life.

Power Supply: Batteries are used for the power supply. A 6-volt storage battery is used to supply the filament power. The oscillator plate battery is 45 volts; and the amplifier, 150 volts. A 4½-volt grid-bias battery is also needed.

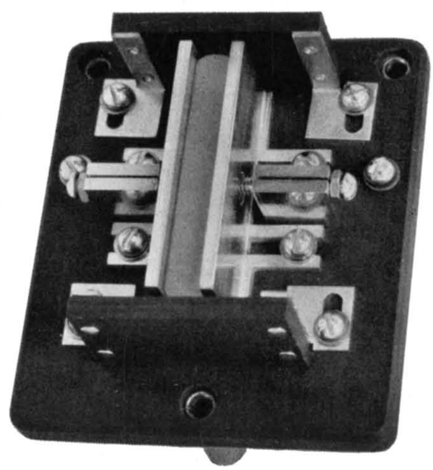
Mounting: This oscillator is designed for mounting in a TYPE 591-A Temperature-Control Unit. The oscillator is supplied mounted in the temperature-control unit, when both units are ordered.

Dimensions: (Length) 7¾ x (width) 3¾ x (height) 6 inches, over-all.

Net Weight: 5 pounds.

Type		*Code Word*	*Price*
590-A	....	STANFREROD	**$75.00**

TYPE 576-A QUARTZ BAR



This quartz bar is used as the frequency-controlling element in the Class C-21-H Standard-Frequency Assembly. Its mounting has been designed to have a minimum effect on the crystal frequency.

The air gap is adjustable independently of the mounting of the bar, which allows frequency adjustments to be made without materially altering the performance of the oscillator.

Baffles are provided to eliminate the effect of high-frequency sound energy radiated from the ends of the bar, making its frequency practically independent of atmospheric pressure changes.

The bar is zero angle cut and vibrates along its longest dimension in a direction perpendicular to the electric axis.

SPECIFICATIONS

Frequency: These bars are usually supplied for operation at 50 kilocycles. Other frequencies can be supplied on special order.

Cut: The bar is of the type usually known as zero-angle, Curie, or X-cut.

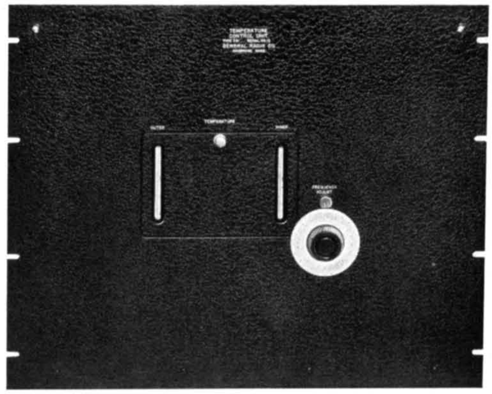
Temperature Coefficient: The temperature coefficient of frequency is less than five parts per million per degree Centigrade.

Dimensions: Base, (length) 3⅝ x (width) 3 x (thickness) 5/16 inch; electrode faces, (length) 2¼ x (height) 1 inch.

Net Weight: 1 pound.

Type		*Code Word*	*Price*
576-A	....	PIEZOMUSH	**$145.00**

TYPE 591-A TEMPERATURE-CONTROL UNIT



This unit houses the TYPE 576-A Quartz Bar and the circuit elements of the TYPE 590-A Oscillator. It consists of two temperature-controlled boxes, one inside the other, the combination being enclosed in a balsa-wood box. The two boxes are identical in construction, differing only in size.

Each box consists of:

1—A layer of distributed heaters
2—An aluminum distributing layer
3—An asbestos press board attenuating layer
4—A second aluminum distributing layer

This construction is shown in detail on page 18.

Separate heaters and thermostats are provided for each box. The use of two units provides a very accurate control of the temperature, since the inner box has to work against the variations in the outer unit only. The outer box controls to approximately ±0.1°C., and the inner to approximately 0.01°C.

The inner box provides space for mounting one TYPE 576-A Quartz Bar, or, with TYPE 591-P4 Adapter, one TYPE 376-H Quartz Plate. The outer box houses the TYPE 590 Piezo-Electric Oscillator, which is mounted in the box at the factory.

Mechanical coupling is provided between a dial on the panel and the small variable condenser of the TYPE 590-A Piezo-Electric Oscillator for adjustment of the crystal frequency.

SPECIFICATIONS

Controls: The necessary relays, rheostats, and meters are mounted on the TYPE 594-A Heat-Control Unit.

Although the TYPE 590-A Piezo-Electric Oscillator and the TYPE 594-A Heat-Control Unit are not included in the price of the TYPE 591-A Temperature-Control Unit, it is recommended that these three be ordered together if the latter is to be used in a frequency-standard system.

Thermometers: Inner, 46°-54°C. (0.1°C. graduations); outer, 40°-60°C. (0.5°C. graduations). Both thermometers are removable through a door in the panel. For replacements, see page 57 in Catalog G.

Normal Operating Temperatures: Inner compartment: 50° ± 0.01°C.; outer compartment: 45° ± 0.1°C.

Mounting: The unit is mounted on a standard 19-inch relay-rack panel, finished in black crackle lacquer. The balsa-wood box is given a coat of varnish. Cabinet-mounting models can be supplied on special order. When a TYPE 590-A Piezo-Electric Oscillator is ordered with this unit, the combination is assembled at the factory.

Dimensions: Panel, (width) 19 x (height) $15\frac{3}{4}$ inches; behind panel, (width) $17\frac{1}{4}$ x (height) $14\frac{1}{2}$ x (depth) $19\frac{1}{2}$ inches.

Net Weight: 60 pounds.

Type		*Code Word*	*Price*
591-A	....	STANFREPIG	**$450.00**

TYPE 594-A HEAT-CONTROL UNIT

The necessary auxiliary control equipment for use with the TYPE 590-A Piezo-Electric Oscillator and TYPE 591-A Temperature-Control Unit is mounted on this panel. It includes the rheostat, filament voltmeter and plate milliammeter for the oscillator, and the rheostats, relays, and heat indicators for the temperature box.

