THE General Radio EXPERIMENTER

VOLUME XVIII No. 4 SEPTEMBER, 1943

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

IN THIS ISSUE

IDENTIFICATION OF HARMONICS IN A HARMONIC SERIES

IN USING frequency standards, the useful output of which consists of one or more series of harmonics, the ready identification of certain or all of the harmonics in a given frequency range is one of the first problems encountered in calibrating equipment against the standard. Basically the problem is always the same: (1) The identification of a key point, or of widely separated key points; (2) dividing the interval between such points, or the frequency range about one such point, into smaller frequency intervals, and (3) subdividing such intervals into successively smaller intervals. Depending on the method used, the identification and subdividing steps may or may not be combined into a single operation.

I. Using Calibrated Oscillator or Receiver

Within certain ranges, the simplest method depends on the calibration of an oscillator or a receiver, or both. These calibrations must be sufficiently accurate and stable so that the errors are substantially less than one half of the fundamental frequency of the harmonic series, that is, substantially less than one half of the frequency interval between successive harmonics.

If a fine calibration of a piece of equipment is required, it is obvious that as harmonic series having lower and lower fundamental frequencies (to obtain calibrating points nearer and nearer together) are used, a point will be reached where any given oscillator or receiver calibration is not sufficiently precise to identify positively the frequency of any given harmonic.

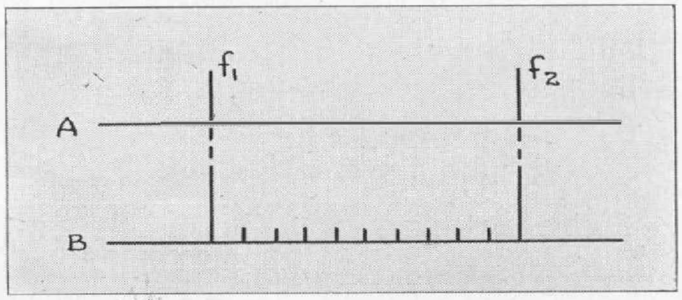


FIGURE 1. 100-kc harmonics identified by calibration of oscillating receiver are shown at A. Knowing f_1 and f_2, points at 10-kc intervals are filled in as at B and the frequencies are known.

II. Using Calibrated Oscillator or Receiver and Successive Harmonic Series

By use of different harmonic series, *in turn*, however, this situation can be overcome. For example, suppose the receiver calibration in the frequency range of interest to be good to ± 5 kc. It is obvious that this calibration would not serve to identify 10-kc harmonics, but it would be entirely adequate to identify 50-kc or 100-kc harmonics.

By first spotting the identifiable 50-kc or 100-kc points on the scale of the equipment being calibrated, such "key" points serve for positive checking when calibration points at, say, 10 kc, or smaller intervals, are filled in as shown in Figure 1.

III. Identifying Harmonics Separated by a Desired Interval

When the frequency range or span of an oscillator is to be checked as covering certain limits, it is convenient to be able to identify two harmonics of a series which are not adjacent harmonics. This span should be checked before detailed calibration is started.

If an auxiliary oscillator is set at a fundamental frequency equal to the de-

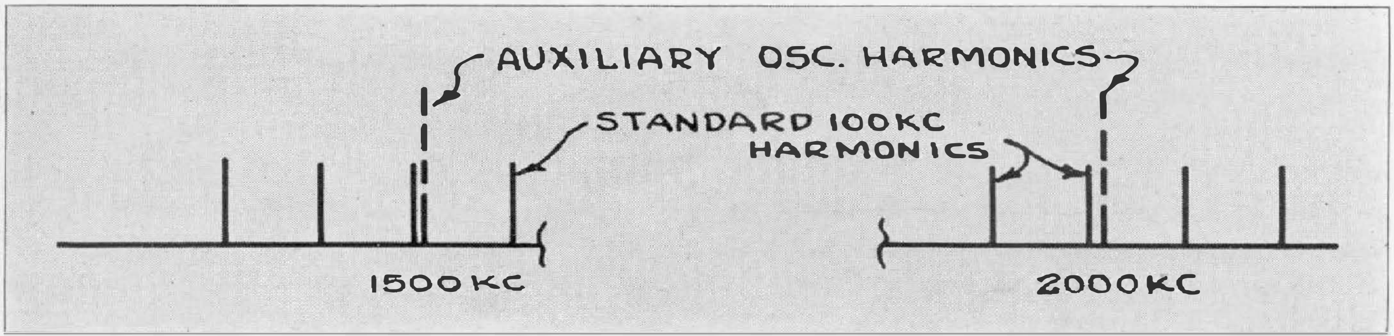


FIGURE 3. Showing how two standard harmonics marking a particular frequency span are identified using an auxiliary oscillator.

