



5 x 10⁻⁸/Week Time Base Accuracy in the 10 MC Frequency Counter

REFINEMENT of techniques in several fields is currently generating a need for making routine frequency measurements to increased degrees of accuracy. A good example of this need lies in the single-sideband field where it has become desirable to be able to make fast, convenient measurements of VHF frequencies to within a matter of cycles in checking transmitter carriers, receiver oscillators, filter response, etc.

SEE ALSO:
Assuring time base performance, p. 5

For such work the -hp- 10-megacycle frequency counter is now available with a new time base crystal oscillator of very high performance. The new time base is rated as having a long-term stability of within ± 5 parts in 10⁸ per week. This tolerance is directly transferable to frequency measurements and means,

for example, that a measurement of a 100-megacycle frequency (using the counter with its heterodyne converter) will be accurate within ± 5 cycles in the week following calibration or ± 10 cycles in the second week, \pm short-term stability in each case.

Actually, the performance of the oscillators has been well above ratings, and the ratings are considered to be subject to later improvement. Short-term stability, for example, is rated as within ± 3 parts in 10⁸, but typical short-term performance is considerably better, as shown in Fig. 2. Note that one major vertical division in Fig. 2 is equal to 1 part in 10⁸ so that the stability can typically be described in parts in 10⁹. It is of interest to recall that this performance, while within about one order of magnitude of that of most high-quality commercial crystal

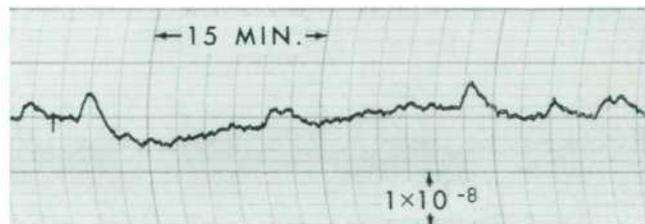


Fig. 2. Typical short-term stability of Model 524D time base. Stability of this order permits very close adjustments to be made in work such as with single-sideband equipment where increased precision is currently involved.

Fig. 1 (left). New Model 524D 0-10 mc Frequency Counter incorporates new high-stability time base for applications requiring advanced precision or where unit is used as frequency standard. Decade form is used for all columns of readout. Counter is shown with panel plug-in unit for measuring frequencies from 100 to 220 megacycles. Basic counter will also be available with in-line readout as pictured on page 4.

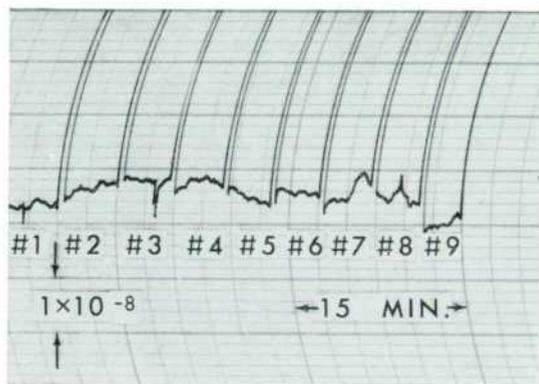


Fig. 4. Record of frequency change in Model 524D time base oscillator resulting from 8 different oscillator tube replacements. Large spikes are where recorder went off-scale as tubes were removed and new tube warmed.

standards, is supplied within the economic limitations necessary for one circuit of a complete frequency-measuring instrument whose total selling price is well below that of such commercial standards alone.

Space limitations make it impractical to present extensive recorded data on long-term stability, but in typical cases the crystals show aging rates of a few parts in 10^9 per week after the initial stabilization period that crystals normally exhibit has passed. Fig. 3 shows sections spaced a week apart from a long-term stability record to illustrate typical stability over a one-week period. It can be seen that the aging rate is less than 1 part in 10^8 for the week. At the *-hp-* plant, in fact, the equipments are not released until the crystals have shown an aging rate of not more than 2.5 parts in 10^8 per week for a 2-week period. This rate normally continues to improve, as indicated in Fig. 3.

