

A METHOD OF MEASURING RADIO FREQUENCY BY MEANS OF A HARMONIC GENERATOR*

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INTRODUCTION

Harmonics of an electron tube generator have been used for radio-frequency measurements¹ for several years. The well-known system for measuring a radio frequency in terms of an audio frequency, devised by Abraham and Bloch² and employing their multi-vibrator is perhaps the best example of such use of harmonics.

It is the purpose of this paper to describe briefly an arrangement which employs a simple type of harmonic generator the fundamental of which is an audio-frequency alternating current. The generator is rich in harmonics of sufficient power to produce appreciable currents in a wavemeter which is coupled to it and tuned to resonance with frequencies which are integral multiples of the fundamental. The arrangement is a convenient one for primary frequency standardization since the fundamental frequency produced by the harmonic generator can be checked during the measurement against the frequency of a standard tuning fork by means of a visually indicating instrument. A large number of harmonics can be utilized since decidedly sharp settings are made possible by the use of another visual indicator. The visual indicators lighten the labor of the observer since it is found easier to take a large number of settings with the eye than by ear.

DESCRIPTION OF THE METHOD

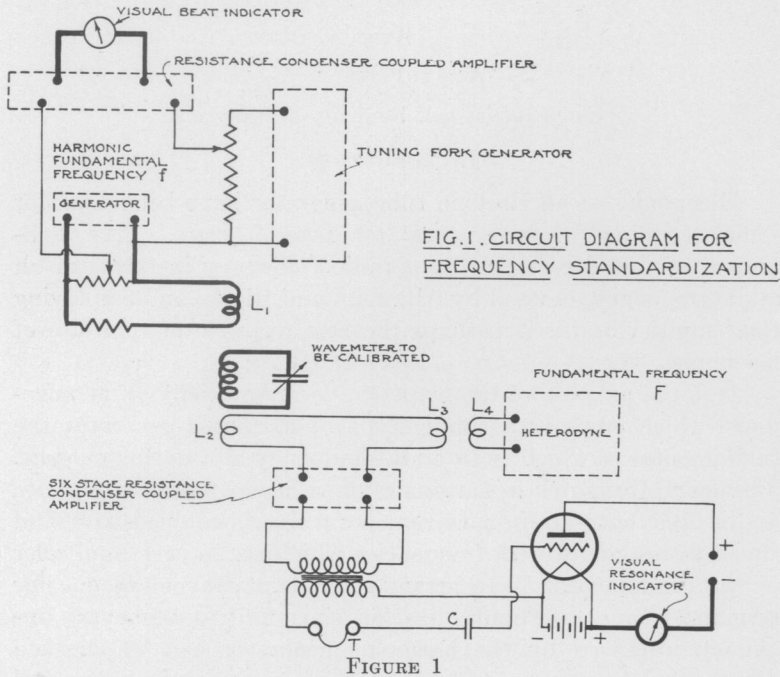
The arrangement for primary frequency standardization is shown in Figure 1. The heavy line portions are the essential parts

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¹ "Radio Instruments and Measurements," Bureau of Standards Circular Number 74, pages 100-104; 1918.

² "Comptes Rendus," volume 168, page 1105; June, 1919.

of the system. The visual beat indicator is a portable galvanometer, with 1 milliampere for full scale deflection. It is used for keeping the fundamental frequency f of the harmonic generator exactly at the value of the frequency of the standard tuning fork generator. The pointer will stand still when the two frequencies are exactly alike. This will also happen when the



two frequencies are very different, but such a shift of frequency is not likely to happen during the measurement and after having the fundamental frequency f adjusted. The visual indicator of resonance will indicate a sharp minimum whenever the wave-meter is tuned to the fundamental frequency f or any integral multiple of it. The procedure of measurement is briefly as follows :

(1) The fundamental frequency f of the harmonic generator is varied until the fundamental alternating current is in synchronism with the current produced by the standard fork generator. The zero beat indicator will then stand still and the least change in the frequency will cause the pointer to swing³

³ Two swings per second, for instance, mean that the fundamental is off by two cycles. The pointer will, of course, also stand still when the harmonic generator is adjusted to $2f$, $3f$, and so on.

to and fro. The frequencies of all possible currents have then the form $(a \times f)$ if a denotes whole numbers such as 1, 2, 3, 4, and so on.

(2) The heterodyne is set to certain fundamental frequency F which is in the neighborhood of the frequency range to be used in the calibration.

(3) While the wavemeter is varied, a series of beat notes will be heard in the telephone receiver T which produce at the same time minimum deflections on the resonance indicator. The telephone receiver is used as a rough guide and the settings are made by means of the visible indications. The minimum deflections will occur whenever

$$a \cdot f = b \cdot F$$

if $b \cdot F$ stands for all possible frequencies of the heterodyne and b denotes integer numbers such as 1, 2, 3, 4 This shows that a minimum indication is obtained whenever the wavemeter is set to a frequency which is an integral multiple a of the fundamental frequency f of the harmonic generator. Beats can also occur between harmonics of the harmonic generator and harmonics of the heterodyne, which is expressed by factors a and b . The factor b can be made equal to unity by choosing a rather loose coupling between the heterodyne and the six-stage amplifier. Such a precaution is, however, not necessary.