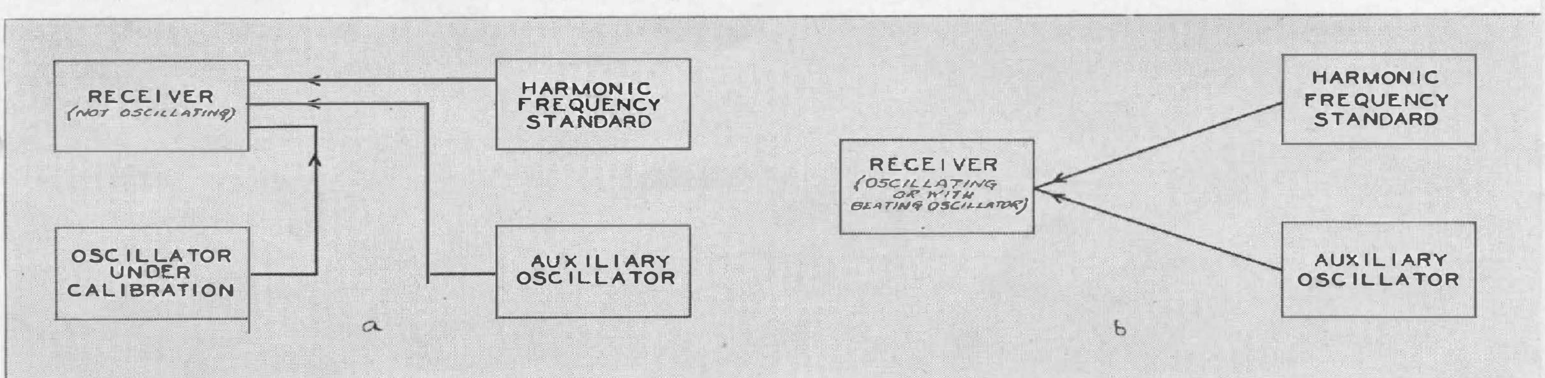
sired span, one of its harmonics then falls at the bottom and one at the top of the desired range. If the span is not a multiple of the fundamental of the harmonic series of the standard, a test span can be chosen which is such a multiple.

If this is done, the auxiliary oscillator is preferably not set in exact zero beat with the standard. If the oscillator is offset slightly, then the top and bottom points of the test span will be identified by two harmonic frequencies of the standard marked by a characteristic double beat tone when picked up in a non-oscillating receiver, while all other standard frequency harmonic points will be marked by single beat tones, as the oscillator frequency is varied through its range. A block diagram of the system is shown in Figure 2a. An oscillating receiver, or one with a heterodyning oscillator, can also be calibrated by this method, as shown in Figure 2b.

As an example, let us assume that one range of a multi-range frequency meter to be calibrated covers a span from 1460 to 2090 kc. If the auxiliary oscillator is set at 500 kc, a test span of 1500 to 2000 kc is marked off by the third and fourth harmonics. If this oscillator is set off from 500 kc by 30 cycles or so, then a characteristic double beat will be heard when the test oscillator is set at 1500 or 2000 kc. When these two points have been checked as falling within normal limits on the frequency meter scale, the auxiliary oscillator is turned off and final calibration started in terms of the standard alone.

This same procedure provides for setting up, in effect, a harmonic series of higher fundamental frequency than the highest available from a given frequency standard. For example, if the highest frequency harmonic series is 50 kc, an auxiliary oscillator set at 500 kc, and slightly offset from the standard, identifies every 10th 50-kc harmonic by the characteristic double beat tone, which is equivalent to a standard harmonic series of 500 kc. This series extends over the range covered by harmonics of the auxiliary oscillator. Final calibrations at any such points should

FIGURE 2. (a) Block diagram showing the process of calibrating an oscillator by means of an auxiliary oscillator set to the desired frequency span. (b) A similar system for calibrating a receiver.



be taken directly against the 50-kc harmonics, with the auxiliary oscillator effectively disconnected from the detector.

Finally, if several series of standard frequency harmonics are available, identification of any desired harmonic of the low frequency series can be made by counting, provided only that harmonics of the highest frequency series can be identified. For example, if a receiver calibration identifies any harmonic of a 100-kc series, and is set to one such harmonic, we can, on substituting a 10-kc series, count the number of 10-kc points passed over in tuning the receiver to either lower or higher frequencies. By counting not more than five 10-kc harmonics, we can set the receiver to any required 10-kc multiple.

