THE General Radio EXPERIMENTER

VOLUME XVIII No. 9 FEBRUARY, 1944

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

Also

IN THIS ISSUE

MOTOR SPEED CONTROL WITH THE VARIAC

AN IMPORTANT USE of the Variac is the control of speed on fractional-horsepower a-c motors. Successful use of the Variac in this application, however, depends upon both the type of motor and the type of load, and it is important that this be kept in mind when considering the Variac as a speed control.

Repulsion and Series Motors

Repulsion and series motors are by far the easiest to control through voltage variation. The speed of each of these types is sensitive to voltage, and control can be obtained over a wide range of speed for practically any type of load. The curves of Figures 1 and 2 show typical speed-voltage characteristics for these types of motors with a belt-driven load. The repulsion type used was a ¼ hp and the series type a $^1/_{15}$ hp. The characteristics of these two motors are somewhat similar to those of the d-c series motor.

Induction Motors

In general, speed of an induction motor cannot be controlled by voltage. The motor tends to run at a speed approaching the synchronous value determined by the number of poles on the stator winding. Speed can be varied only by changing slip, and, for belt drives and other fairly constant loads, a reduction of voltage changes the slip only slightly until the breakdown point is reached and the motor stalls.

One outstanding exception, however, is found for fan loads, where the effective load varies greatly with the speed. Some types of induction motors can be made to operate satisfactorily for this service with Variac control, and stable operation can be had on a wide range of speeds. This is discussed below.

www.americanradiohistory.com

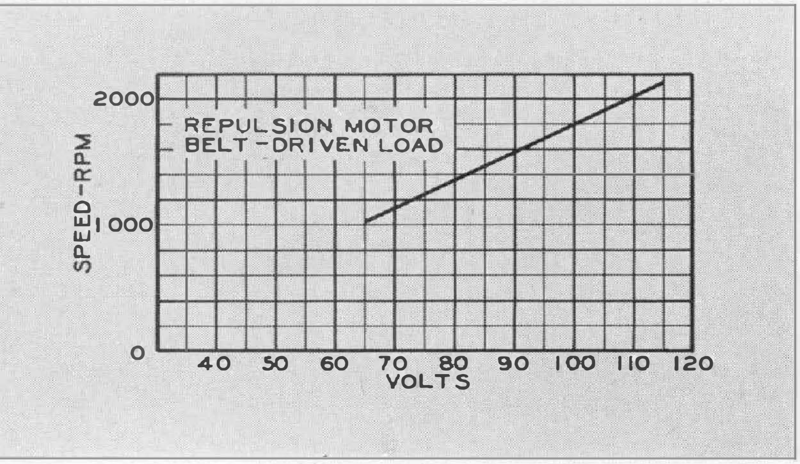


FIGURE 1.

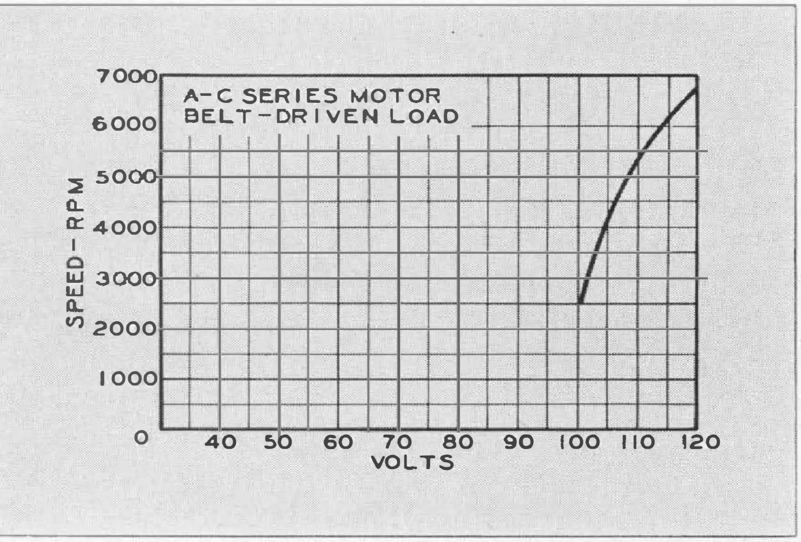


FIGURE 2.