(4) Knowing approximately the fundamental frequency F of the heterodyne driver it is easy to determine the particular harmonic frequency $a \times f$ to which the wavemeter is tuned. The simplest way, however, is to substitute the wavemeter by one the calibration of which is known approximately. (Example : Suppose the fundamental frequency $f = 1$ kc. (kilocycle per second) and the approximate frequency is found to be $a \cdot f = 21.13$ kc., then the true setting is 21 kc., since a must be a whole number).

When the precautions above mentioned are followed, this method may be used to obtain resonance settings on a wavemeter up to the 100th harmonic. It has been found possible to obtain as high as the 360th harmonic of a 1,000-cycle fundamental frequency, but this requires much skill and does not appear useful in actual wavemeter standardization work. For the higher frequencies it is preferable to use a tuning fork of higher fundamental frequency f , or to employ an additional harmonic generator and measure its fundamental frequency f' against a certain harmonic $(a \times f)$ by another zero beat indicator in the same way as f is checked against the fork driver. An an example, suppose the fundamental frequency f of the first harmonic

generator is adjusted to the frequency of the tuning fork, which let us assume to be $f=1$ kc. The fundamental frequency f' of the second harmonic generator may be adjusted by another zero beat indicator to the 20th harmonic of f , that is, $f'=20$ kc. A calibration of a wavemeter at 500 kc. would then require only the 25th harmonic of the second harmonic generator instead of the 500th harmonic of f .

PRACTICAL HINTS AND DESCRIPTION OF APPARATUS

(I) The *harmonic generator* is shown in Figure 2. It makes use of the fact that a circuit of this type produces strong harmonics and especially when much inductance with pronounced distributed capacity is used in the grid and plate circuits and a crystal rectifier in the output branch. In order to accomplish this a hard rubber tube, one-half inch in diameter and five inches in length was used as a core for a coil with 48,000 turns of wire. Using wire, about Number 30, American wire gauge, and winding the coil in the ordinary way will give pronounced coil capacity. Taps were taken off every 3,000 turns as indicated in the figure, giving enough sections of different inductance to produce distorted audio currents ranging from about 10 cycles per second to 15 kilocycles per second. An ordinary air condenser connected from the plate to the grid gives a means for varying the frequency gradually within a small range. A tube capable of giving from 2 to 10 watts power is sufficient for the measurement. Two tubes connected in parallel can also be used. The entire generator should be shielded by copper foil with the output coil outside of the screen.

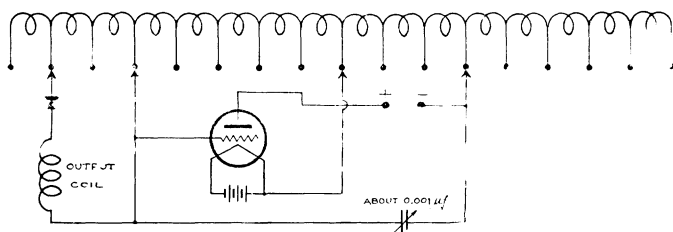


FIGURE 2—Diagram of Connections for the Harmonic Generator

(II) The 6-stage *amplifier* (Figure 3) is used for amplifying the beat effects between the current of frequency $a.f$ to which the wavemeter is tuned and the current produced by the heterodyne. It acts normally as an audio-frequency repeater since the beat notes are usually within the audible range of frequencies. It operates as a radio-frequency amplifier when no heterodyne

is used. This is only possible for comparatively low frequencies (not much higher than the 20th harmonic of f). It seems therefore best to use the heterodyne for all settings. The entire arrangement is surrounded by a shielding of copper foil. If possible the "B" battery should be within the shielding, otherwise a by-pass condenser should be used within the screen and across the terminals leading to the "B" battery.

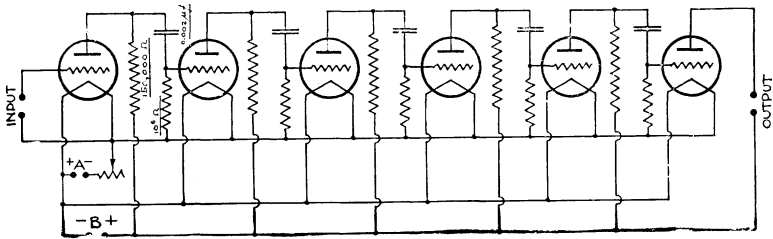


FIGURE 3—Six-Stage Resistance Condenser Coupled Amplifier

(III) The *amplifier* leading to the visual beat indicator is likewise resistance-condenser coupled and shown in Figure 4.