For example, if 1670 kc is to be identified, set the receiver at 1700 kc, as checked against 100-kc harmonics. Leaving the receiver at this setting, substitute the 10-kc harmonic series. Tuning the receiver toward lower frequencies, the first 10-kc harmonic reached is 1690 kc, the second 1680, and the third is the desired point of 1670 kc.

IV. Identifying Harmonics on Uncalibrated Equipment

It is feasible, and, in many cases, very convenient to have a system of identifying *any standard frequency harmonic*, without the necessity of having any calibrated radio-frequency equipment. To do this it is necessary to have means of measuring audio frequencies with precision but, since such equipment is usually available with the frequency standard, this is generally no new problem.

If it is desired, for example, to know which 100-kc standard harmonic has been tuned in on an *uncalibrated* receiver, an auxiliary setup or "identifier," consisting of a crystal oscillator and 100-kc multivibrator, is needed. This crystal oscillator need not be of elaborate design. If the crystal has a low temperature coefficient and the circuit is provided with a *fine* frequency adjustment, for purposes of accurately adjusting the difference in frequency, or "offset," between the standard and identifier frequencies, occasional readjustment is all that is required.

The use of an "offset" frequency standard as a means of avoiding very low beat frequency differences when measuring radio frequencies is well known. The particular feature of using a specific offset for identification purposes was proposed by the writer's co-worker, Mr. H. H. Hollis.

This auxiliary crystal oscillator is adjusted to a frequency that is a definite number of cycles below 100 kc and the multivibrator is controlled from it. For example, if the crystal is set Δ cycles low on the 100-kc fundamental, the frequency of any identifier harmonic is $nf_i = n(f_s - \Delta) = nf_s - n\Delta$ cycles, where f_i is the identifier fundamental frequency and f_s is the standard frequency.

Now, if the *uncalibrated* non-oscillating receiver is tuned to some harmonic

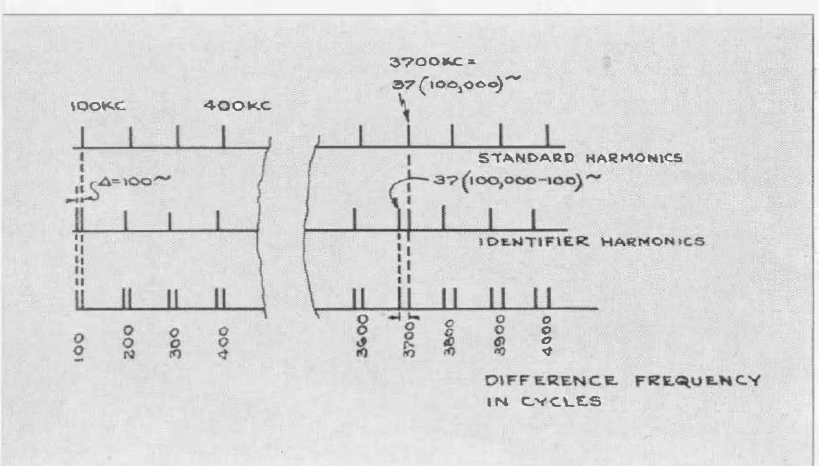


FIGURE 4. Showing operation of identifier.

of the standard, its frequency is nf_s. If, then, the standard and identifier outputs are both connected to the receiver input, a beat output from the receiver is obtained equal to

$$\begin{aligned} f_b &= nf_s - (nf_s - n\Delta) \\ &= nf_s - nf_s + n\Delta \\ &= n\Delta \text{ cycles} \end{aligned}$$

which is the beat frequency measured with the audio-frequency measuring equipment.

In general, we are not interested in the *number* of the harmonic n; we wish to know its *frequency*. By choosing Δ appropriately, the beat $n\Delta$, *in cycles*, can be made equal numerically to the frequency nf_s of the standard harmonic, *in kilocycles*.

For example, take Δ as 100 cycles, as shown in Figure 4. If the receiver is tuned to the 37th harmonic of the 100-kc standard, the beat output of the receiver will be 100 x 37 = 3700 cycles. The frequency of the harmonic to which the *uncalibrated* receiver is tuned is 3700 kc. The next higher harmonic (38th) would give a beat output of 3800 cycles.