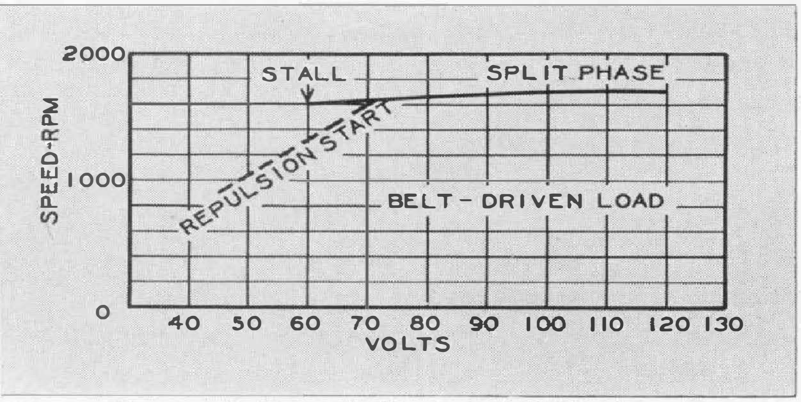
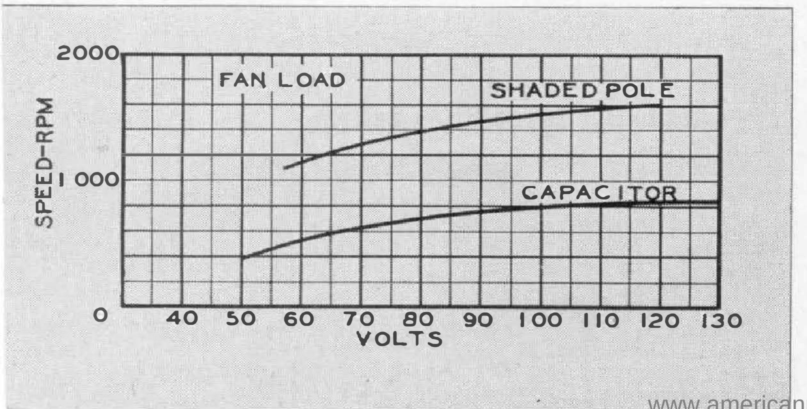


FIGURE 3 (above); FIGURE 4 (below).



Split Phase

The split phase motor with automatic cut-out, in particular, is a type that is not adapted to speed control by voltage variation.

This motor has an auxiliary winding spaced 90 electrical degrees from the main winding. Ordinarily, this winding is used only for starting and is disconnected by an automatic switch when running speed is attained. After the auxiliary winding is disconnected, the speed tends to approach synchronous speed, the slip depending mainly upon the load. Voltage variation has little effect upon speed. The speed of a split phase motor is usually changed by switching taps on the stator winding, which effectively changes the number of poles, and also provides two or more values of synchronous speed. The speed-voltage characteristic of a $\frac{1}{3}$ hp split phase motor controlled by a Variac is shown in Figure 3.

Repulsion-Start Induction Motors

The repulsion-start induction motor is provided with an inducing winding, commutator, and brushes, by means of which the rotor is brought up to running speed by operation as a repulsion motor. The commutator bars are then short-circuited by an automatic switch, and the motor runs as a single-phase induction motor. While the motor can be Variac-controlled during the starting period when it is running as a repulsion motor, or whenever the voltage is reduced to the point where the repulsion-start system cuts in, the range of speed variation is necessarily low, and, if the repulsion winding is not designed for continuous service, excessive heating may occur. Figure 3 shows a voltage-speed curve for a $\frac{1}{3}$ hp repulsion-start type of motor.