TUBE REPLACEMENT

A question that often arises in regard to stable oscillators concerns the amount of frequency shift that occurs when a tube is changed. This is a factor that is more under the control of the designer than is often realized, and in this oscillator it is one of the factors that has been carefully controlled. Fig. 4 shows typical performance in this respect. Eight replacement tubes were installed and allowed to operate for several minutes each. Overall effect among all nine tubes was less than 1 part in 10^8 . Tube-to-tube changes, in fact, were less than 3 parts in 10^9 in all but one case.

Somewhat related data are shown in Fig. 5. This curve demonstrates the effect of discrete changes in capacitance at three points in the oscillator circuit. Information of this nature is used to establish approximate coefficients of frequency change to evaluate design factors.

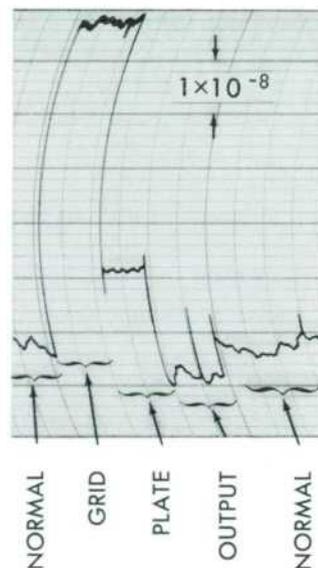


Fig. 5. Record of frequency change resulting from placing lumped capacitance of 10 mmf at grid, plate and output of oscillator to investigate effect on oscillator of very small changes in circuit capacities.

The first upward step in the curve shows the frequency shift caused by placing a lumped capacity of 10 mmf directly across the grid of the oscillator. A frequency change of about 6 parts in 10^8 or a coefficient of 0.6 parts in 10^8 per mmf resulted. This information is both a guide to tube replacement changes as well as a measure of the effect of possible slight changes in circuit capacity owing to slight shifts in wiring, etc., that might occur in transporting the instrument. Such shifts probably cannot exceed a few tenths of a micro-microfarad so that resulting

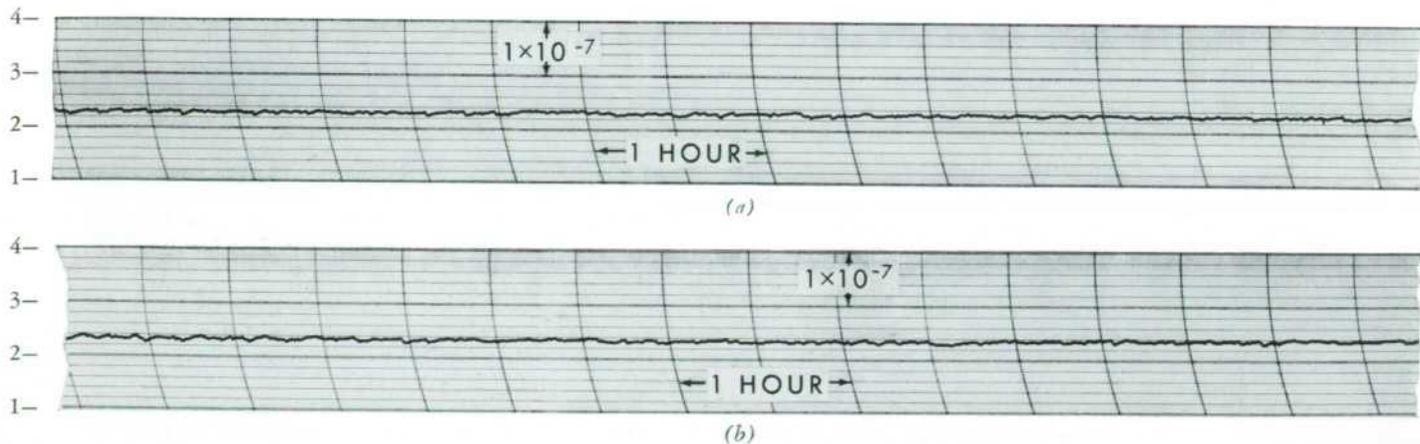


Fig. 3. Sections taken a week apart from long-term stability record of typical Model 524D time base. Low time-base oscillator aging rate minimizes need for calibration checks.

