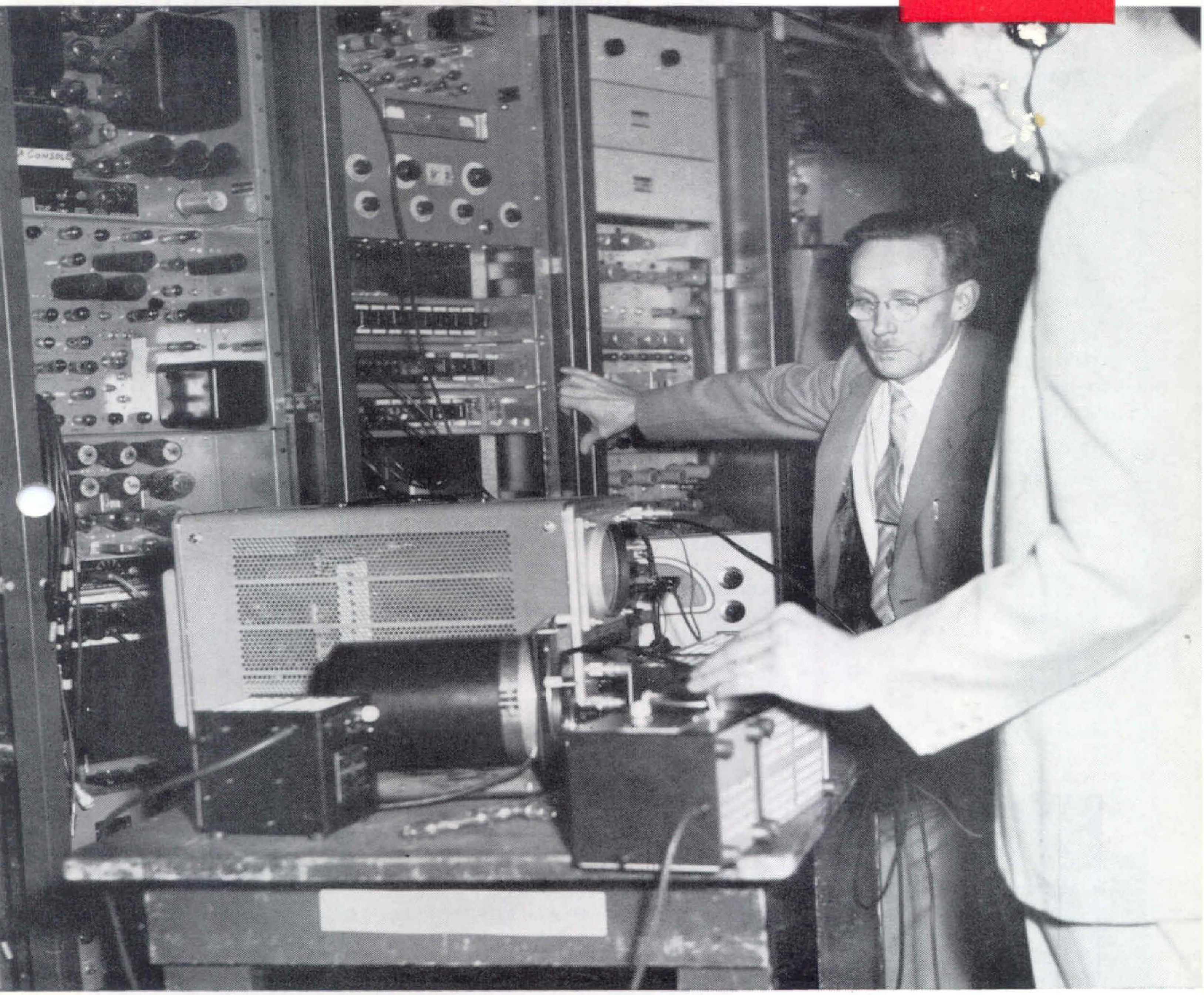
THE GENERAL RADIO
EXPERIMENTER



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Time/Frequency Calibrator

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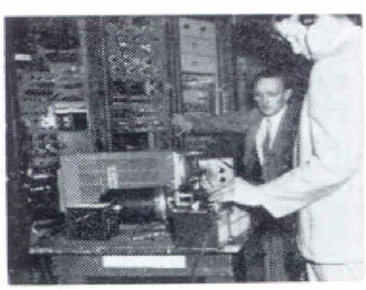
COVER