SPECIFICATIONS

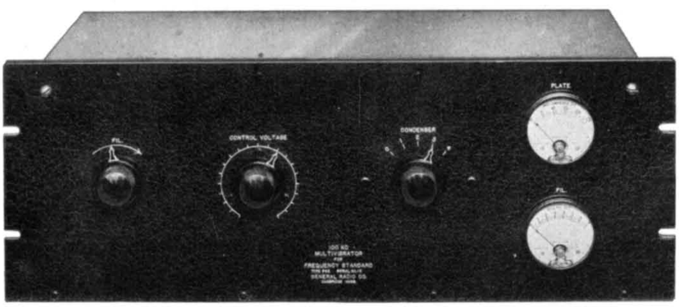
Mounting: The unit is mounted on a standard 19-inch relay-rack panel, finished in black crackle lacquer, with dust cover of nickel-plated brass.

Dimensions: Panel, (length) 19 x (height) 7 inches; behind panel, (width) 17¼ x (depth) 10 x (height) 6¾ inches.

Net Weight: 25 pounds.

Type		*Code Word*	*Price*
594-A	....	STANFRETOP	**$100.00**

TYPE 592-A MULTIVIBRATORS



These instruments are designed for use in General Radio standard-frequency assemblies as frequency dividers, but are well adapted to general laboratory and experimental use. A description of the multivibrator is given in Part I, page 19.

All three models have identical circuits, differing only in the values of circuit constants as chosen to facilitate operation in the region of the rated fundamental frequency. They may be easily adapted by the user for operation at other frequencies than those specified. Directions are included in the instruction book.

Each unit includes a voltage divider for adjusting the magnitude of the control voltage, an isolating input amplifier, a multivibrator, and an output amplifier. Plug-in resistances are supplied for operation near rated frequency, others may be substituted by the customer for operation at other frequencies. The circuit capacitance is adjustable in five steps from front of panel.

SPECIFICATIONS

Frequency: Multivibrators are supplied for operation at three fundamental frequencies (see price list) but each can be adapted for operation at other frequencies by the user (see instruction book).

Tubes: Four 112-A type (RCA or equivalent) are required. Not furnished with the instrument.

Power Supply: 6-volt battery for filament; 90-150-volt battery for plate supply (not furnished).

Terminals: Jack-top binding posts are mounted on a strip at the rear of the shelf. A plug-in plate for power supply is furnished.

Mounting: The unit is mounted on a standard 19-inch relay-rack panel, finished in black crackle lacquer, with a dust cover of nickel-plated brass.

Meters: A filament voltmeter and a plate milliammeter are included.

Dimensions: Panel, (length) 19 x (height) 7 inches; behind panel, (length) 17¼ x (height) 6¾ x (depth) 10 inches.

Net Weight: 20 pounds.

Type	*Fundamental Frequency*	*Code Word*	*Price*
592-A	**1 kc**............................	STANFREANT	**$150.00**
592-A	**10 kc**............................	STANFREBOY	**150.00**
592-A	**100 kc**............................	STANFRECAT	**150.00**

TYPE 593-A TIMING UNIT

The Type 593-A Timing Unit contains a Type 511 Syncro-Clock, which is operated from the 1-kilocycle multivibrator output in the Class C-21-H Standard-Frequency Assembly. The clock is so geared that when the driving frequency is 1 kilocycle, the clock keeps true time. The reading of this clock is compared with standard time pulses, such as radio time signals, by means of an adjustable contact on the 1-second shaft of the clock. This contact can be adjusted until it operates at the same instant that the time signals are received. The mean frequency of the system is then determined from the error in the clock reading as compared with standard time. Comparisons can be made to better than 0.01 second.

The 1-second contact can also be used in timing and chronograph work.

In addition to the clock and its associated input amplifier, the unit includes an output amplifier for delivering a standard 1-kilocycle voltage to other apparatus in the laboratory.

SPECIFICATIONS

Frequency: 1 kilocycle.

Tubes: The following tubes (not supplied) are required:

2—112-A type (RCA or equivalent)
2—171-A type (RCA or equivalent)

Power Supply: Batteries are used for the power supply. The following batteries are required:

6-volt battery for filaments
150-volt battery for plate supply
The total plate current is about 50 milliamperes.

Meters: On the panel are mounted a filament voltmeter and a plate milliammeter.

Mounting: All apparatus is mounted on a standard 19-inch relay-rack panel, finished in black crackle lacquer and a shelf of nickel-plated brass. A nickel-plated brass dust cover is included. A door is provided for access to the clock and micro-dial mechanisms.

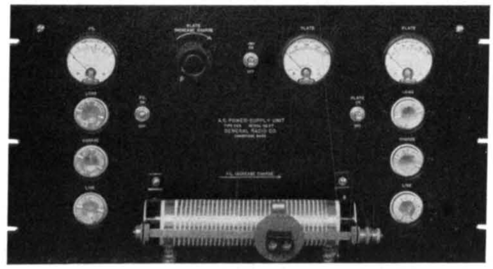
Dimensions: Panel, (length) 19 x (height) 7 inches; behind panel, (length) 17¼ x (height) 6¾ x (depth) 10 inches.

Net Weight: 28¼ pounds.

Type		*Code Word*	*Price*
593-A	....	STANFREBUG	**$400.00**

TYPE 595-A POWER-SUPPLY UNIT

This unit is designed for use in trickle charging the batteries of a Class C-21-H Standard-Frequency Assembly. It includes a 6-volt, 6-ampere charger for the filament batteries and a 150-volt, 100-milliampere charger, with smoothing filter, for the plate supply. All necessary fuses, switches, rheostats, and meters are provided.



SPECIFICATIONS

Tubes: One 280 type (RCA or equivalent) is required. It is not supplied with the instrument. A Tungar bulb is supplied with the instrument.

Power Supply: 110-115-volt, 50-60-cycle, alternating-current line.

Meters: The following meters are included: ammeter for filament charger, milliammeter for plate charger, and plate voltmeter.

Fuses: Fuses are provided in both supply and load sides of the charger circuits and also in the battery load circuits.

Mounting: All parts are mounted on a standard 19-inch relay-rack panel, finished in black crackle lacquer and a nickel-plated brass shelf. To facilitate the conduction and radiation of heat, no dust cover is used.

