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Accuracy in *-hp-* Voltmeters and Oscillators

ONE of the matters most interesting to visitors at the *-hp-* plant has been the equipment and procedures used to calibrate *-hp-* voltmeters and oscillators. Often, the visiting customer has been able for the first time to verify the high degree of accuracy of his *-hp-* instrument.

Calibration of the wide line of *-hp-* oscillators and voltmeters is an extensive operation. *-hp-* oscillators require calibration from frequencies below 0.01 cps to more than 10,000 megacycles. *-hp-* voltmeters must be calibrated from less than 100 microvolts to 300 volts—even to 25 kilovolts with dividers. Frequency-wise, *-hp-* voltmeters must be checked from 1 cycle per second to frequencies above 700 megacycles. To insure that *-hp-* instruments are well within their rated accuracy under all conditions, a considerable amount of special equipment and techniques have been designed.

As each voltmeter and oscillator is received at the end of the assembly line, it is given a complete electrical and mechanical inspection before power is ever applied. This inspection reveals any shorts, unsoldered connections, loose components, or errors that may have occurred in the wiring. Power is then applied and a rough check is made to determine that each instrument is functionally sound. After this, the instrument is stored in a rack and allowed to operate or heat run for at least 24 hours before the first calibration work is begun. Such heat runs are helpful in showing up weak components and in stabilizing others.

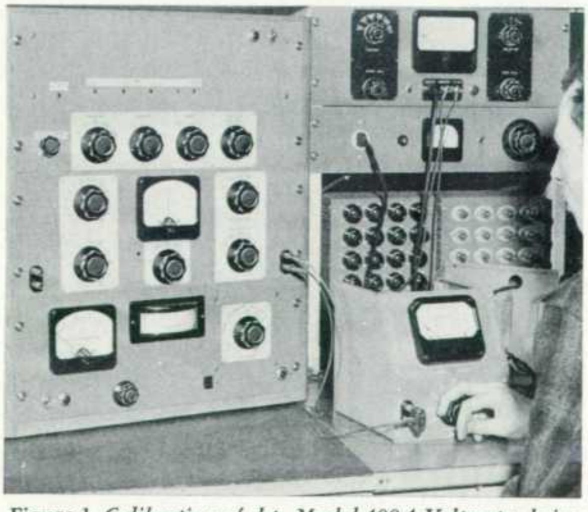
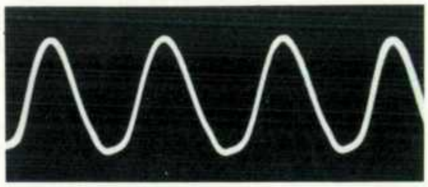
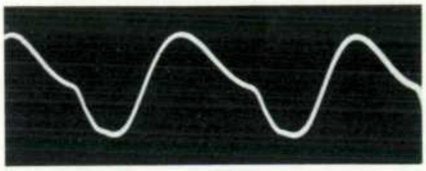


Figure 1. *Calibration of -hp- Model 400A Voltmeter being checked against special standard voltage generator.*

At the end of the heat run period, the instruments are sent to the calibration department, which is divided into sections that specialize in the calibration of one type of instrument. In the voltmeter section, each production voltmeter is tested and the necessary adjustments are made to fix the voltmeter readings within specified accuracy. In this calibration process, elaborate precautions are taken to avoid errors arising from waveform irregularities. To avoid possibility of such errors, special standard voltage generators are necessary so that peak-reading, average-reading or rms type meters can be calibrated. Voltmeter accuracy is determined by comparing the voltmeter readings with known voltages generated by these standard generators. A number of different special standards are provided in the department for calibrating different types of voltmeters. A typical standard generates accurate voltages from 300 microvolts to 300 volts, a-c as well as d-c. Other standards pro-



(a)
500 kc waveform



(b)
200 kc waveform

Figure 2. *Oscillograms of output waveform from representative r-f signal generators operating at low r-f frequencies.*

vide accurate voltages at frequencies up to more than 700 megacycles. All standards are designed to be highly flexible and many provide means for checking scales calibrated in volts or decibels. Each standard is checked several times daily against other standard instruments.

The calibration of a voltmeter logically divides itself into two basic procedures. First, the instrument is calibrated for accuracy at a low audio frequency; then, the response is adjusted to maintain the specified accuracy at all frequencies within the range of the instrument. In order to be capable of performing each of these steps, the voltage generator is constructed with a high-level oscillator of pure waveform. The oscillator output is monitored by a standard meter of the dynamometer type whose accuracy can be referred to a standard cell. The high-level oscillator feeds into two attenuators. One is a high-precision wirewound attenuator used for checking basic accuracy of voltmeters. The second is a carbon resistor attenuator used for checking frequency response.