Copyright, 1944, General Radio Company,
Cambridge, Mass., U. S. A.

www.americanradiohistory.com

Capacitor and Capacitor-Start Motors

Split phase operation is often obtained by using a capacitor in series with the auxiliary winding. If the auxiliary winding is opened by an automatic switch when running speed is reached, the motor is called a capacitor-start motor. If the auxiliary winding is connected permanently, the motor is called a capacitor motor.

The capacitor-start type cannot be controlled by a Variac. The capacitor-type can be, particularly if the load is a fan or blower.

Speed Control for Fans and Blowers

The torque required to drive a fan or blower is a function of speed, and, consequently, stable operation can be had with induction motors operating at high values of slip. Capacitor motors and shaded pole motors are often used for this service.

With the shaded-pole motor, speed control over a considerable range can be obtained, as shown in Figure 4. For low speeds, however, it is often necessary to start at a fairly high voltage and then reduce the voltage to a lower value for running.

The capacitor motor can be controlled by varying the voltage on both the main and auxiliary windings simultaneously. Some capacitor motors, however, are so designed that a fixed voltage can be applied to the auxiliary winding and a variable voltage to the main winding. Figure 4 shows the speed-voltage characteristic obtained with a typical capacitor motor driving a squirrel-cage fan when the voltage on both windings is varied.

A split-phase motor can be controlled in the same way, if it is designed for operation with the auxiliary winding permanently connected. While a few of these are used for fan service, they are not as common as the shaded-pole and capacitor types.

Within each basic type of motor, the designer can vary many factors to produce a motor suited to any particular job. To cover the complete range of possibilities is considerably beyond the scope of this article. With any given type of motor the speed-voltage characteristic is, of course, dependent upon the torque-speed characteristic of the load as well as that of the motor itself. The speed of some types of motors is voltage-sensitive, however, and that of others is not, and this should be considered first when the use of a Variac for motor speed control is contemplated.

CONTINUOUS INTERPOLATION METHODS

PART II

●**LAST MONTH'S ARTICLE** outlined the various methods of continuous interpolation. Method 1, Direct Interpolation, and Method 2, Direct Beating, were considered in detail. This portion of the article discusses Methods 3, 4, and 5.

Method 3: Direct Beating

This method, utilizing the higher of the two beat frequencies, $f_x - nf_s$ or $(n + 1)\ f_s - f_x$, is adaptable to high frequency measurements because of the limitation of the interpolator range to $f_s/2$ to f_s. For example, with a standard frequency of 1 Mc, the lower beat frequency (Method 1) ranges from 0 to 0.5 Mc; the higher (Method 2) ranges from 0.5 to 1.0 Mc.[4]

For frequencies of these magnitudes, a broadcast receiver can be used for an interpolator, readings being taken from the receiver calibration. For improved accuracy, the beat frequency can be compared with a lower standard frequency, the difference frequency in the receiver output being measured by an interpolation oscillator (as in Method 1).

In common with other methods, difficulties are encountered when f_x lies near a standard frequency, giving a difference frequency to the next higher or next lower harmonic which is near to the value of the standard frequency. Thus two frequencies are impressed on the receiver instead of one.

Method 4. Sliding Harmonics

To reduce the difficulties enumerated above and to simplify operation, this system is designed so that no beat difference frequency is used and the only beat utilized is solely for matching, — zero beat. The interpolator control operates on all frequencies simultaneously, so no selection of "lower" or "higher" beat frequency differences and no measurement of any beat frequency difference is required.

The system illustrated can be set up as follows: The standard consists of a 950 kc crystal oscillator, in terms of which all measurements are made and against which the interpolator can be calibrated or checked. The interpolator consists of a 50 to 60 kc variable frequency oscillator, straight line, direct reading calibration. The scale has 1000 divisions, giving 10 cycles per division.

The standard and interpolator outputs are impressed on a modulator and the upper side frequency is selected by a filter in the modulator output. This filtered output is of 1000 kc, when the interpolator is set at zero on the dial (50 kc) and can be varied up to 1010 kc at 1000 on the dial (60 kc), a total range of one percent. Since there are 1000 divisions, each division is 0.001 percent or 10 parts per million.