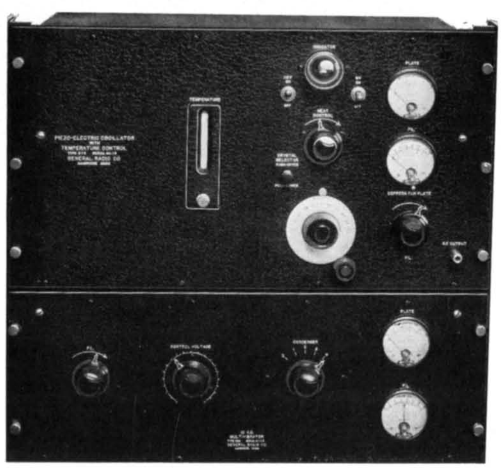
Dimensions: Panel, (length) 19 x (height) 10¾ inches; behind panel, (length) 17¼ x (height) 10½ x (depth) 13 inches.

Net Weight: 50 pounds.

Type		*Code Word*	*Price*
595-A	....	STANFREDOG	**$200.00**

CLASS C-10 STANDARD-FREQUENCY ASSEMBLY

This is a secondary standard of frequency, consisting of a piezo-electric oscillator and a single multivibrator. It furnishes a harmonic series, the accuracy of which is 0.002 per cent or better. Its use is described in detail in Part II, page 38. The accuracy of its frequency, while not as good as that of a primary standard, is guaranteed to better than 0.002 per cent, and if frequent checks are made against standard-frequency transmissions, a still higher degree of accuracy can be realized.



The assembly consists of the following units, each described on the page indicated.

Unit	*Page*
1—Type 575-D Piezo-Electric Oscillator	67
1—Type 376-J Quartz Plate (100 kc)	78
1—Type 592 Multivibrator*	64
1—Type 480-B Relay Rack	78

*The multivibrator can be supplied to operate normally 100 kc or 10 kc. Please state frequency when ordering.

SPECIFICATIONS

Frequency Range: The multivibrator supplies a harmonic series extending from its fundamental frequency to several megacycles.

Accuracy: The guaranteed accuracy is 0.002%.

Tubes: The following tubes (not supplied with the assembly) are required:
1—232 type (RCA or equivalent)
4—112-A type (RCA or equivalent)

Power Supply: A 6-volt storage battery and a 135-volt plate battery (*not* supplied) are required.

Mounting: Both units are mounted on standard 19-inch relay-rack panels, finished in black crackle lacquer. Nickel-plated brass dust covers are included. The panels are mounted on the Type 480-B Relay Rack, which is designed for table or bench use.

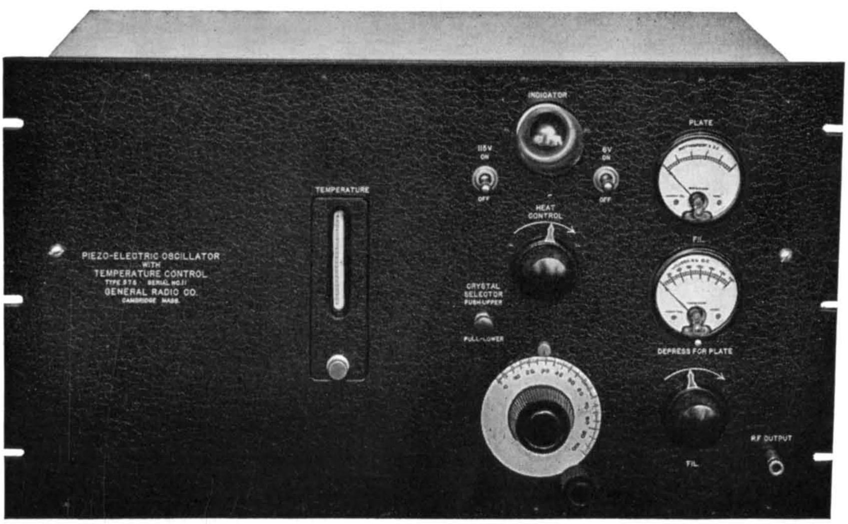
Dimensions: Complete assembly, (width) 20 x (depth) 11.5 inches.

The assembly occupies 17.5 inches of vertical panel space on the relay rack, the total height of which is 44 inches.

Net Weight: 71 pounds.

	Price
Class C-10 Standard-Frequency Assembly	**$465.00**

TYPE 575-D PIEZO-ELECTRIC OSCILLATOR
WITH TEMPERATURE CONTROL



This unit is an improved type of piezo-electric oscillator for use as a secondary frequency standard for the laboratory or for monitoring purposes. It has a greater accuracy and better stability than any other secondary standard thus far available.

This performance is made possible through the use of a new oscillator circuit, a modified form of the tuned-grid circuit using a screen-grid tube. A stabilization system is provided to reduce the effect on the frequency of variations in operating voltages and tubes. The difficulty of adjusting the oscillator circuit elements to duplicate the conditions under which the oscillator was calibrated is eliminated in the Type 575-D Piezo-Electric Oscillator, since the proper operating point is determined by adjusting the tuning condenser until the plate current is at its minimum value.

A temperature-control chamber for housing the quartz plate is provided similar to the TYPE 547-A Temperature-Control Box described on page 56 of Catalog G. The temperature of the quartz plate is held to within 0.1°C. for room temperature variations of ±11°C. Mountings for two TYPE 376 Quartz Plates are provided.

This oscillator is intended to be used with TYPE 376-J* and TYPE 376-K* Quartz Plates. Using a TYPE 376-J Quartz Plate, the absolute accuracy of the frequency is guaranteed to 0.002 per cent; with TYPE 376-K, the accuracy is 0.003 per cent. Over long periods of time the frequency will remain constant to 0.005 per cent.

The TYPE 575-D Piezo-Electric Oscillator is used in the General Radio visual frequency monitor for broadcast stations (see page 48).

*See page 78.

SPECIFICATIONS

Output: A radio-frequency voltage of the crystal frequency may be obtained from the terminals marked RF OUTPUT on the terminal strip of the instrument. Neither of these posts is grounded within the instrument.

Power Supply: Jack-top binding posts are provided on the terminal strip for connecting (a) 6-volt battery for filament and heat-control relay; (b) 135-volt plate battery, and (c) 105- to 115-volt (alternating-current or direct-current) supply for heaters.

Tubes: One RCA 232 type, or equivalent. (Not supplied with instrument.)

Inductor: One TYPE 575-DP Inductor suitable for use at the frequency of the crystal is supplied with each instrument.