General Radio engineers C. A. Cady and W. P. Buuck measuring frequencies in a radio and television station with the Type 1213 Time/Frequency Calibrator.

A TIME/FREQUENCY CALIBRATOR OF IMPROVED STABILITY

The Unit Time/Frequency Calibrator, TYPE 1213,[1,2] is a unique instrument. Seldom have seven electronic tubes done so much in so small a package and at so low a cost. In less than ⅓ cubic foot it provides all the functions of a secondary standard.

The circuitry and the design of this compact little instrument have received a continuing attention, both in our own laboratories and among our customers, with the result that its performance has been periodically improved as new methods and components became available. The latest design, TYPE 1213-D, embodies a new quartz crystal and its associated oscillator circuit, together with an improved 10-1 Mc multivibrator. With these improvements, the short-time stability of the output frequencies is increased by a whole order of magnitude and is now better than 1 part in 10^7.

The new circuit and design features are described in this article; the balance of the instrument is identical with that described in reference 2.

[1]Robert B. Richmond, "The Unit Crystal Oscillator," *General Radio Experimenter*, February, 1952.

[2]R. W. Frank, F. D. Lewis, "The TYPE 1213-C Unit Time/Frequency Calibrator," *General Radio Experimenter*, June 1956.

BASIC CIRCUIT SYSTEM AND ITS FEATURES

Figure 2 is a block diagram of the redesigned instrument. The circuits consist of a 5-Mc oscillator and frequency doubler, which can be set against WWV by use of a radio receiver or against a local standard. Three multivibrators are used to produce the standard frequencies of 1 Mc, 100 kc, and 10 kc, which are available at a cathode follower for time calibration. The four standard frequencies also generate harmonic spectra which can then be fed to external systems for calibration or mixed with externally generated signals to produce a beat note within the instrument for the calibration of externally produced rf signals. Thus, the instrument can be used to:

1. Calibrate the time axis of oscilloscopes.
2. Calibrate receivers in frequency.
3. Control the timing of external systems.
4. Calibrate oscillators by either Lissajous figures or zero-beat techniques at any frequency from 10 kc to at least 1000 Mc.

Figure 1. Panel view of the Type 1213-D Unit Time/Frequency Calibrator with Type 1203-B Unit Power Supply.

5. Calibrate (and monitor the calibration of) high-frequency oscillators on any frequency to a high degree of accuracy. In this application a standard signal generator is first calibrated by the standard frequencies and then used to permit precise offset of the harmonic series.

The performance of this instrument hinges, as with any frequency standard, upon the short-term frequency stability of the oscillator. In most crystal oscillators the chief factor affecting the stability is temperature. To minimize frequency changes caused by temperature, two methods are available. One is the use of a temperature-controlled oven, the other the use of a crystal with an adequately low temperature coefficient of frequency.