This output frequency is used to control one or more multivibrators. A one-megacycle multivibrator, with a special output amplifier, provides harmonics of usable magnitude up to 200 Mc. This harmonic output is utilized in connection with a heterodyne frequency meter having a range of 100 to 200 Mc, calibrated at each megacycle.

The system is particularly intended, as described, for the measurement of frequencies in the range from 100 to 1000 Mc (approximately). Through the addition of a second multivibrator, 0.1 Mc and the use of a Heterodyne Frequency Meter covering 10–20 Mc, measurements in the range from 10 to 100 Mc could be made.

Now, with the interpolator dial at zero, the output frequency $(f_s + f_i)$ is exactly 1 Mc and the harmonic frequencies of the multivibrator are all multiples of 1 Mc. Thus the heterodyne frequency meter can be checked at every point on its scale. If the interpolator dial is set at 1000, each harmonic frequency is increased by 1 percent. At the 100th harmonic this means that the frequency has been raised from 100 Mc to just 101 Mc. Also, complete coverage over this interval has been obtained. For any higher harmonic, the 1-percent range exceeds the difference between the given harmonic and the next higher one. Consequently complete coverage of the entire range from 100 to 200 Mc is assured.

---

[4] "An U.H.F. Measuring Assembly," S. Sabaroff, PROC. I.R.E. 27–3, p. 208, March, 1939.

www.americanradiohistory.com

To make a measurement, the heterodyne frequency meter is set to zero beat against f_x, either on the fundamental or a harmonic. With the heterodyne frequency meter at this setting, the interpolator dial is advanced from zero until the first beat is heard between a multivibrator harmonic and the frequency meter. This beat is set to zero. The unknown frequency is then

$$f_x = nf_s(1 + \Delta) = nf_s + nf_s\Delta,$$

where Δ is given directly by the interpolator dial, on pointing off 5 decimal places. The used harmonic frequency of the multivibrator is identified at once from the dial of the frequency meter.

If the frequency being measured is slightly above 162 Mc and the interpolator dial reading is 276 divisions, the frequency is $162 + 162 \times 276 \times 10^{-5} = 162 + 0.447 = 162.447$ Mc.

Since the frequency change to move any harmonic up to the position of the next higher is always just one megacycle, the number of divisions on the interpolator dial necessary to accomplish this can be determined in advance and tabulated. The fraction of a megacycle involved in measuring any frequency is then [(observed number of divisions)/(divisions for 1 Mc)] × 1 Mc.

The question can be raised as to what would happen if the heterodyne frequency meter calibration were in error by 1 Mc. The calibration can be positively checked at both ends of the scale. With the interpolator dial at zero, set the heterodyne frequency meter to the point marked 101 Mc and set to zero beat. Leaving the heterodyne-frequency meter at this point, advance the interpolator dial to 1000 divisions. At this setting zero beat should again be obtained. If no beat is heard, or if the beat is heard before the dial has been advanced the full 1000 divisions, the heterodyne frequency meter is not set to 101 Mc but to a point above, or below, this value respectively. A similar check can be obtained at 202 Mc.

Method 5. Cathode-Ray Oscilloscope

Through the use of a cathode-ray oscilloscope, interpolations can be made over an extended frequency range, *without the use of harmonics*. The working upper limit depends principally on the ability to open out the pattern.

The basic method is to combine the unknown frequency f_x with a second known and adjustable frequency, from an interpolating oscillator, f_i, so that the difference in frequency, $f_x - f_i$, is a multiple of a third, known and fixed frequency f_s.[5]

The setup is extremely simple. The unknown, f_x, and interpolator, f_i, oscillators are effectively connected in series to the vertical deflection plates of a cathode-ray oscilloscope. The standard frequency source, f_s, is connected to the horizontal deflection plates, and should be capable of supplying a large voltage so that high-frequency patterns can be opened out for easy viewing. The pattern produced by the two voltages in series, as viewed against a linear sweep, is indicated in the sketch, for unequal and equal amplitudes. This pattern appears similar to a modulated wave, but it differs in several important respects.[6] The important feature, for present purposes, is that the frequency of the *envelope* is that of the *difference of the two applied frequencies.*

For illustration, assume that a standard frequency of 1000 cycles and an interpolation oscillator having a range of 11,000 to 11,500 cycles, calibrated at

---

[5] "An Interpolation Method for Setting Laboratory Oscillators," F. R. Stansel, Bell Labs. Record, 1940, 19, p. 98 (Nov. 1940).