Quartz Plate: This oscillator is designed for use with General Radio TYPES 376-J and 376-K Quartz Plates.

When used with the TYPE 581-A Frequency-Deviation Meter, the oscillator operates at a frequency differing from the assigned carrier frequency by 1000 cycles per second. TYPE 376-J Quartz Plates for this purpose can be supplied.

For use as an improved secondary frequency standard for laboratory purposes, we can supply a 100-kc crystal and inductor. The oscillator can then be used to control one or more TYPE 592 Multivibrators to obtain harmonic series of 100 kc or a submultiple of 100 kc. See page 22.

Meters: Plate-current meter, 0-5 mla.; filament and plate voltmeter, 0-7 and 0-140 volts with a push-button switch.

Mounting: The instrument is mounted on a 1/4-inch aluminum panel, for standard 19-inch relay-rack mounting. The panel is finished in black crackle lacquer. A dust cover of nickel-plated brass is supplied which also partially shields the unit from stray electrical fields.

Accessories Supplied with Instrument: One TYPE 547-P2 Adjustable Mercury Thermostat, one TYPE 547-P3 Thermometer, one heat-indicator lamp, one TYPE 575-DP Inductor of suitable range. Replacement thermometers and thermostats are described on page 57 of Catalog G.

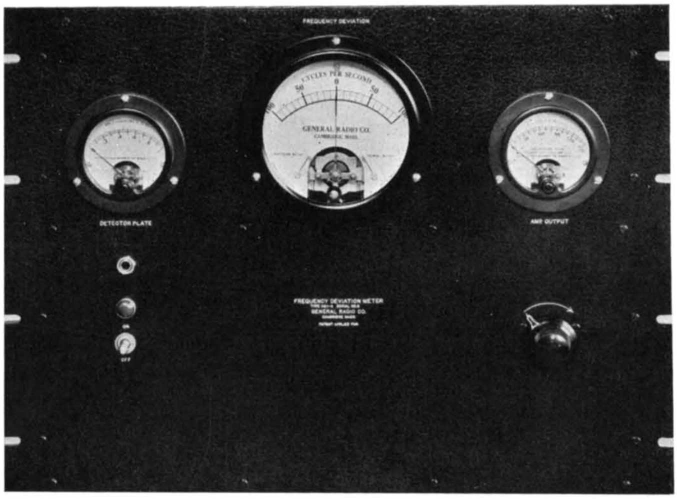
Additional Accessories Required: One or more TYPE 376 Quartz Plates; one 232-type vacuum tube; batteries as listed under *Power Supply*.

Dimensions: Panel, (width) 19 x (height) 10½ inches; dimensions of apparatus behind panel, (width) 17¼ x (height) 10¼ x (depth) 10 inches, with dust cover.

Net Weight: 30 pounds, including dust cover.

Type		*Code Word*	*Price*
575-DR	....	ADEPT	**$215.00**

TYPE 581-A FREQUENCY-DEVIATION METER



This instrument is designed to be used in conjunction with the TYPE 575-D Piezo-Electric Oscillator to indicate continuously by visual means the deviation in cycles per second of the carrier frequency of the broadcast transmitter from its assigned value. The instrument indicates this deviation directly, and shows whether the carrier frequency is too high or too low. The meter scale is of the zero-center type and is graduated in 10-cps steps from −100 cps to +100 cps. A change of one cycle is readily discernible.

The TYPE 581-A Frequency-Deviation Meter consists of a detector, an audio-frequency amplifier, and a frequency meter. It operates from a voltage derived from the *unmodulated master oscillator* or a buffer amplifier of the transmitter. It is essential that the transmitter be of the master oscillator type, in which the master oscillator itself is not modulated.

The frequency of the monitoring piezo-electric oscillator is adjusted in the laboratory of the General Radio Company to be 1000 cps above (or below) the assigned frequency of the transmitter. Voltages of the monitor frequency and that of the carrier of the transmitter are applied to the detector, and the resulting 1000-cps beat is passed through the audio-frequency amplifier into a frequency meter, which reads zero at 1000 cps and indicates cycles per second above and below 1000 cps. For instance, if the transmitter frequency is 50 cps too high, the beat between it and the standard oscillator will be 950 cps and the meter will indicate 50 cps above zero. The monitoring oscillator may be 1000 cps higher or lower than the assigned transmitter frequency, since reversing the leads to the indicating meter will reverse its reading.

The necessary power supply and amplifying equipment for the frequency-deviation meter are contained within the instrument. The only external connections required are the radio-frequency connections to the monitoring oscillator and the master oscillator of the transmitter and the connections to the 115-volt, 60-cps line. Connections are provided for using an additional frequency indicator.

While the TYPE 581-A Frequency-Deviation Meter will function with any monitoring oscillator, the frequency of which differs from the assigned carrier frequency by exactly 1000 cps, the requirements which must be met impose rigid restrictions on the stability of the monitor itself. Because of these increased restrictions, the TYPE 575-D Piezo-Electric Oscillator has been developed especially for use with the deviation indicator.

SPECIFICATIONS

Accuracy: The instrument is guaranteed to be accurate to within ± 5 cycles per second, below 50 cps.

Meters: Detector plate meter, 0–1 mla. Output voltmeter, copper-oxide-rectifier type, 0–150 volts. Frequency-indicating meter, −100 cps to +100 cps.

Power Supply: 105-115 volts, 60 cps alternating current.

Tubes: Four UY-227, CY-327, or equivalent. One UX-245, CX-345, or equivalent. One UX-280, CX-380, or equivalent. Two of the 227-type tubes, which are used in the frequency-meter unit, are supplied with the instrument. Other tubes must be purchased separately. A method of selecting replacement tubes for use in the frequency-meter unit is described in the instruction book supplied with the instrument.

Mounting: The instrument is mounted on a ¼-inch aluminum panel 19 inches wide, which is finished in black crackle lacquer, ready for mounting on a standard 19-inch (Type 480) relay rack. A dust cover of nickel-plated brass is supplied.

Accessories Supplied with the Instrument: Two 227-type vacuum tubes for frequency meter; inductor for coupling the instrument to the transmitter.

Additional Accessories Required: Two 227-type vacuum tubes. One 245-type amplifier tube and one 280-type rectifier tube.