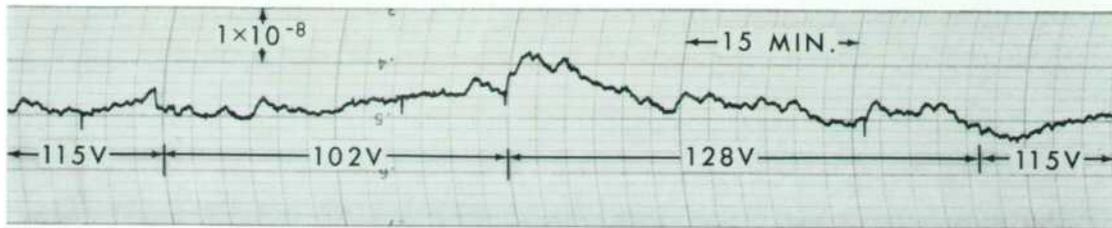


Fig. 6. Typical effect of large line-voltage variations on time-base oscillator stability.

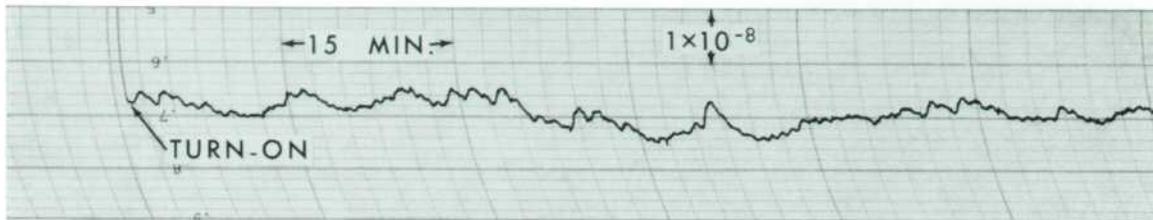


Fig. 7. After over-night standby, a few-minute warmup returns time base to its previous frequency and stability.

shifts in frequency should be less than 2 parts in 10^9 .

The next two smaller steps in Fig. 5 show the effect of a 10 mmf increase in capacitance at the oscillator plate and at the oscillator output. Additional buffering is used between the oscillator output and the point where the signal is extracted, and a 10 mmf increase at this point causes no detectable change in frequency.

TYPICAL USAGE SITUATIONS

The frequency counter is rated for operation from power line voltages within the range from 103.5 to 126.5 volts. Within this range line voltage level has very little effect on time base stability. This is demonstrated in Fig. 6 which shows the

effect of very severe steps in line voltage—actually somewhat beyond ratings. The only noticeable frequency change occurred when line voltage was changed from 102 volts to 128 volts, i.e., a positive step of 25%.

Two other situations about which performance data are of value to the user concern standby operation and initial turn-on characteristics. The instrument is provided with a standby power switching arrangement such that crystal oven temperature is maintained as long as the instrument remains connected to a power source. Fig. 7 shows turn-on characteristics from standby operation after the instrument proper has been turned off for an overnight interval. A few minutes' warmup in this con-

dition is adequate for accurate measurements.

Standby operation is also essentially free of the permanent or semi-permanent shifts sometimes exhibited by crystal oscillators. This is demonstrated in Fig. 8, which shows the stability during three switchings to standby and back.

When the instrument has been completely disconnected from power for a significant time such that the crystal has cooled to room temperature, the cooling and subsequent re-heating of the crystal often causes it, in common with any quartz crystal, to undergo a new but accelerated aging cycle which, in effect, may cause a small, permanent shift in the crystal frequency. It is not practical to place ratings on