[6] See, for example, "Applied Electronics," E. E. Staff, M.I.T., John Wiley & Sons, p. 699 et seq.

www.americanradiohistory.com

every cycle, are available, and that a laboratory oscillator is to be set to a frequency of 323,383 cycles.

The interpolator oscillator is set to 11,383 cycles by its calibration. The oscillator to be adjusted is then set to 323,000 cycles, as read from a previous calibration. This adjustment need not be precise — it is to insure that the final result will not be in error by one, or more, multiples of 1000 cycles.

The oscillator frequency is then increased from 323,000 cycles. The envelope of the combined wave on the cathode-ray tube is that of the difference of the two oscillator frequencies, but *no pattern appears until this difference is made a multiple of 1000 cycles.* This occurs when the oscillator frequency has been increased from 323,000 cycles to 323,383 cycles. At this frequency the difference of oscillator and interpolator frequencies is 323,383 − 11,383 = 312,000 cycles, which is an integral multiple of the standard frequency of 1000 cycles, and the envelope pattern stands still. (The individual oscillations of the "carrier" wave would not be seen because of the high frequency.)

Actually two patterns appear, the "front" and the "back" traces, as sketched. These can be separated by phase shifting networks, but this is not usually necessary.

The error, *in cycles*, in making this adjustment is numerically equal to the error in cycles in setting the interpolator frequency. This error can be made very small, so that the method is capable of high accuracy.

If the oscillator is set at some frequency, to be measured, the interpolator is varied until the pattern appears and is made stationary. The frequency increment is then read from the interpolator scale, the appropriate multiple of the standard frequency being identified from the oscillator calibration.

In the example an interpolator frequency of 11,383 cycles was used, but patterns can be obtained with any frequency which gives a multiple of the standard frequency when subtracted from or added to the desired frequency. For example, the frequency of 323,383 cycles gives a pattern for interpolation oscillator frequencies of either 11,383 (11,000 + 383) or 10,617 (11,000 − 383). The interpolator oscillator consequently needs to have a range of only one-half the standard frequency to obtain complete coverage.

The interpolator frequency does not have to be as low as 11,000 cycles, but may be of the order of the unknown frequency. A high interpolator frequency has the advantage of lowering the frequency of the envelope and hence the pattern is easier to spread out. The absolute accuracy of a high frequency interpolator is usually less, so high accuracy demands the lower frequency.

Using an interpolator of 11,000–11,500 cycles range, measurements can be made to within a cycle to above one megacycle. To extend the frequency range, a higher frequency interpolator, say 30–35 kc, can be used with a 10 kc standard, with a somewhat larger error.

For convenience the scale of the interpolator is marked only in frequency increment, 0–500 cycles for the range 11,000 to 11,500. A second scale marked 500–1000 cycles is convenient when the required increment is negative, avoiding subtraction.

—J. K. CLAPP

www.americanradiohistory.com

Summary

Method 3 : Direct Beating

The standard frequency nf_s and the unknown frequency f_x are impressed on a high frequency receiver, which is tuned to accept both. The *higher* beat frequency difference is obtained in the receiver output and is measured by tuning of the low frequency receiver (or by comparing with a suitable standard frequency in this low-frequency receiver, as previously described). The beat frequency difference lies between $f_s/2$ and f_s.

$$f_x = nf_s \pm f_b$$

Principal Limitations are:

(*a*) Standard frequency harmonics must be of usable magnitude in region around f_x.
(*b*) The frequency of the used harmonic nf_s must be determined.
(*c*) The sign of the beat frequency must be determined.
(*d*) The over-all accuracy depends on the calibration of the low frequency receiver.