Dimensions: Panel, (width) 19 x (height) 14 inches. Dimensions of apparatus behind panel, (width) 17¼ x (height) 13¾ x (depth) 10 inches, with dust cover on.

Net Weight: 53 pounds, including dust cover.

Type		*Code Word*	*Price*
581-A	....	ABOUT	**$250.00**

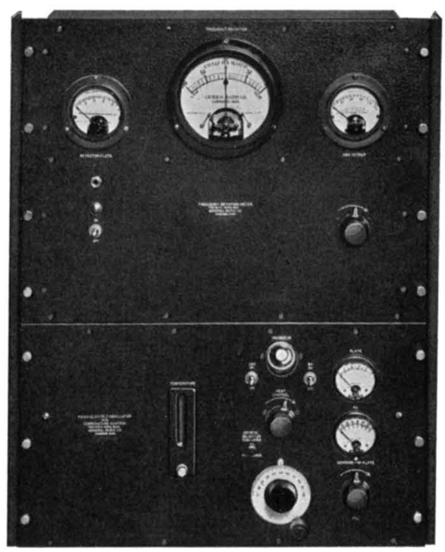
FREQUENCY MONITOR FOR BROADCASTING STATIONS

The outstanding features of the General Radio broadcast frequency monitor, now used by nearly two hundred United States broadcasting stations, are high accuracy and low cost.

The use of the new Type 575-D Piezo-Electric Oscillator allows a greater accuracy and permanence of calibration to be obtained than has previously been possible with piezo-electric secondary standards. This monitor has an over-all accuracy which is well within the 50-cycle limit prescribed by the Federal Radio Commission, and means are provided for bringing its frequency into agreement with the measurements of government monitoring stations.

The operation of the monitor is completely described on pages 48 to 50. Specifications will be found under the descriptions of the individual units. Complete operating instructions are furnished.

The monitor is made up of the following units:



Type 575-D Piezo-Electric Oscillator	$215
Type 376-J Quartz Plate	85
Type 581 Frequency-Deviation Meter	250
Total	**$550**

TYPE 615-A HETERODYNE FREQUENCY METER

This instrument is a portable oscillating frequency meter of high stability. The portable feature is of considerable advantage, since the instrument can be calibrated in the laboratory and then taken to points remote from the laboratory for making frequency measurements. A detector is included for listening to heterodyne beats. A thermometer is mounted on the panel to indicate the temperature inside the instrument, which allows the calibration to be corrected for difference between calibration and operating temperatures.

The oscillator uses a modified Colpitts circuit which is stabilized to reduce frequency variations due to supply voltage changes. The condenser and inductance system have been carefully designed for maximum stability.

The condenser is of the worm-drive precision type, similar in construction to

General Radio Type 222 Precision Condenser. The plates are shaped to give a linear variation in frequency with scale reading. The ratio of maximum to minimum frequency for any coil position is 1.4 to 1, and the effective range is 1.3 to 1.

The inductance system consists of three tapped coils providing eleven ranges, selection of which is made by a switch.

The use of a calibrated heterodyne frequency meter in frequency measurements is described on pages 45 to 47. It can also be used to interpolate between standard frequencies.

SPECIFICATIONS

Frequency Range: The fundamental frequency is adjustable from 275 kc to 5000 kc. In frequency measurement, the use of harmonic methods extends its useful range to about 30 megacycles.

Calibration: A list of calibrated points is supplied. Ten or more points are calibrated at each of the eleven settings of the inductance switch. Since the condenser scale is linear in frequency, calibration curves can be easily drawn if desired.

Accuracy: It is recommended that the calibration be checked frequently. The accuracy of the original calibration can be relied upon to 0.1% for long periods provided a correction is made for the difference between calibrating and operating temperatures.

Tubes: The following vacuum tubes are supplied with the instrument:

1—RCA 232 type
1—RCA 230 type

Power Supply: Power is furnished by self-contained batteries. The following batteries are required:

Filament supply: Two 6-inch dry cells. Plate supply: Two 45-volt vertical B-batteries (Burgess No. 5308 with insulated cap nuts).

Space for batteries is provided in the cabinet. A cable for use with external batteries is also supplied.

Output: Two coupling systems are provided, one capacitively coupled to the oscillator anode and the other a radio-frequency transformer in the detector plate circuit for obtaining harmonic output.

Terminals: Coupling terminals and telephone terminals (for listening to beats) are mounted on the panel of the instrument.

Meters: A plate milliammeter and a filament-plate voltmeter are mounted on the panel.

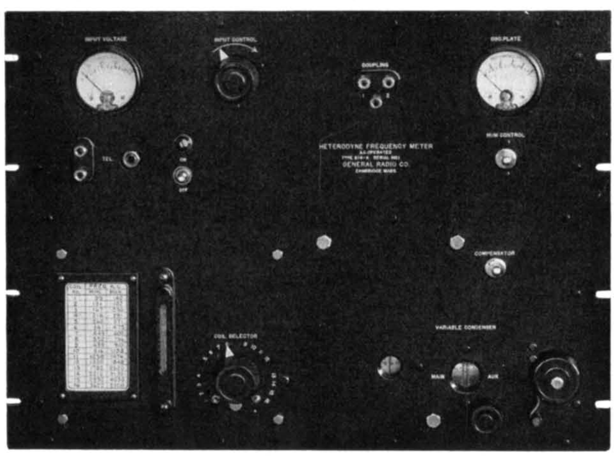
Mounting: The instrument is mounted on an aluminum panel and is enclosed in an aluminum cabinet with cover and carrying handle.

Dimensions: (Length) 20 x (width) 8 x (height) 13½ inches, over-all.

Net Weight: 34 pounds.

Type		*Code Word*	*Price*
615-A	....	MANLY	**$375.00**

TYPE 616-A HETERODYNE FREQUENCY METER



This instrument is an oscillating frequency meter for use either as a calibrated frequency-measuring device or as an interpolation oscillator in conjunction with standard-frequency equipment. It consists of a highly stable radio-frequency oscillator, a detector and audio amplifier for listening to heterodyne beats, and a harmonic output transformer.

The condenser has an auxiliary dial by means of which zero-beat settings may be made accurately at the low radio frequencies where the zero audible-beat zone is several divisions wide. This dial is also very convenient in making interpolations on the scale of the instrument, since scale intervals are indicated directly without the necessity of subtracting two readings.