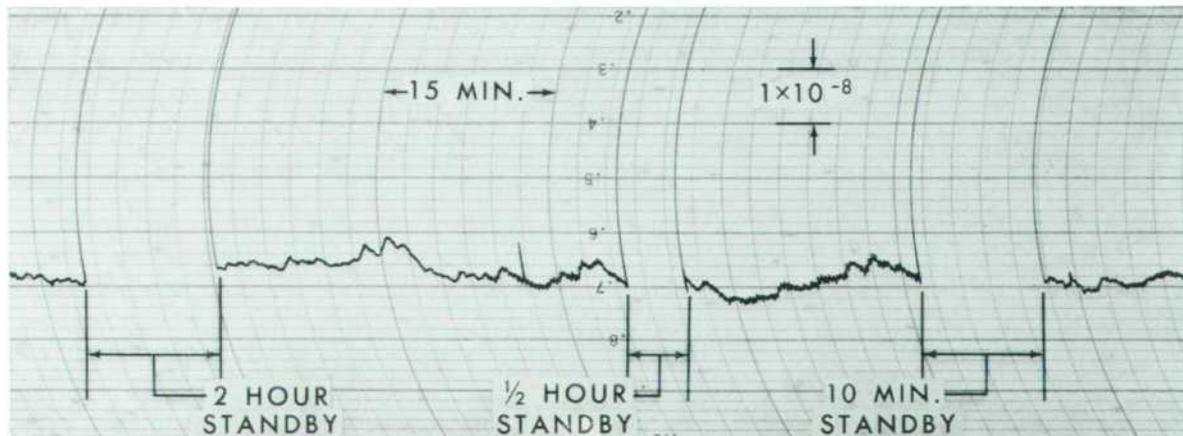


Fig. 8. Use of standby feature is free of shifts in frequency sometimes encountered when crystal oscillators are thus operated, as indicated by three switchings to standby and back in above record.

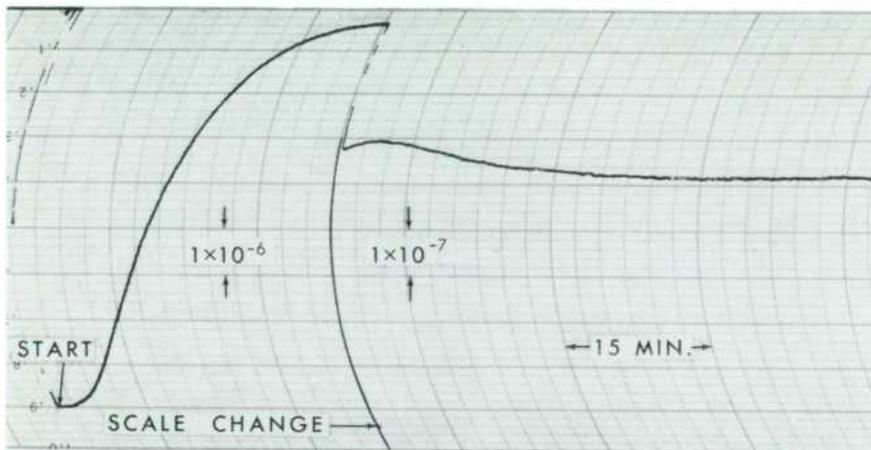


Fig. 9. After complete cool-off of instrument and crystal, time base oscillator will typically follow a warm-up characteristic as indicated above.

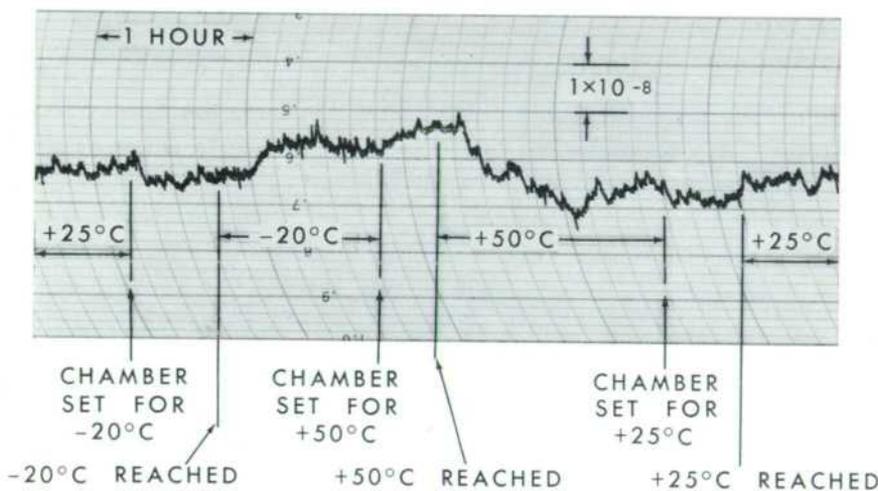


Fig. 10. Record of time-base oscillator stability as complete frequency counter was temperature-cycled in chamber which reached -20° and $+50^{\circ}$ C.

these effects, but they are usually relatively small. In any case, where highest precision is sought, it is desirable to make use of the standby feature and to minimize complete turn-offs. Short-time turn-offs, of course, such as might be caused by short power failures or moving the instrument a limited distance, do not appreciably alter the crystal temperature and thus cause no noticeable effect.