Principal Advantages are:

(*a*) A high frequency standard can be used.
(*b*) The low frequency receiver, or interpolator, range is from $f_s/2$ to f_s, instead of from 0 to $f_s/2$ (Method 2); the interpolator is therefore more easily designed.
(*c*) Improved accuracy can be obtained by comparing f_b with a suitable frequency from the standard, in the low frequency receiver.

Method 4. Sliding Harmonics

The frequency f_x is impressed on a detector with the output of the variable harmonic standard. The frequency f_s is then increased to a new value f_s' such that $nf_s' = f_x$ (zero beat). From the standard controls, the change $nf_s' - nf_s$ is known. Then

$$\begin{aligned} f_x = nf_s' &= nf_s(1 + \Delta) \\ &= nf_s + nf_s\Delta \end{aligned}$$

where f_s is the known, fixed, standard frequency and Δ is the *fractional* change in f_s required to make $nf_s' = f_x$.

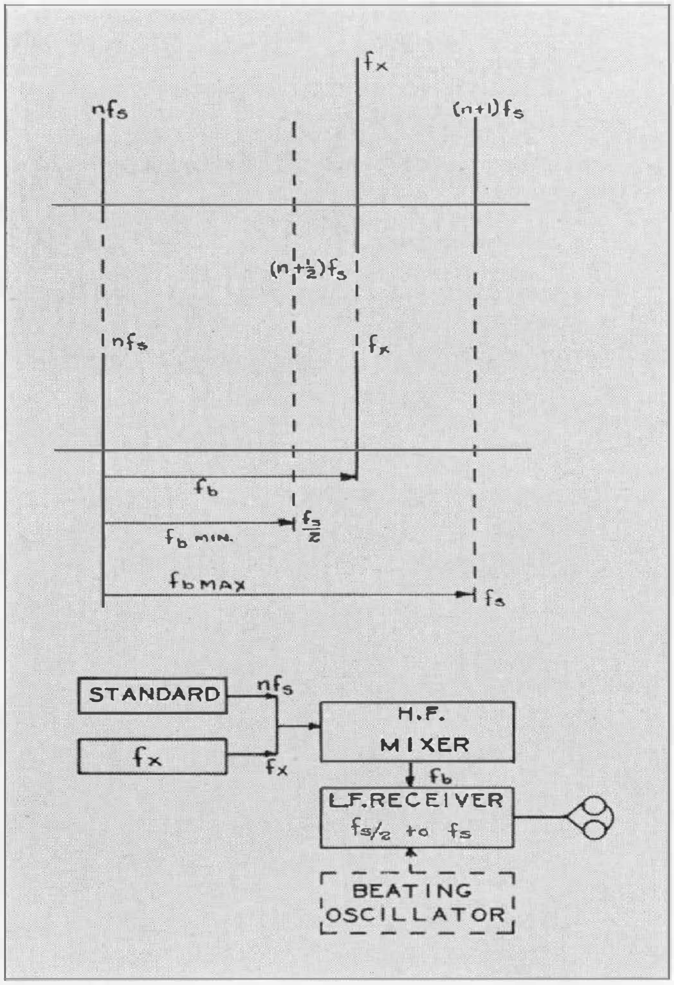
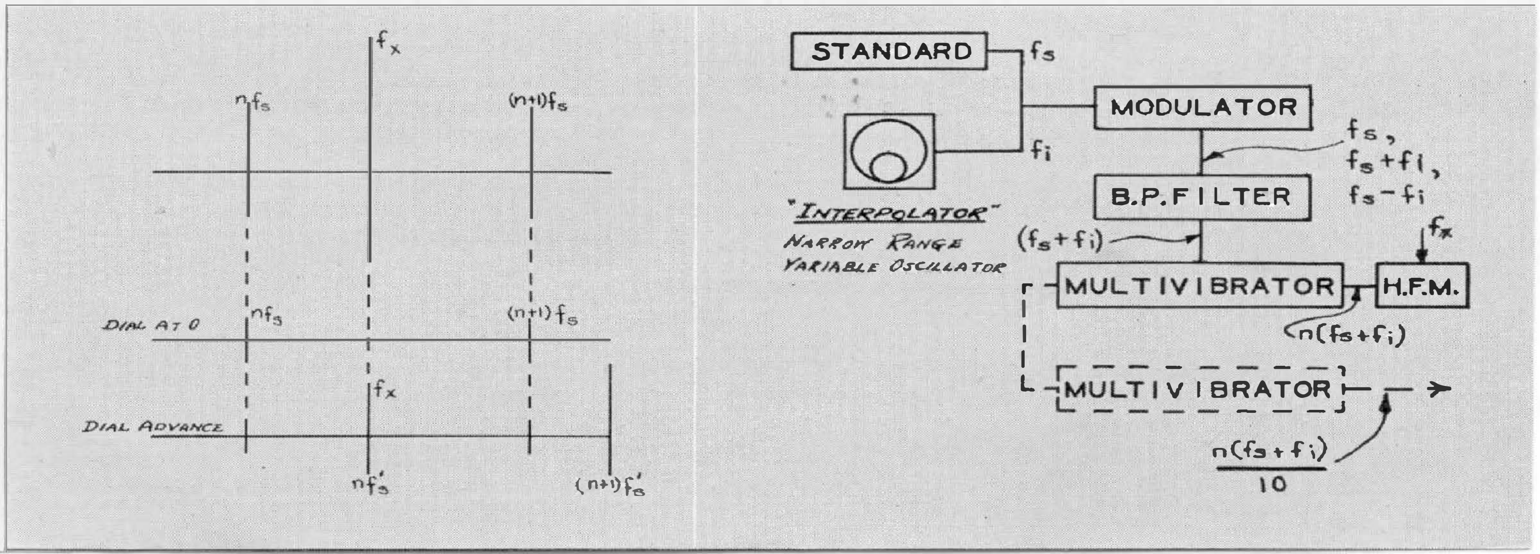