Its performance characteristics are similar to those of the Type 615-A Heterodyne Frequency Meter just described. The same oscillator circuit is used with a straight-line-frequency precision condenser. It differs from the portable instrument in that it covers a wider fundamental frequency range, is alternating-current operated, and is designed for relay-rack mounting.

SPECIFICATIONS

Frequency Range: Fundamental: 100 kc to 500 kc. Harmonics can be used up to 30 megacycles.

Calibration: A list of calibrated points (about ten points per coil) is supplied. Since the scale is linear, curves can be easily drawn from this data.

Accuracy: When used as a calibrated device, it is recommended that the calibration be checked frequently. The original calibration can be relied upon to 0.1% for long periods if a correction is made for the difference between calibrating and operating temperatures.

Output: Two coupling systems are provided, one of which is capacitively coupled to the plate of the oscillator tube and the other of which is a radio-frequency transformer in the detector plate circuit. The first system is ordinarily used when listening in the heterodyne unit itself. Fundamental and harmonic output for use with external apparatus is obtained from the second arrangement.

Terminals: The output coupling terminals, and also telephone terminals, are brought out on both the panel and the rear of the unit.

Meters: A line voltmeter and a plate milliammeter are mounted on the panel.

Tubes: The following tubes are supplied:
1—RCA 57 type
2—RCA 56 type

Power Supply: Power is obtained from a 110- to 115-volt, 50- to 60-cycle alternating-current line. A connecting cord and plug assembly are supplied. The power drawn from the line is about 30 watts.

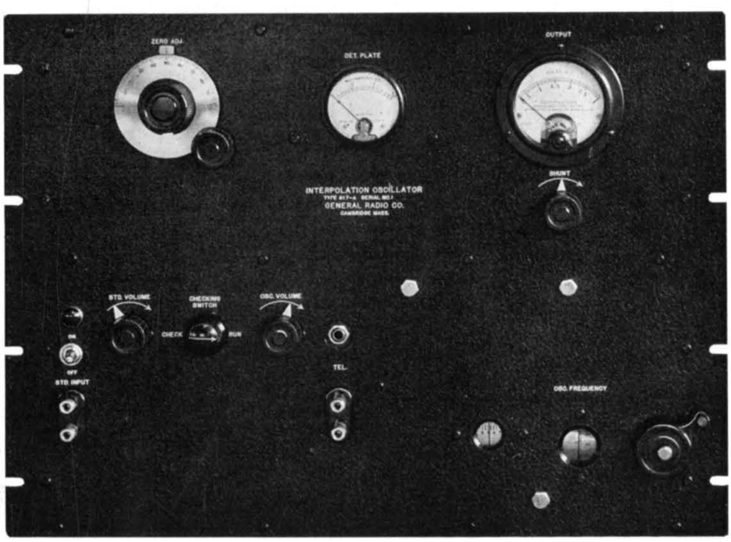
Mounting: The instrument is mounted on a 19-inch relay-rack panel, finished in black crackle lacquer. A nickel-plated dust cover is furnished.

Dimensions: Panel, (length) 19 x (height) 14 inches; behind panel, (length) 17¼ x (depth) 10½ x (height) 13⅝ inches.

Net Weight: 56½ pounds.

Type		*Code Word*	*Price*
616-AR	....	MANOR	**$500.00**

TYPE 617-A INTERPOLATION OSCILLATOR



A rapid and accurate means of measuring the difference between a frequency under measurement and a standard 10-kilocycle harmonic is indispensable in precise frequency measurement work. The Type 617-A Interpolation Oscillator has been designed specifically for this purpose. The oscillator is of the beat-frequency type. The radio-frequency oscillators are similar to those used in the TYPES 615-A and 616-A Heterodyne Frequency Meters.

The condenser controlling the frequency of the variable oscillator is of the precision worm-drive type similar to the TYPE 222. The plates are shaped to give a linear variation in frequency with dial reading. The scale is direct reading, one cycle per scale division.

This oscillator is primarily intended to be used with a Class C-21-H Standard-Frequency Assembly from which calibrating frequencies may be obtained for checking at a number of points of the range. This provides a rapid and convenient means for measuring differences between radio frequencies with an accuracy of one cycle. Means for introducing standard calibrating frequencies are provided. Beats between the oscillator and standard frequencies may be observed on a visual beat indicator. This allows the calibration to be checked whenever used. Where an audio-frequency standard is not available, the zero-beat setting or the 60-cycle alternating-current line may be used to adjust the scale.

SPECIFICATIONS

Frequency Range: 0-5000 cycles per second.

Accuracy: The scale is direct reading in frequency to better than ±5 cycles per second. A correction curve is furnished which enables an accuracy of ±1 cycle per second to be obtained.

Output: The output voltage varies from 2.0 to 3.5 volts over the frequency range.

Terminals: Terminals, both on the panel and at the rear, are provided for telephones and for introducing a standard calibrating voltage.

Tubes: The following tubes are supplied:
2—RCA 57-type Oscillators
2—RCA 56-type Det-amp.
1—82-type Rectifier

Meters: A detector plate current meter and an oxide-rectifier-type output voltmeter are provided.

Power Supply: The instrument operates from a 110- to 115-volt, alternating-current 50- to 60-cycle line. The power input is 30 watts.

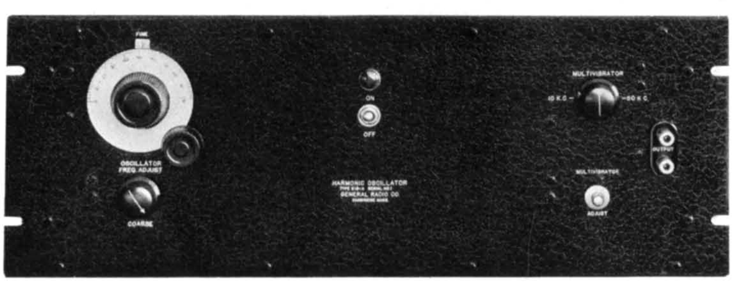
Mounting: The oscillator is designed for mounting in a standard 19-inch relay rack. The panel is finished in black crackle lacquer. A nickel-plated brass dust cover is included.

Dimensions: Panel, (length) 19 x (height) 14 inches; behind panel, (length) 17¼ x (height) 10½ x (depth) 13⅝ inches.