When the instrument has been cooled to room temperature, it can be expected to follow an initial pattern similar to that shown in Fig. 9. It is rather usual that the frequency will return to within a few parts in 10^8 of its previous value within a few hours, but the previous stability may not be reached for several days.

AMBIENT TEMPERATURE EFFECTS

-hp- instruments are rated for operation over normal room temperatures, but *-hp-* policy has always been to design for considerably wider temperature ranges as a safety factor, and instruments are normally "type-tested" in this and other respects over wider than rated ranges. Fig. 10 is a record of time base frequency stability during a temperature test in which the ambient temperature was varied to -20° C and to $+50^{\circ}$ C as a check on the adequacy of the oven design as well as a check on the remainder of the frequency counter. During this test the time base changed less than 2 parts in 10^8 , while the complete instrument operated properly.

GENERAL

The *-hp-* 10-megacycle frequency counter using the new time base described above can be seen to provide a very high level of accuracy, making the instrument suited to use in laboratory measurements as well as exacting production measurements. The instrument can also serve in the dual role of a laboratory standard frequency generator, since it provides an output (at 100 kc)

(Concluded on page 6)

NEW READOUT FEATURES IN THE NEW COUNTER



The *-hp-* 10-megacycle counter with the advanced time base described in the accompanying article has the model number 524D. In addition to its new time base this instrument also has a full 8-decade readout as shown on front page. In other respects, the instrument is the same as the well-known Model 524B.

The new time-base counter will also be available in the late spring with an in-line readout using glow-indicator tubes (left) for applications where this type of readout is preferred. The in-line readout instrument has the model number 524C.

ASSURING TIME BASE PERFORMANCE

IT IS OFTEN of special interest to engineers visiting the *-hp-* plant to observe the procedures used to ascertain the accuracy and stability of precision time base oscillator circuits—particularly those that achieve stabilities of within a few parts in 10^8 such as the Model 524D time base discussed previously in this issue. By way of illustration, it can be noted that an accuracy of 5 parts in 10^8 (the rating of the Model 524D) corresponds to knowing the distance between a point in New York City and a point in London to an overall accuracy of within about 1 foot. Obviously, precision of this order requires extensive and very careful procedures on the part of an instrument manufacturer.

Since the stability of the time base in the Model 524D is rated in terms of a week, it is necessary in proving these time bases to conduct sufficient tests to assure that ratings will be met over a week's time when the instrument is in service. Because the heart of the time base is a quartz plate and because newly-cut-and-processed plates usually have not assumed their final character, such assurance means that tests must be conducted over a several-to-many week period on each plate and that test results must be significantly better than ratings, as dictated by good engineering practice.

TEST PROCEDURES

As supplied by a crystal processor, quality quartz plates are usually rated as to their equivalent electrical units—inductance, Q (activity), resonating capacitance, etc. They may also be rated as to aging, based on the methods and care that the processor uses. The operation of a plate in a circuit, however, as well as the quality of performance the plate exhibits during and after its break-in period must be determined.

At *-hp-* the testing of high-precision quartz plates is carried out in three main steps. Newly-received



Daily measurements of crystal frequency are made and recorded while plate is continuously operated in test stands for several-week period. Before aging, crystal temperature characteristic is plotted with automatic set-up (foreground) and proper oven temperature determined.

plates are connected into special test instruments that first measure their Q and electrical values as a preliminary test of general acceptability. The operating temperature of a plate is then continuously increased from room temperature to insure that the plate Q does not exhibit any irregularities or any severe decreases up to the temperature at which it will be operated. This procedure insures that the plate characteristics do not change in such a way as to cause the oscillator to stop oscillating during some portion of a future warm-up.