FIGURE 4. Interpolation and functional diagrams for Method 3.

Principal Limitations are:

(*a*) The variable frequency harmonics must be of usable magnitude in region around f_x.
(*b*) The frequency of the used harmonic must be determined.
(*c*) Result is on a fractional basis (not in cycles directly) unless added equipment is used.
(*d*) Accuracy of the order of 25 parts per million; can be greatly improved with added equipment.

FIGURE 5. Interpolation and functional diagrams for Method 4.



Principal Advantages are:

(*a*) Only one zero beat setting is required for a measurement.

(*b*) A wide measurement range is covered by a narrow range oscillator.

(*c*) The full range of the variation control covers 1% or less of the measured frequency.

(*d*) The sign of the frequency increment is always positive.

(*e*) Wide-pass circuits, filters, etc., are avoided at f_x; only a detector for setting zero beat is necessary.

Method 5. Cathode-Ray Oscilloscope

The three frequencies f_x, f_i, and f_s exist physically, where f_i = frequency of an interpolation oscillator, f_s = standard frequency.

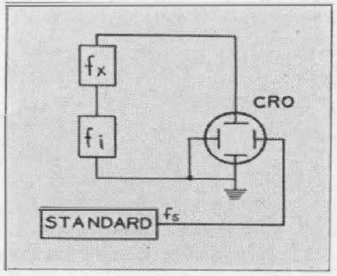


FIGURE 6. Functional block diagram for Method 5.

The used multiple nf_s of the standard frequency does not exist physically; neither does the frequency difference $f_x - f_1$. These relationships are established by patterns on the oscilloscope screen.

The interpolator frequency is adjusted so that $f_x - f_i = nf_s$.

Then $f_x = nf_s + f_i$.

Principal Limitations are:

(*a*) The frequency f_x must be stable enough to observe a pattern.

(*b*) The used multiple nf_s of the standard must be identified.

(*c*) The sign of the increment must be determined.

(*d*) Absolute accuracy depends on oscillator f_i and accuracy of setting.