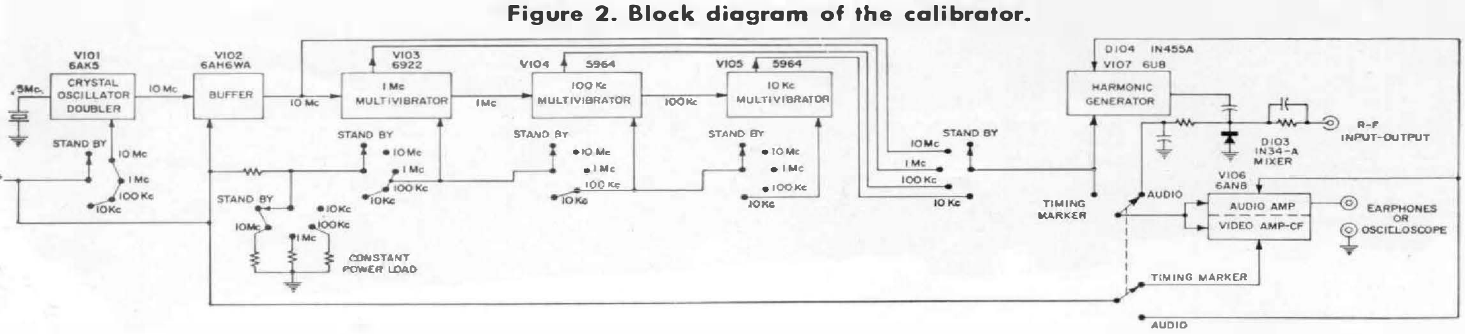
The conventional method is to control the temperature of the crystal. Unless elaborate ovens are used, however, the temperature of the crystal will cycle, resulting in cyclic variations of frequency. If cost or size is important, small ovens, usually with bimetallic thermostats, must be used. Temperature cycling is of the order of ±1°C, with resulting periodic frequency variations of as much as 1 ppm. The cycling effect is particularly undesirable when the unit is to be used as a transfer oscillator with reference to WWV, because the rate of variation can be as great as 1 ppm per minute.

The second method requires that the crystal have a low temperature coefficient of frequency over the entire contemplated range of operating temperature. Because there is no temperature cycling, there will be no rapid changes in frequency. After thermal equilibrium has been reached, the temperature of the crystal can be made quite stable over short periods of time. This short-term stability can be increased by the addition of thermal inertia to the crystal unit. Stabilities of a few parts in 10^8 per minute are possible with a temperature coefficient of 1 in 10^7/°C for the crystal.

Another design objective is the reduction of warm-up drift. This can be met if the crystal is kept at ambient temperature or if the crystal temperature rise is kept very low. The high component density of modern vacuum-tube instruments makes this difficult without the use of forced air cooling, and forced air cooling materially adds to size, noise, weight, and cost. The use of transistors would reduce the temperature rise, but at present their higher cost will not permit their use in low-priced instruments. As a consequence, the crystal should have a very low temperature coefficient, not only over its operating range, but in its warm-up range as well.

The crystal for the TYPE 1213-D Unit Time/Frequency Calibrator was designed for an operating range of 20-60°C. After thermal equilibrium has been reached, the crystal temperature is approximately 20°C higher than the ambient. This determines an operating ambient range for the instrument of 0°C to 40°C. Figure 4 shows the frequency-versus-temperature characteristics of the crystal. The solid line shows the ideal design characteristics. The

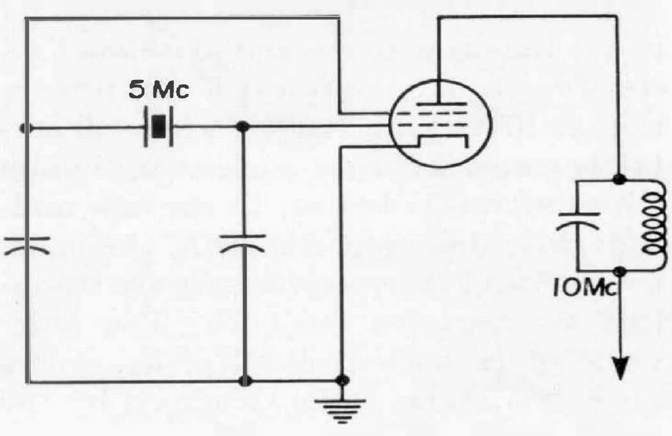
Figure 2. Block diagram of the calibrator.