During the final portion of the calibration process, a record card is filled out for each instrument. On this card, readings are made of some 40 to 75 voltages, depending upon the voltmeter model. Also recorded are scale linearity, the effects of line voltage changes, etc. After the calibration is completed, the voltmeter is turned off and later periodically cycled by turning power on and off a number of times during an extended period. The instrument is then tested again by a different test engineer, and the readings previously recorded on the instrument card are rechecked to determine that the instrument is stable and without drift. After passing this inspection, the voltmeter is sent to the shipping department and the record card retained in permanent *-hp-* files. If a change of calibration is found during the final inspection, the trouble is sought out and corrected and the entire calibration process repeated.

VOLTMETER FIELD CHECKS

Occasionally, the user of a voltmeter has need for checking the calibration of his voltmeter. If no standard generator of the type described above is available, field checking of voltmeters becomes difficult, especially at the higher frequencies, because of the need of obtaining pure sinusoidal voltages whose values are known precisely.

At low frequencies in the range below a few hundred cycles, the calibration of a voltmeter can be checked against a dynamometer or other type standard meter. Such a check does not reveal the performance of the voltmeter at high frequencies, but does permit the basic sensitivity of the instrument to be measured. In all *-hp-* voltmeters one or more controls, described in the instrument manual, are provided to adjust the basic low-frequency sensitivity of the instrument.

Probably the most practical method for checking the accuracy of an *-hp-* voltmeter above the low-frequency range is to compare readings of the voltmeter in question with those given by one or more other *-hp-* voltmeters. When other *-hp-* voltmeters are not available for comparison checking, the satisfactory solution is to ship the voltmeter to the factory or to an authorized station[1] for repair. Experience has shown that this step, taken promptly, saves time and money in the long run.

An alternate method that frequently comes to mind for checking the high-frequency performance of a voltmeter is to compare the voltmeter readings with the calibrated output of an r-f signal generator. However, there are serious deficiencies in the use of the signal generator method at low r-f frequencies and in general it is not recommended. There are several reasons for this. First, the accuracy of the power output monitor in r-f signal generators most often is poorer than the accuracy of the *-hp-* voltmeter. Second, the frequency response of signal generator monitors is usually considerably less constant than the frequency response of the voltmeter. Several design problems in the usual signal generator contribute to the variations in response of its monitor. For one thing, the signal generator monitor frequently does not monitor the power applied to the output attenuator but rather the level in the preceding stage. Thus, variations in coupling between the oscillator or amplifier stage and the attenuator are not indicated by the monitor.

In addition to these variables, the waveform generated by signal generators at low r-f frequencies is seldom good. The usual reason for this is that such frequencies lie in the lower portion of the generator's frequency range and involve the use of tuned circuits having adverse L/C ratios. As a result, the output waveform is distorted to an extent plainly noticeable to the eye. Oscillograms[2] of the output of typical signal generators in the lower r-f range are shown in Figure 2. Distortion of

[1]Such stations are located at Alfred Crossley & Associates, 4501 Ravenswood Ave., Chicago 40, Illinois, and at Burlingame Associates, 103 Lafayette St., New York 13, New York.

[2]These oscillograms were made from non *-hp-* generators having L-C circuits. No *-hp-* signal generators are produced for the frequency range under discussion.

this magnitude can easily result in a monitor error of 10%, especially if the monitor circuit is that of a peak-reading voltmeter, as is often the case.

On the other hand, most *-hp-* voltmeters are average-reading instruments calibrated with a pure sine wave. The error on distorted sine waves given by peak-reading meters is invariably much greater than that given by the average-reading meter.

HIGH-FREQUENCY VOLTMETER

Testing of the *-hp-* Model 410 700-megacycle voltmeter presents special problems. Insuring the accuracy of this instrument up to its 700-megacycle limit requires the use of a voltage standard built especially for the purpose.

Model 410 voltmeters are first calibrated with a modified version of the procedure used to calibrate lower frequency voltmeters, and the accuracy of the d-c and ohmmeter circuits in the instrument are also checked. Then, the voltmeter is connected to a special high-frequency voltage standard that checks accuracy out to the limit of the voltmeter. Basically, this voltage standard consists of a concentric-line oscillator feeding a 50-ohm line. A special fitting similar to the Model 455A coaxial "T" connector is connected into the line as a means of applying the known voltage to the probe of the voltmeter.