Net Weight: 62 pounds.

Type		*Code Word*	*Price*
617-AR	....	MAPLE	**$500.00**

TYPE 618-A HARMONIC OSCILLATOR



This instrument is designed for use in conjunction with standard-frequency radio transmissions. When adjusted to zero beat with the standard frequency, it supplies a harmonic series of either 50 kilocycles or 10 kilocycles for use in frequency measurement. One specific application is the checking of a broadcast transmitter frequency against the 5-megacycle transmissions of the U. S. Bureau of Standards. This and other uses of this instrument are discussed on pages 43 and 44.

The 50-kilocycle oscillator uses the Colpitts circuit and is stabilized to prevent changes in supply voltage from affecting the frequency.

SPECIFICATIONS

Frequency: Oscillator, 50 kc. Multivibrator, 50 kc and 10 kc.

The multivibrator supplies a harmonic series similar to that obtainable from a standard-frequency assembly.

Calibration: The oscillator frequency is adjustable over a narrow range and is adjusted at the factory to operate at 50 kilocycles at approximately the center of the range of variation.

Accuracy: No accuracy guarantee is made. The instrument is designed to be used only in conjunction with a standard-frequency radio transmission or other standard-frequency sources.

Output: Multivibrator output terminals are provided on the panel.

Tubes: The following tubes (not supplied) are required:

1—57 type (RCA or equivalent)
3—56 type (RCA or equivalent)

Power Supply: Power is supplied by a 110- to 115-volt, 50- to 60-cycle alternating-current line. The power drawn from the line is approximately 25 watts.

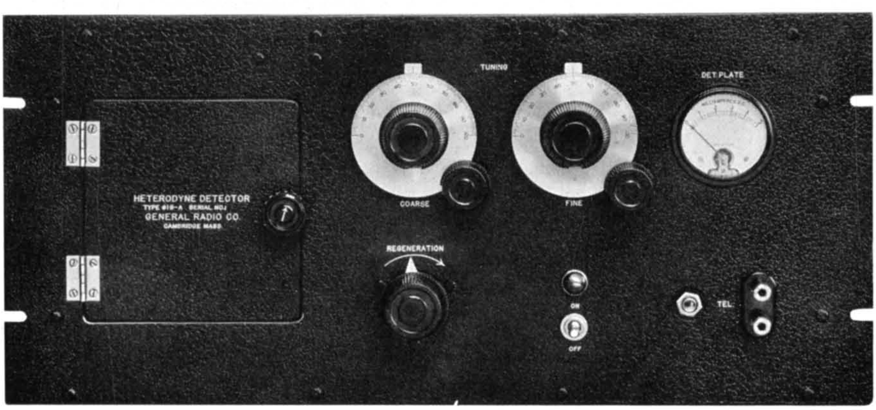
Mounting: The instrument is designed for mounting in a standard 19-inch relay rack. The panel is finished in black crackle lacquer. A nickel-plated brass dust cover is provided. A cabinet model can also be furnished. See price list below.

Dimensions: Panel, (length) 19 x (height) 7 inches; behind panel, (length) 17¼ x (depth) 10½ x (height) 13⅝ inches.

Net Weight: 26 pounds.

Type	*Description*	*Code Word*	*Price*
618-AR	**Relay-Rack Mounting**	AIROL	**$120.00**
618-AM	**Cabinet Mounting**	ALACK	**135.00**

TYPE 619 HETERODYNE DETECTOR



This instrument is a general-purpose laboratory heterodyne consisting of a tuned detector and a two-stage audio-amplifier. A regeneration control is provided so that the detector may be used in either the oscillating or the non-oscillating condition, as the user desires. The heterodyne detector was designed as one of the units of the frequency-measuring systems described in Part II. It is also useful as a detector in conjunction with a radio-frequency bridge.

SPECIFICATIONS

Frequency Range: The frequency range is from 90 to 6000 kilocycles. Twelve plug-in coils are provided to cover this range. In order to spread out the high-frequency range, two condensers are used, one covering frequencies from 90 kc to 1800 kc and the other covering the high-frequency range from 1500 kc to 6000 kc.

Calibration: A calibration is supplied. While this calibration is accurately determined, it is not guaranteed since the heterodyne is not intended for use as a calibrated frequency-measuring device.

Coupling: Three sets of coupling terminals are provided, each connected to the detector grid through a small condenser.

Mounting: Both types are for mounting on a standard 19-inch relay rack. The panels are finished in black crackle lacquer. A nickel-plated dust cover is included.

Dimensions: Panel, (length) 19 x (height) 8¾ inches; behind panel, (length) 17¼ x (height) 8½ x (depth) 10½ inches.

Net Weight: TYPE 619-A, 39 pounds; TYPE 619-B, 32½ pounds.

TYPE 619-A HETERODYNE DETECTOR ALTERNATING-CURRENT OPERATED

Tubes (not furnished with instrument):
3—56 type (RCA or equivalent)
1—82 type (RCA or equivalent)

Power Supply: This unit operates from a 110- to 115-volt, 50- to 60-cycle alternating-current line. The power drawn from the line is approximately 25 watts.

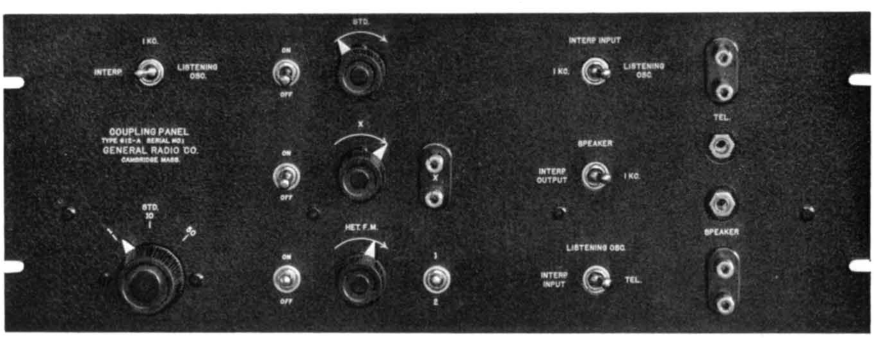
TYPE 619-B HETERODYNE DETECTOR BATTERY OPERATED

Tubes (not furnished with instrument):
3—112-A type (RCA or equivalent)

Power Supply: This unit operates from batteries. The following batteries (not furnished) are required:
6-volt battery for filament
90- to 135-volt battery for plate

Type	*Description*	*Code Word*	*Price*
619-AR	**A-C Operated**....................	MATIN	**$250.00**
619-BR	**D-C Operated**....................	MAXIM	**225.00**

TYPE 612-A CONTROL PANEL



This panel is provided in order that all controls and switches necessary to operate a complete frequency-measuring assembly may be made from a single operating position. The panel carries all the controls which are required in making frequency measurements with the equipment described in pages 29 to 37.