dotted lines show the upper and lower extremes due to manufacturing tolerances. The temperature coefficient is small at temperatures down to 0°C, which fulfills the requirements for low warm-up drift from the lowest ambient temperature for which the instrument is operative. An additional requirement is that the crystal activity should be constant over the entire temperature range. This combination of requirements makes the manufacture of the crystal unit quite difficult; in fact, in some instances dips in activity near 0°C cannot be avoided. The activity is essentially constant above 5°C. This means that, if the instrument is turned on at 0°C ambient, the oscillator may not start until the crystal has warmed up to over 5°C. This will require about 5 to 10 minutes of warm-up time. Thermal equilibrium will be reached in about 1 hour. Thermal insulation around the crystal unit was added to eliminate rapid changes in crystal temperature caused by drafts. This improved the minute-to-minute stability by about one order of magnitude.

It has been pointed out above that the temperature rise at the crystal is about 20°C owing to the power dissipated within the instrument. In the switching provided for the several functions of the instrument, loads are substituted for circuits not active, so that the total power input to the instrument remains constant.

Figure 3. Elementary schematic of the crystal oscillator.



The plate supply of the oscillator is regulated to reduce the effect of ±10% line-voltage variations to an equivalent frequency shift of less than 5×10^{-8} when the inexpensive Type 1203-B Unit Power Supply is used.

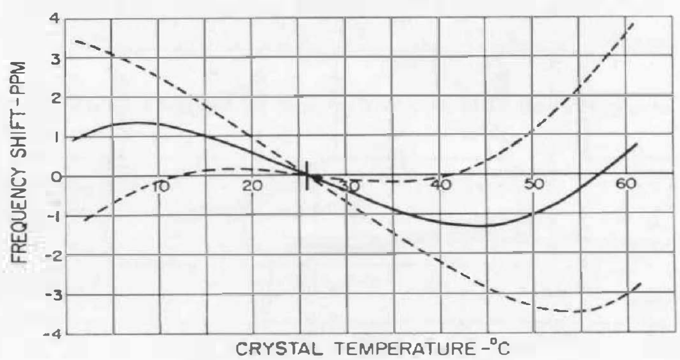
With the newly designed oscillator and crystal, the over-all stability of the unit is better than 10 ppm for six months, and when this accuracy is adequate, no calibration against a precise standard is necessary. If higher accuracy is needed, the crystal can be calibrated against standard-frequency radio transmission (WWV), or another frequency standard of adequate accuracy, immediately before its use. With this transfer method, frequency measurements and calibration to about 2×10^{-7} are practical.

CIRCUITS

Oscillator and Buffer

A 5-Mc crystal controls the frequency of a triode oscillator formed by the screen grid, control grid, and cathode of a pentode. A panel control for frequency is calibrated in ppm incremental frequency change. When unknown frequencies near zero beat are being measured, it is convenient to deviate the

Figure 4. Frequency-vs-temperature characteristics of the crystals, showing tolerance limits.



crystal oscillator frequency slightly without disturbing its basic frequency setting. For this purpose, a "touch-button" is provided on the front panel. Touching this button with the hand decreases the oscillator frequency slightly and permits a sense determination of the beat note. The plate circuit of the oscillator stage is tuned to 10 Mc and drives a buffer-limiter. The buffer provides constant output voltage even if the oscillator output changes due to changes in crystal activity. The buffer output is adjustable by means of a screen-grid voltage control to permit precise setting of the synchronizing voltage for the 10:1 frequency-dividing multivibrator.