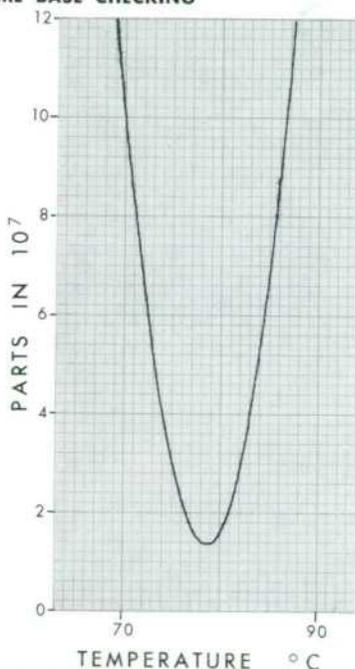
The second step is a detailed examination of the temperature characteristic of the plate. While operating in a test circuit, the plate is heated to a high but safe temperature and allowed to cool at a slow rate which previous experience has shown to be satisfactory. During the cooling period the frequency change of the crystal is automatically plotted against temperature in order to determine its temperature coefficient

characteristic as well as its zero-coefficient temperature at which the plate will eventually be operated. At the same time the operation of the plate is carefully observed to insure that no coupling to unwanted vibrational modes exists and that no mechanical instability exists in its mounting.

At this point a full set of data exists on the plate as to its characteristics, the change of these characteristics with temperature, and the mechanical suitability of the mounted plate. It remains to determine that the plate is stable over long intervals. To accomplish this, the plate is installed in its final oven which has been pre-adjusted to operate at the zero-coefficient temperature determined from the earlier tests. The oven is then inserted in special test stands wherein the plate is operated at its rated frequency (1 megacycle in the case of the Model 524D). The test stand continuously operates the plate and includes

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TIME BASE CHECKING



Typical crystal temperature characteristic automatically plotted with equipment shown on page 5.

high-precision frequency-measuring equipment so that the day-to-day changes in the vibrating frequency can be determined. Typically, for "good" plates of the type used in the Model 524D, a daily change in frequency of about 1 part in 10^8 will occur in the earlier part of the run-in period. In plates of this quality these day-to-day changes are usually attributed to changes in the lattice structure and will normally occur in the same direction and thus be additive. As the plate continues to operate, the day-to-day changes become smaller and usually taper off into changes that are only a few parts in 10^9 . When a plate has stabilized such that it operates within 2.5 parts in 10^8 per week for a two-week period, it is considered to have aged satisfactorily and is released for production instruments, provided its history during the stabilization period is entirely free of any erratic performance. Some plates, for example, may show a sudden, discrete shift in frequency and these are not released, at least until a much longer testing period has shown them to be satisfactory.

PRODUCTION CHECKS

When the crystal in its oven is now installed in a production counter, it is al-

lowed to fully reach its oven temperature and then adjusted to be within 1 part in 10^8 of its f_0 value in the new circuit. The complete frequency counter is then connected to a power-cycling device which applies power to the instrument for alternate half-hour periods for 4 days. The instrument is thus turned on some 96 times and turned off a like number of times. This test is designed as an overall check on the complete instrument as well as the crystal oscillator. At the end of this period the oscillator frequency is again measured and adjusted to be within a few parts in 10^9 .

From this time on during the remainder of testing that the instrument undergoes the oscillator must remain within 2 parts in 10^8 in order to be released at final test.

It can be seen from the foregoing that *-hp-* time bases are put through extremely rigorous tests indeed to insure that ratings can be depended on in field use. Further, since quartz plates that are free of imperfections and properly operated circuitwise have a broad history of improving with time, their performance can, in general, be expected to improve with time up to the limits set by the oven itself.

10 MC COUNTER

(Continued from page 4)

from its time base. The aging rate of the new time base is sufficiently low that calibration need be done only infrequently, probably less than once a month, for the instrument to retain very high accuracy.

At the same time the new time base is provided in an instrument that is the industry's first and most proved high-speed frequency counter. Combined with its heterodyne converters, it can be used to measure frequencies up to 220 megacycles. It can also be used with the *-hp-* trans-

fer oscillator to measure up to 12 kilomegacycles. At the other extreme the counter can be used with its period multiplier unit to measure the average period of low frequencies to high accuracy.