From this we can see that the frequency of the identifier crystal oscillator should be set carefully just 100 cycles below the standard, which is most easily done by tuning in a known high-frequency harmonic and adjusting the crystal oscillator to obtain the correct beat frequency. We also can see that, for a given Δ and a given audio-frequency measuring range, there is an upper limit to the number of standard harmonics which can be identified. For example, if the audio-frequency measuring equipment covers a range up to 5000 cycles, the highest standard frequency harmonic which can be identified is 5000 kc or 5 Mc.

With some care in adjusting the identifier crystal oscillator frequency, and in operating the audio-frequency measuring equipment, a Δ of 10 cycles can be used, which gives beat frequencies one tenth of those given above. The frequency of the harmonic in kc is then *10 times* the audio-beat frequency. The upper frequency limit is also ten times higher — 50,000 kc or 50 Mc.

From the preceding descriptions we can see that, to obtain decimal multipliers for converting the observed beat frequency to the frequency of the standard harmonic, we should choose a Δ which is a decimal fraction of the standard frequency. For example, if the standard frequency is 50 kc, a Δ of 50 cycles gives beat frequencies in cycles which are numerically equal to the frequencies of the standard harmonics in kilocycles.

If the identifier is set up as described above for identification of standard harmonics on the direct-reading basis, then the addition of a lower frequency multivibrator to the identifier will provide for identifying the harmonics of this lower standard frequency. If a 10-kc multivibrator be added to the identifier of the preceding paragraph, the effective Δ is 50 divided by 5, becoming 10 cycles. Therefore the audio beat obtained between a standard 10-kc harmonic series and the 10-kc series from the identifier is again, in cycles, equal to the frequency of the 10-kc harmonic, in kilocycles.

A further limitation on the number of harmonics which can be identified by this method comes about when the beat frequency, $n\Delta$ reaches or exceeds one half the fundamental frequency of the harmonic series. With Δ taken as 10 cycles, as described in the last paragraph, with a 10-kc harmonic series, $n\Delta$ becomes equal to $f_s/2$ when the beat is 5000 cycles, corresponding to the 500th harmonic. While it is possible to

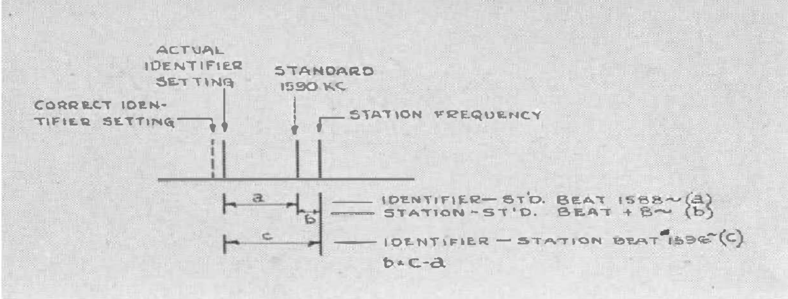


FIGURE 5. Showing use of identifier in avoiding very low beat frequencies in measuring a radio frequency very near a standard harmonic.

interpret the results when the beat frequency effectively exceeds this value, it is generally simpler and much more convenient to choose a value for Δ which avoids this situation in the frequency range of interest.

Summarizing, a value for Δ can be chosen which will identify practically all useful harmonics of a high frequency series, within the limits of a given audio-frequency measuring range. This same value of Δ will identify harmonics of a lower frequency series up to the limit of the audio-frequency measuring range or $f_s/2$, whichever occurs at the lower frequency, where f_s is the fundamental of the low frequency harmonic series.

In many cases this method of identification need be applied only to the highest frequency harmonic series of the frequency standard. In any given frequency range a large number of identified key frequencies are then available. The intervals between these known key frequencies can then be subdivided by one of the other methods described, without the necessity of using a lower frequency identifier series.

The use of a definite value of offset from standard for the identifier crystal oscillator frequency in no way impairs the use of the system in avoiding low beat frequencies when measuring a radio frequency. If a broadcast station frequency is being measured, the beat obtained between a 10-kc standard harmonic and the station frequency would only be a few cycles. If the audio beat between the standard and identifier series, at the harmonic corresponding to the station frequency, is first measured and then the beat between the identifier series and the station frequency, the difference of these beat frequencies is the number of cycles that the station is off frequency.