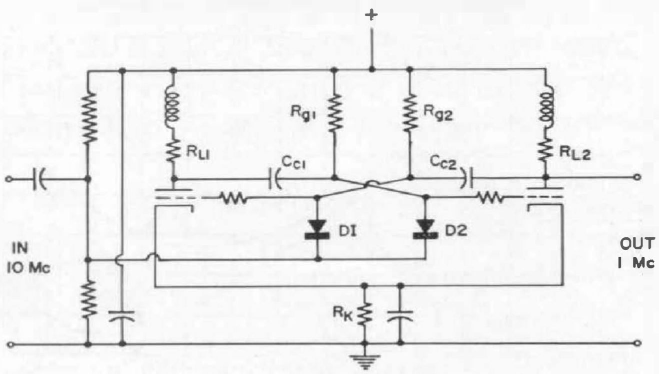
Frequency-Dividing Multivibrator

The 10-Mc buffer drives either an output circuit (in the 10-Mc switch position) or the 1-Mc multivibrator. The multivibrator design originated for the TYPE 1213-C has been improved for the D model. The original tube has been replaced by a new frame-grid type, and the circuit has been completely redesigned to permit the maximum possible tube aging before a failure of the multivibrator by miscounting occurs.

The multivibrator circuit is shown in Figure 5. In the June 1956 issue of the *Experimenter*, the design of frequency-dividing multivibrators for maximum stability against tube and component aging was discussed, including the general problem of proper circuit design for optimum stability at lower frequencies. Additional factors not previously considered are important in the higher frequency divider circuits, where the high values of plate load resistors necessary for "hard-bottoming" cannot be used, because recovery time would be too great. Let us consider a typical multivibrator designed to divide some higher frequency down to 1 Mc. This multivibrator must have a free-running frequency near 1 Mc, and, if the circuit is symmetrical, the plate voltage of the "off" side must recover to nearly the plate supply voltage (say four time constants) in one-half microsecond. A realistic value for the distributed capacitance at a multivibrator plate consisting of the plate capacitance, the load capacitance, and the grid capacitance referred to the plate is about 40 pf. With this value of capacitance, the maximum load resistor determined by the recovery time constant will be 4000 ohms.

With a load resistor of this magnitude, the classical circuit is very sensitive to changes in the tube cathode emission. For example, let us assume that the tube in the circuit of Figure 5 is a high performance triode with an initial $\bar{r}_p$ of 3000 ohms. The total resistance of the tube plus the plate load will be 7000 ohms, and a 10% change in current (and hence the drop across the plate load resistor) will be occasioned if the tube $\bar{r}_p$ rises to 3700 ohms (23%). This will certainly cause failure of even an optimally adjusted multivibrator. In the new multivibrator design of Figure 5, the characteristics of the vacuum tube are stabilized by negative feedback. The large value of cathode resistance, R_k, causes the $\bar{r}_p$ variations to be swamped by the

Figure 5. Elementary schematic of the 10-1 Mc multivibrator.



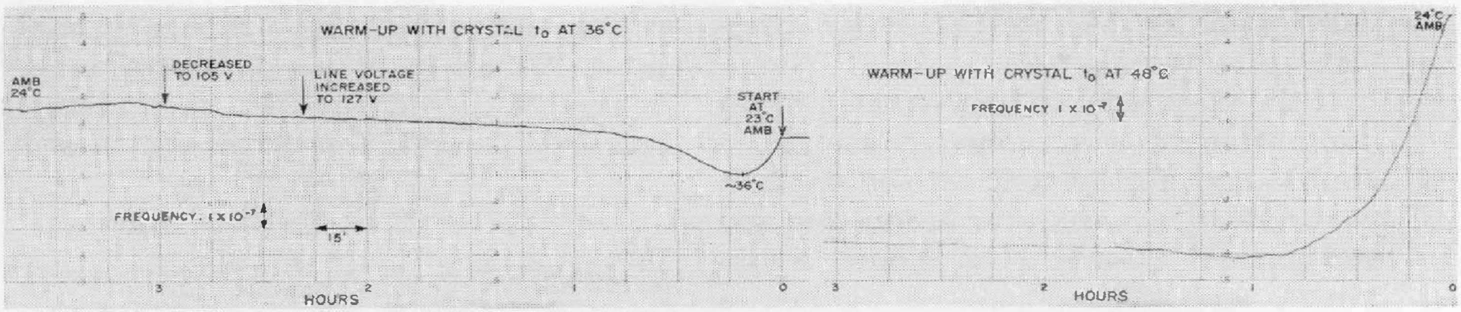


Figure 6. Warm-up characteristics of the instrument with two different crystals, one having its zero-temperature-coefficient point at 36°C, the other at 48°C. Note that time in hours runs from right to left.