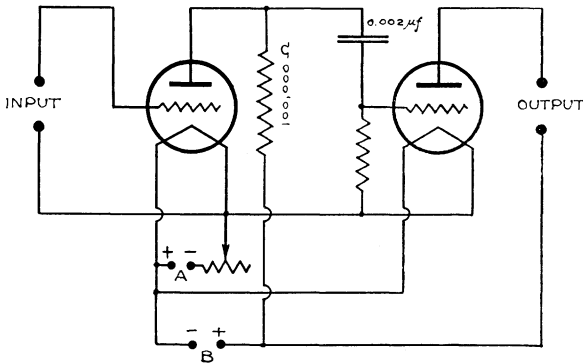


FIGURE 4—Resistance Coupled Amplifier for Zero Beat Indicator

(IV) The circuits leading to the *visual resonance indicator* are shown in Figure 1. An ordinary audio-frequency transformer is employed for coupling the output branch of the 6-stage amplifier to the circuit with the visual resonance indicator. It was found that the resonance settings can be made sharper when a dip method is used. Such an indication is obtained when a grid condenser of about $0.0001 \mu f.$ is employed without a leak in the detector circuit. When the different beat notes affect the detector tube the microammeter in the plate circuit will show a sharp dip. If the frequency measurement is carried out in a

laboratory where many outside disturbances affect the grid, the telephone receiver T (Figure 1) indicates the presence of interfering voltages. Under such circumstances the use of a grid leak is advantageous.

(V) The *tuning fork generator* provides the fundamental frequency in terms of which the measurement is made. It is therefore essential to use a standard fork the frequency of which is constant and known. It seems best to use a fork employing an electron tube drive of such a type that the circuits can produce alternating current only when the fork is vibrating at its own natural frequency. For most work a fork having a frequency of about 1,000 vibrations per second is convenient. A fork giving about 100 vibrations per second would have the advantage of giving more points on the wavemeter to be calibrated, but the disadvantage of not giving calibrations at frequencies as high as can be obtained with a 1,000-cycle fork.

(VI) The *heterodyne* is an ordinary electron tube generator covering a range of frequencies from about 10 to 1,500 kc. Copper foil is used for shielding the entire apparatus except the coil L_4 (Figure 1) which couples to the 6-stage amplifier. A tube giving about one-tenth of a watt radio frequency power will do.

(VII) The inductances of the *coupling coils* L_1 , L_2 , L_3 and L_4 shown in Figure 1 depend on the range of frequency used, while the shape of coils L_1 and L_2 depends, besides, on the shape of the coil used in the wavemeter. A loose coupling to the wavemeter is essential. The best distance between L_1 and the wavemeter, L_2 and the wavemeter, and between L_3 and L_4 is found by trial for which case it is convenient to use the telephone receiver T as well as the resonance indicator because the relative positions of the coils may be so much off that the indicator will not respond at all. The coils L_3 and L_4 are made to slide in a box which is covered with copper foil.

(VIII) The *zero beat indicator* in Figure 1 can also be replaced by a cathode-ray oscillograph (the hot-cathode type is convenient). The usual way of using this apparatus applies the two voltages E_1 and E_2 coming from the harmonic generator and fork generator, respectively, to the two deflection condensers of the oscillograph. Synchronism is then recognized by a stationery pattern (Lissajous figure) on the fluorescent screen of the cathode-ray tube. Another way is partly indicated in Figure 5. The current coming from the fork generator produces a circle on the screen of the cathode-ray tube. The battery between the hot cathode and the anode of the oscillograph is connected

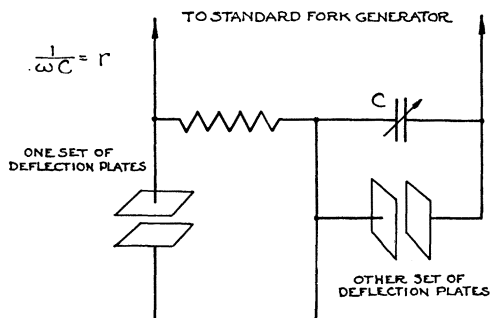


FIGURE 5—Zero Beat Indicator, Using a Cathode Ray Tube

in series with the output of the harmonic generator. If the fundamental frequency of this generator is not exactly the same as the frequency of the fork, the diameter will increase and decrease at the rate of the frequency difference.

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SUMMARY : An improved method has been developed for standardizing a wavemeter by means of the harmonics produced by a simple type of harmonic generator the fundamental of which is an audio-frequency alternating current. The arrangement is adapted to primary frequency standardization since the fundamental frequency can be checked during the measurement against the frequency of a standard tuning fork by means of an instrument using visual indication. A large number of harmonics (up to 100 and higher) can be utilized since very sharp settings are made possible by the use of a visual resonance indicator.