For example, suppose a station at 1590 kc is being checked, as illustrated in Figure 5. If the identifier is set exactly, the beat difference between the identifier and standard at this harmonic would be 1590 cycles. Suppose the identifier is slightly off frequency, giving a beat of 1588 cycles. If the beat between the identifier and station frequencies is 1596 cycles, the station is 1596 − 1588 = +8 cycles (high); if the beat were 1583 cycles, the station would be 1583 − 1588 = −5 cycles, or the station would be 5 cycles low. The error in setting the identifier does not appear in the final result. — J. K. CLAPP

SERVICE DEPARTMENT NOTES

Tell Us What Is Wrong

In writing about erratic operation of an instrument, please describe in detail the type of service, hours of usage, operating conditions, power source, and results obtained from following directions given in Instruction Books, and Service and Maintenance Notes. It will often be possible for us to analyze the trouble and to send directions for its correction by return mail.

If it is necessary that an instrument be returned for reconditioning, this detailed information will prevent delay in doing the work.

Service and Maintenance Notes

This information is mailed without charge to all users of General Radio equipment. The Notes will help you in making adjustments and repairs, thus avoiding time lost in having reconditioning done at the factory. If you do not have a set of Service and Maintenance Notes, send us a list of your General Radio instruments, giving type and serial numbers, and your copy will be mailed promptly.

Check Your Equipment Now

Constant usage of General Radio equipment will eventually result in the wearing of moving components, deterioration of tubes and batteries, changes in the values of resistors and capacitors, and the collecting of dust and grit throughout the assembly. These conditions occur very gradually and the effects are not noticed until errors become serious or poor operation develops.

Why not check your equipment now to see if it conforms to the specifications in the catalog? The information given in the Instruction Book and in the Service and Maintenance Notes will help you in determining if operation is normal and in making readjustments. Keep your instruments in first-class operating condition in order to get accurate results from your measurements.

VARIACS

Most of the Variacs returned for repairs have damaged windings. Defective brushes or poor contact of the brushes on a corroded or blackened winding surface result in arcing, eventually dam-

aging the coils. Occasional inspection and cleaning of your Variacs will prevent delays caused by return to the factory for repairs. Orders for replacement brushes are shipped promptly. Please specify type of Variac on your order.

Replacement Parts

While an effort is made to maintain a reasonable stock of parts, such a supply must necessarily be limited, because of general shortages. In placing a requisition for replacement parts, please order only the amount sufficient for your immediate needs. Orders for larger quantities may deprive another customer from getting parts needed in an emergency.

Whenever possible, repair minor damage in your own plant. If you cannot make repairs to parts of General Radio manufacture, why not return them to us for repair rather than order a replacement? Prompt service can be given and strategic materials will be conserved.

— H. H. DAWES

Group of employees holding the "E" banner.

A STAR FOR OUR "E" BANNER

The men and women of the General Radio Company are proud that their efforts have merited a renewal of the Army-Navy "E" award. To our suppliers and our subcontractors we express our thanks for their help in adding this star to our "E" banner.

The Navy's letter of award.

DEPARTMENT OF THE NAVY
OFFICE OF THE UNDER SECRETARY
WASHINGTON

9 July 1943

Mr. Melville Eastham, President
General Radio Company
Cambridge, Massachusetts

Dear Mr. Eastham:

At the last meeting of the Navy Board for Production Awards the question was taken up whether your company would be granted a renewal of the Army-Navy 'E' Award for an additional period of six months dating from June 15, 1943.

It is with great pleasure that I inform you that affirmative action was taken in the case of the General Radio Company at Cambridge. Accordingly, there is being forwarded to you a new pennant with one star affixed, which you should receive in the near future. The Navy Department desires that no ceremony be held in connection with the star award.

The men and women of the General Radio Company have achieved a signal honor by continuing their splendid production in such volume as to justify this renewal of their award. In the first instance it was difficult to win the Army-Navy 'E' and by meriting a renewal, the management and employees have indicated their solid determination and ability to support our fighting forces by supplying the equipment which is necessary for ultimate victory.

The Navy Department extends to each and every man and woman of your company its hearty congratulations on their accomplishment and desires to express a fervent hope that future production will be even more outstanding.

Sincerely yours,

C. C. Bloch

C. C. BLOCH
Admiral, USN (Ret.)
Chairman, Navy Board for Production Awards

GENERAL RADIO COMPANY

30 STATE STREET - CAMBRIDGE 39, MASSACHUSETTS

BRANCH ENGINEERING OFFICES

90 WEST STREET, NEW YORK CITY 6

1000 NORTH SEWARD STREET, LOS ANGELES 38, CALIFORNIA

PRINTED IN U.S.A.