—LaThare N. Bodily and
Leonard S. Cutler

SPECIFICATIONS -hp- MODEL 524D ELECTRONIC COUNTER

(Basic Unit for Frequency Measurements from 0 cps to 10.1 mc)

FREQUENCY MEASUREMENT (without plug-in units)

Range: 10 cps to 10.1 mc.

Gate Time: 0.001, 0.01, 0.1, 1, 10 seconds or manual control.

Accuracy: ± 1 count $\pm 0.000005\%$.

Reads In: Kilocycles; decimal point automatically positioned.

PERIOD MEASUREMENT (without plug-in units)

Range: 0 cps to 10 kc.

Gate Time: 1 or 10 cycles of unknown.

Accuracy: $\pm 0.3\%$ (measurement one period). $\pm 0.03\%$ (ten period average).

Standard Frequency Counted: 10 cps, 1 kc, 100 kc, or 10 mc; or externally applied frequency.

Reads In: Seconds, milliseconds, or microseconds; decimal point automatically positioned.

GENERAL

Registration: 8 places (99,999,999 maximum counts).

Stability: Short term: ± 3 parts in 10^8 ; long term: ± 5 parts in 10^8 per week; may be standardized against WWV or used with external 100 kc or 1 mc primary standard.

Display Time: Variable 0.1 to 10 seconds but not less than gate time. Display can be held indefinitely.

Output Frequencies: Secondary standard frequencies available at front panel: 10 cps, 1 kc rectangular; 100 kc positive pulse; 10 mc sine wave. (Stability as above.)

Self Check: Panel control provides automatic count of internal standard 100 kc and 10 mc frequencies to assure accuracy of gate and proper operation of counter.

Input Voltage: 1 volt rms minimum/1.5 volt peak. Rise time .2 sec (max.).

Input Impedance: Approximately 1 megohm, 40 μF shunt capacitance.

External Standard: 100 kc or 1 mc signal from external primary standard can be applied to unit for highest accuracy. 2 volts rms required. Nominal input impedance: 1 megohm, 40 μF shunt.

Connectors: BNC Type.

Power Supply: 115/230 volts $\pm 10\%$, 50-60 cps, approximately 600 watts.

Dimensions: Cabinet Mount: 20" wide, 21 1/4" high, 23 1/2" deep overall. Rack Mount: 19" wide, 19 1/4" high, 22 1/2" deep behind panel.

Weight: Cabinet Mount: Net 118 lbs., Shipping 168 lbs. Rack Mount: Net 108 lbs., Shipping 172 lbs.

Accessories Furnished: *-hp-* AC-16K Cable Assembly, 48" RG-58/U cable, terminated each end with UG-88/U BNC male Connectors.

Plug-in Units: *-hp-* 525A Frequency Converter, 10 cps to 100 mc, \$250.00.

-hp- 525B Frequency Converter, 100 mc to 220 mc, \$250.00.

-hp- 526A Video Amplifier, 10 cps to 10.1 mc, \$175.00.

-hp- 526B Time Interval Unit, 1 μsec . to 10⁷ sec, \$175.00.

-hp- 526C Period Multiplier, 0 cps to 10 kc, \$225.00.

Complementary Equipment: *-hp-* 540A Transfer Oscillator, Cabinet Mount, \$615.00. Rack Mount, \$600.00.

-hp- Model 440A Detector Mount, \$85.00.

-hp- 560A Digital Recorder, Cabinet Mount, \$1,265.00.

Rack Mount, \$1,250.00.

Accessories Available: Test Cable Set to interconnect *-hp-* 524 and 525/526 units during test and adjustment of auxiliary units. Specify *-hp-* 524B-16P, 16 conductor cable \$20.00, and *-hp-* 524B-16Q, 8 conductor cable \$15.00. *-hp-* 524D-95A, Model 560A Digital Recorder Adapter Kit for field installation, \$35.00.

Price: *-hp-* 524D Electronic Counter, Cabinet Mount, \$2,150.00.

Rack Mount, \$2,125.00.

For Model 560A Digital Recorder operation, add \$75.00, specify C03-524D.

Prices f.o.b. Palo Alto, California.

Data subject to change without notice.