feedback, and the tube drives its plate load resistor as a stabilized current source. Instead of $\bar{r}_p$ as a variational quantity, therefore, we have $\bar{r}_p$ plus R_k $(1+\mu)$, and both R_k and μ are relatively stable with aging. This condition is valid as long as the tube remains in the negative grid region.

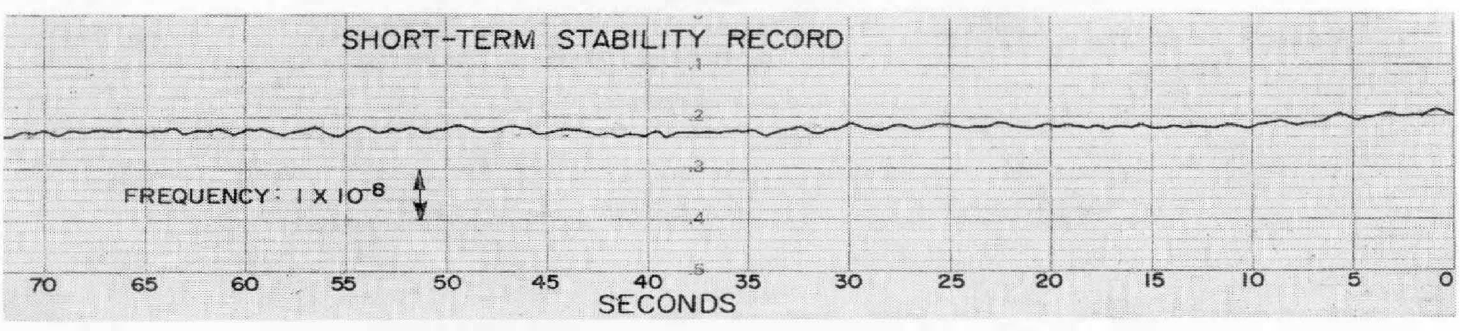
The diodes in the grid circuit, D-1, D-2, are returned to a source impedance low with respect to the grid timing resistors, and thus they hold the grid in the negative region. With this connection the 1-Mc multivibrator can be stabilized to less than a 5% frequency shift with a doubling (100% change) of $\bar{r}_p$. Plate current stabilization feedback, however, exacts a price. The performance of a new tube has been reduced to that of an aged tube in order to obtain reliability. This general circuit technique can be applied to all sorts of pulse circuits in which the end value of plate current is of importance, but in oscillatory circuits such as the free-running multivibrator, the loop gain may often be insufficient to permit self-oscillation. In fact, a trigger or transient may have to be supplied before the circuit will operate at all. Such a characteristic can be a distinct advantage in frequency-dividing multivibrators because, before the tube has aged sufficiently to cause a multivibrator division error, the circuit will simply not operate at all.

APPLICATIONS

When the Time/Frequency Calibrator is used as an independent standard, its over-all accuracy is about 10 parts per million. When standardized against WWV radio transmissions or other known standard, accuracies comparable with that of the reference standard can be attained, that is, a few parts in 10^7. When the instrument is calibrated before each measurement, the accuracy is determined by the short-term stability of the crystal oscillator, the effects of switching, and external connections. The total error from these sources will be less than 2×10^{-7}.