Measurements are also made of the voltmeter's input capacity, input resistance at low and high frequencies, and other effects of transit time of the high-frequency diode used in the voltmeter probe. Substandard diodes or probes encountered during this checking process are weeded out.

CALIBRATION OF OSCILLATORS

Oscillators, as their assembly is completed, are given preliminary mechanical and electrical inspections much like those given voltmeters. Oscillators also are placed in movable racks to heat run, a standard *-hp-* instrument practice. After the heat-run period, oscillators are sent to the oscillator section of the calibration department, where preliminary adjustments are made and the dial calibrated. Both pre-calibrated and hand-calibrated dials are used, hand-calibrated dials being favored where high resolution or maximum accuracy are desired. For oscillators that have a high-frequency limit of less than a few megacycles, the dial calibration is made with the aid of lissajous patterns on an oscilloscope. A number of standard frequencies are available at each test engineer's position for use in this calibration.

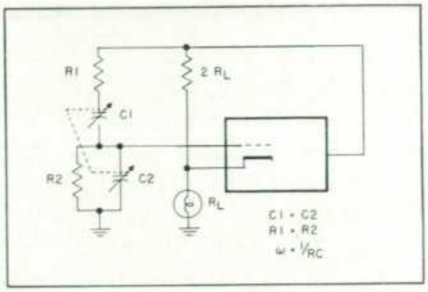


Figure 3. *Basic circuit of RC oscillator.*

The adjustment and calibration of the RC oscillator is an easy and quick process once the proper procedure is known, but is difficult when the procedure is not known. Fortunately, once the instrument has been aligned at the factory there is no further need in any maintenance procedure for again aligning the circuit. However, instrument damage and other infrequent difficulties do bring up an occasional urgent requirement for re-alignment. A discussion of the engineering considerations in aligning the circuit is included here as a matter of engineering interest and for reference purposes in the event of an urgent situation requiring quick action.

A basic circuit for the RC oscillator is shown in Figure 3. This circuit, as used in *-hp-* oscillators, is designed so that $C_1=C_2$ and so that $R_1=R_2$. The frequency of oscillation of the circuit is then $\omega=1/RC$. If the constants of the network are unequal, the circuit may still oscillate, but will do so at a frequency $\omega=1/(C_1C_2R_1R_2)^{1/2}$. However, if the network constants do not retain a fixed relation as frequency is changed, the feedback voltage applied to the grid will vary, leading to dips and peaks in the generated voltage.

The need for alignment of the circuit arises from the fact that stray capacity exists from the tuning capacitor to the chassis. The tuning capacitor in the frequency-determining network is usually a four-gang variable type, two sections of which are connected in parallel to form one of the network capacities and the remaining two sections connected in parallel to form the second network capacity. Sometimes two or more such four-gang units are used.

The manner in which stray capacity appears in the network is illustrated in Figure 4. These strays are typically in the order of 30 to 50 mmf and are of greatest significance when the main tuning capacitor is set for minimum capacity (about 20 mmf).

Effectively, most of the stray capacity adds to the grounded sections of the main tuning capacitor, seriously modifying the network relationships.

In production equipment, the

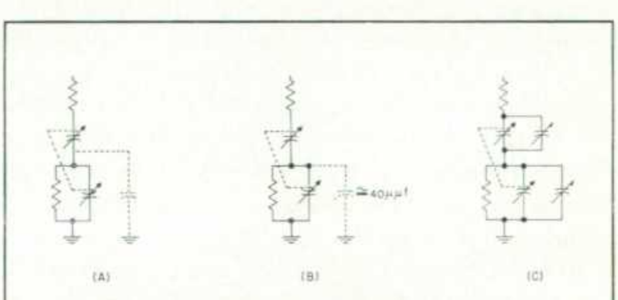


Figure 4. *Diagrams illustrating unbalance of frequency-determining network caused by stray capacity.*

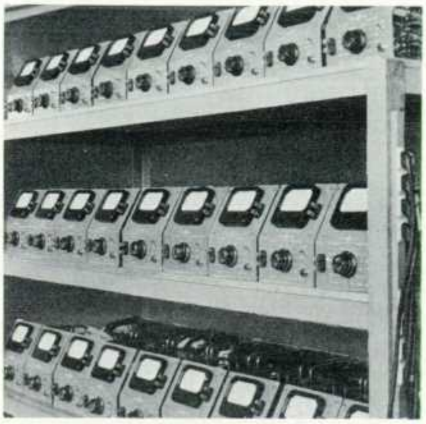


Figure 5. *-hp- Model 400C Voltmeters on heat run. Mobile racks with built-in power outlets facilitate handling of instruments.*

strays are absorbed by use of trimmer capacitors (Figure 4c). In essence, the alignment procedure consists of adjusting these trimmers so that the capacities in the network are made equal. When hand-calibrated dials are used, only one trimmer is necessary. Pre-calibrated dials, however, are designed on the basis of a fixed maximum: minimum capacity ratio, necessitating the use of two trimmers for best accuracy.