SPECIFICATIONS

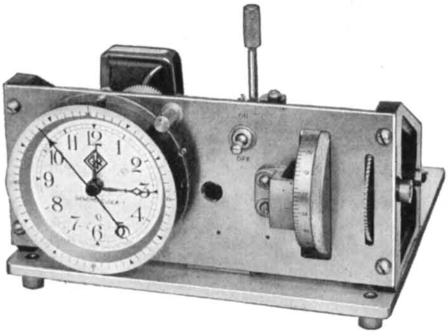
Mounting: All parts are mounted on a standard 19-inch relay-rack panel, finished in black crackle lacquer.

Dimensions: Panel, (length) 19 x (height) 7 inches; behind panel, (length) 17¼ x (height) 6¾ x (depth) 3½ inches.

Net Weight: 6¼ pounds.

Type		*Code Word*	*Price*
612-A	....	MARRY	**$65.00**

TYPE 511 SYNCRO-CLOCKS



TYPE 511-C Syncro-Clock. The micro-dial is adjusted by the knurled wheel at the right

TYPE 511-B Syncro-Clock. Tone generators and other attachments can be mounted in the space at the right of the sub panel

In a primary frequency standard of the type described in Part I the synchronous-motor-driven clock provides the connecting link between frequency and time. When driven by a standard-frequency oscillator, this device may be used as a source of precisely-determined time intervals, and, conversely, when its indication is compared with standard time, a measure of the driving frequency is obtained.

The TYPE 511 Syncro-Clocks are designed to operate from the output of a low power vacuum tube. The motor is of the impulse type and since no accelerating torque is present in the system, the motor must be brought up to synchronous speed by hand. They are normally supplied for operation from a 1000-cycle source, although units to operate on other frequencies can be obtained on special order.

The micro-dial system obtainable on two stock models of these clocks consists of a cam-operated contact, closing once a second, the time of which is adjustable over a range of one second. The use of this device in making time comparisons is described on page 19. In addition it can be used to supply impulses spaced one second apart for timing the operation of other equipment.

Additional accessories can be obtained, among them low-frequency generators. These are iron armature discs rotating in a magnetic field, and the frequency so generated depends upon the speed of the disc and the number of teeth on its circumference.

SPECIFICATIONS

Frequency: Clocks are normally supplied to operate at 1000 cycles. Other frequencies can be obtained on special order.

Power Consumption: Two 171-A-type tubes or one 245-type tube supply sufficient power to drive the motor. A direct-current component is necessary in the driving voltage to provide a magnetic bias. The steady plate current of the vacuum tube used to drive the motor is sufficient for this purpose.

Micro-dial: Micro-dials are supplied as regular equipment on TYPE 511-C and TYPE 511-D. Micro-dials may be added later at the factory.

Mounting: Table- and panel-mounting models are available. Table-mounting models have the clock face in a horizontal plane; panel-mounting models, in a vertical plane. See the accompanying illustrations.

Dimensions: Table-mounting models (Type 511-B and Type 511-D): (Length) 10¾ x (height) 7½ x (depth) 9¼ inches, over-all.

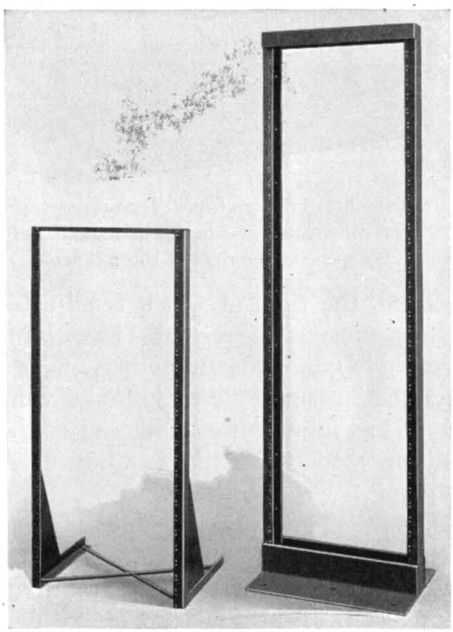
Panel-mounting models (Type 511-A and Type 511-C): (Length) 9 x (height) 6½ x (depth) 8 inches, over-all.

Net Weight: Table-mounting models, 15 pounds; panel-mounting models, 11 pounds.

Type	*Description*	*Code Word*	*Price*
*511-A	Panel mounting without micro-dial	SYNCROFORD	$160.00
511-B	Table mounting without micro-dial	SYNCROFROG	160.00
*511-C	Panel mounting with micro-dial	SYNCROGOOD	220.00
511-D	Table mounting with micro-dial	SYNCROTOAD	225.00

*Built to order, not carried in stock.

TYPE 480 RELAY RACKS



Left: Type 480-B; *right*, Type 480-A

Standard 19-inch relay racks suitable for mounting frequency-measuring equipment are listed on page 161 of Catalog G. Type 480-A provides vertical panel space of 63 inches and is designed for floor mounting. Type 480-B is intended for bench or table mounting and provides space for 43¾ inches of panel.

TYPE 376 QUARTZ PLATES

Type 376-J and Type 376-K Quartz Plates which are used in the Type 575-D Piezo-Electric Oscillator are described on pages 54 and 55 of Catalog G. Other Type 376 Quartz Plates are also listed. Since the frequencies of General Radio quartz plates are guaranteed to a high degree of accuracy, it is necessary to impose some restrictions on the operating conditions under which the guarantee is valid. For this reason the operating temperature range is specified, as well as the oscillator circuit, tube, and operating voltages. Read carefully the specifications in Catalog G before ordering.

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All instruments using the Dow oscillator circuit are licensed under pending patent applications

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