With this instrument, oscillators and receivers can be calibrated at 10-Mc intervals up to at least 1000 Mc, at 1-Mc intervals up to 500 Mc, at 100-kc inter-

Figure 7. Short-term stability record of the crystal oscillator. Total change in one minute is less than 6 parts in 10^9.



vals up to 100 Mc, and at 10-kc intervals up to 10-Mc.

If the frequency to be measured is not a multiple of a standard harmonic, a double transfer system can be used. A beat note of the unknown frequency and the nearest standard harmonic is obtained and then compared against a calibrated variable low-frequency oscillator. An accuracy of a few parts in 10^7 is possible up to 100 Mc. This method has been described in detail elsewhere.[3]

— R. W. FRANK
H. P. STRATEMEYER

[3] C. A. Cady, W. P. Buuck, "Frequency Measurements in the Broadcast Field," *Technical Publication B-10*, General Radio Company. (Copies available on request.)

SPECIFICATIONS

Output Frequencies: 10 Mc, 1 Mc, 100 kc, 10 kc.

Output Amplitudes: 10 Mc: 5 v peak-to-peak; 30 v peak-to-peak at lower output frequencies from pulse amplifier; rf harmonics usable to 1000 Mc from 10-Mc output, to 500 Mc from 1-Mc output, to 100 Mc from 100-kc output, and to 10 Mc from 10-kc output.

Output Impedance: Video cathode-follower, 300 ohms; rf output obtained from crystal-diode harmonic generator.

Frequency Stability:

1. *Temperature*

a. Warm-up Characteristics:
For ambient temperatures of 25°C, or over, the warm-up drift will not exceed -2×10^{-7}/°C. With ambient 0—10°C crystal may not operate until instrument attains operating temperature. Minimum operating ambient 0°C.

b. Operating Characteristics:
In ambient range 20-40°C, the oscillator drift is between -1×10^{-7}/°C and $+2 \times 10^{-7}$/°C.

2. *Line Voltage Effects*
Momentary line voltage changes of ±10% affect frequency by less than 5×10^{-8}. Changing line voltage will affect frequency per temperature specification above. (±10% line will change temperature ±4°C.)

3. *Switching and Loading Effects*
The combined effects of switching and loading due to external connections are less than 1×10^{-7}.

Sensitivity: Usable beat notes can be produced with 50 millivolts signal input to mixer over the harmonic ranges specified above under "Output amplitudes."

Tubes: One each 6AK6, 6AH6WA, 6922, 6AN8, 6U8; two 5964.

Power Required: 6.3 v ac, 3 amp; 300 v dc, 60 ma. TYPE 1203-B Unit Power Supply is recommended.

Accessories Supplied: TYPE 1213-P1 Differentiator, TYPE 874 Coaxial Connector, and multipoint connector.

Mounting: Aluminum panel and sides finished in gray; aluminum cover finished in clear lacquer. Relay rack panel (TYPE 480-P4U3) is available for mounting both calibrator and power supply.

Dimensions: Width 10½, height 5¾, depth 7 in., over-all.

Weight: 4 lb., 10 oz.

Type		*Code Word*	*Price*
1213-D	Unit Time/Frequency Calibrator*	REBEL	$310.00
1203-B	Unit Power Supply	ALIVE	40.00

*U. S. Patent 2,548,457; licensed under patents of the American Telephone and Telegraph Co., of Radio Corporation of America, and of G. W. Pierce (pertaining to piezo electric crystals and associated circuits).

SEE THEM AT THE SHOWS

Many of the new General Radio instruments that you have been reading about in the *Experimenter* will be displayed at technical meetings this fall.

Place	*Date*	*Meeting*	*GR Booth Number*
Chicago	**Oct. 12-14**	**National Electronics Conference**	**177, 178, 179**
Atlanta	**Nov. 9-11**	**4th Instrumentation Conference**	**C6**
Boston	**Nov. 17-19**	**Northeast Electronics Research and Engineering Meeting**	**9, 10**

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