The recommended method for adjusting the trimmers is first to set the tuning dial precisely to a frequency at the higher frequency end of the dial. This should be done on one of the medium frequency ranges to avoid possible phase shift in the amplifier portion of the oscillator. For most *-hp-* oscillators where the dial calibration ends at "200," the suggested dial setting for alignment is 2000 cps.

The next step is to adjust the trimmers until the proper frequency (say 2000 cps) is generated, while at the same time the generated voltage is equal to the voltage generated at the low-frequency end of the same frequency band. For one not familiar with this technique, the adjustment is difficult to make at first, for there is an indefinitely large number of settings of the two trimmers that give the desired frequency at the wrong voltage and vice versa. One experienced with the technique, however, can adjust the trimmers in a matter of seconds.

The tuning capacitors themselves are aligned at the factory to have the proper curve. If the tuning capacitor becomes accidentally bent, as sometimes occurs, the capacitor can be aligned by hand to cause the generated frequency to agree with the calibration of the tuning dial. Alignment of the capacitor itself consists of bending the split end plates by hand, starting at the minimum capacity end of the rotor and progressing toward the maximum capacity end, making all sections have equal curves. This procedure requires care and experience, however, and is not recommended except as an emergency measure.

The resistances in the frequency-determining network also influence the alignment of the RC oscillator. However, it is rarely necessary to consider these resistors in a re-alignment procedure. The resistors used in the network are highly stable, being of the deposited-carbon type. From the standpoint of accuracy over a long period of time, these resistors give excellent performance. There are numerous cases where such resistors, installed when the deposited-carbon type first became available some five years ago, have remained sufficiently stable that the oscillator calibration is still well within original specifications.

There are instances, however, where a frequency-determining resistor has suddenly shifted value by a large percentage, apparently because of a leakage path inside the seal. Such a shift will cause one range of the oscillator to cease operating, or to operate unstably, or to develop serious dial error. The simplest method for correcting such a condition is to obtain a replacement range switch assembly from the factory. This assembly consists of a ceramic-insulated range switch with the frequency-determining resistors mounted on the switch body. The assembly is adjusted to the necessary precision at the factory and can usually be replaced without further adjustment.

LOW- AND HIGH-FREQUENCY OSCILLATORS

Calibration of low-frequency oscillators and low-frequency work in general have always been something of a special problem. When working at frequencies too low to permit the use of a long-persistence c-r tube, much time is consumed in making an accurate frequency check. Common methods for making such measurements have been to use an electro-mechanical counter and stop-watch or to use a recording meter.

More recently, however, the development of the *-hp-* Model 524A Frequency Counter[3] has introduced a substantial simplification into low-frequency measurements. Using this instrument, frequencies of 0.01 cps can be determined with the necessary precision by measuring the period of only 1 cycle of the unknown.

High-frequency oscillators whose frequency range is higher than a few megacycles are calibrated using beat-frequency methods. A flexible frequency standard that provides accurate spot frequencies up to 10,000 megacycles is used for this work.

—*Brunton Bauer* and *R. M. Deméré*

[3]A. S. Bagley, *The High-Speed Frequency Counter—A New Solution to Old Problems,* Hewlett-Packard Journal, Vol. 2, No. 5, January, 1951.

1951 WESTERN IRE CONVENTION

The annual combined Western IRE Convention and Pacific Electric Exhibit will be held this year in San Francisco, August 22-24. In addition to a number of interesting field trips and three days of technical sessions, the program includes the extensive electronic exhibit in which more than 130 exhibitors will participate.

The Hewlett-Packard exhibit will be located in booths 711 and 712. *-hp-* instruments to be exhibited include the new Model 202A 0.01 cps generator, the new waveguide measuring equipment, the Model 524A 10-megacycle frequency counter, and others. You are cordially invited to visit the *-hp-* booths, where a number of *-hp-* engineers will be on hand.