Principal Advantages are:

(*a*) No harmonics are necessary.

(*b*) Extreme simplicity of equipment and operation.

(*c*) Wide ranges of f_x can be covered with suitable choice of f_s and f_i.

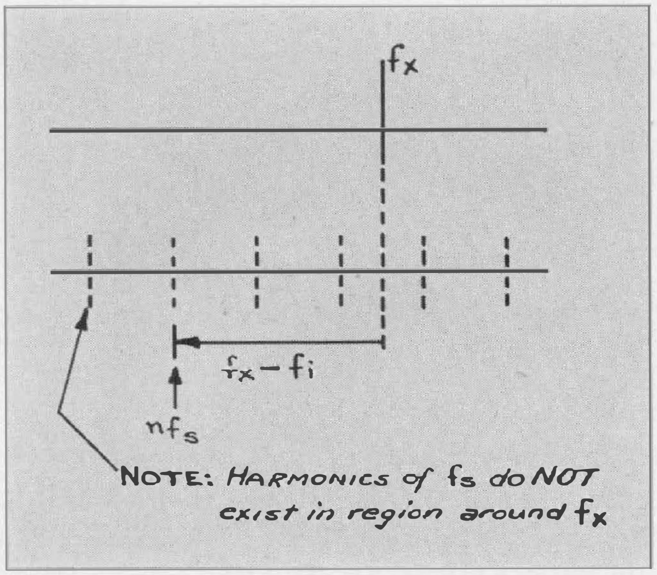


FIGURE 7. Interpolation diagram for Method 5.

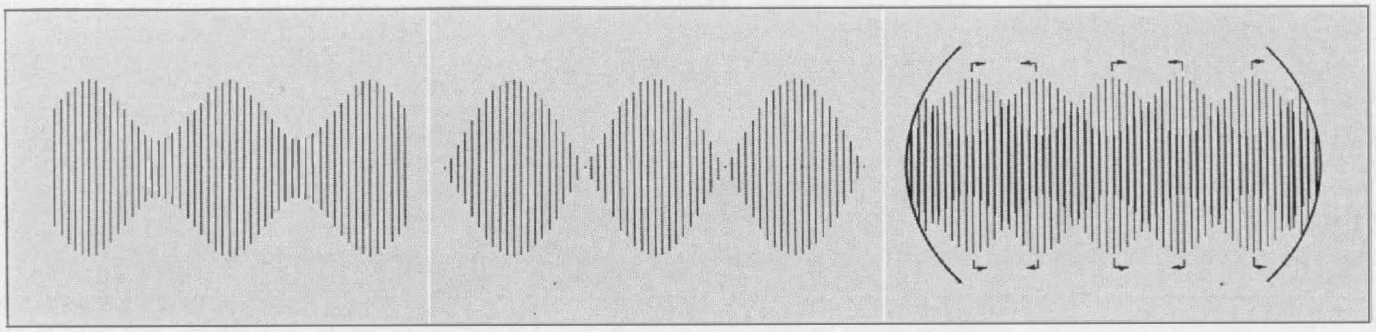


FIGURE 8. Patterns produced by two frequencies applied to one pair of plates of a cathode-ray oscillograph. Viewed against a linear sweep, two frequencies of unequal amplitude appear as shown at the left; with equal amplitudes as shown at the center. The envelope frequency is the difference of the two frequencies.

At the right is shown the pattern produced by two frequencies applied to the vertical deflecting plates, viewed against a sinusoidal sweep of large amplitude. When the pattern is nearly stationary, one envelope moves slowly in one direction, while the other moves slowly in the opposite direction, as indicated by the arrows.

GENERAL RADIO COMPANY
30 STATE STREET - CAMBRIDGE 39, MASSACHUSETTS

BRANCH ENGINEERING OFFICES
90 WEST STREET, NEW YORK CITY 6
920 SOUTH MICHIGAN AVENUE, CHICAGO 5, ILLINOIS
1000 NORTH SEWARD STREET, LOS ANGELES 38, CALIFORNIA

www.americanradiohistory.com