A New Generation of
High-Speed Frequency Counters

A LITTLE over a decade ago the Hewlett-Packard Company introduced what subsequently proved to be one of the electronics field's most important measuring instruments. This was the high-speed frequency counter, the now well-known -hp- Model 524*. This counter automatically measured frequencies up to 10 megacycles and did so with an accuracy superior to that of any but the most elaborate methods of the time. During the ensuing decade, its all-around capabilities brought this counter to the stature of an instrument accepted by all as the standard of the industry.

Advances in the art have now permitted the development of a new generation of two high-speed frequency counters. These are shown in Figs. 3 and 4. One of the new counters measures from 0 cps to 20 megacycles and the second from 0 cps to 50 megacycles. Using a plug-in, each counter will measure to 500+ megacycles. Both counters have a large, in-line readout and high input sensitivity. They are transistorized and use computer-type construction, giving a small physical size with a panel height of only 5 1/2". A full array of plug-ins has been designed to be compatible with this small panel size, as described later. Except for their different maximum counting rates of 20 and 50 Mc, the two counters have essentially the same electrical and mechanical characteristics and use the

same plug-ins. Besides frequency, the counters will also measure period (including multiple-period averages), time intervals, frequency ratios, and phase angles; and will totalize random counts, or scale random or periodic counts. With other -hp- equipment such as transfer oscillators, the counters will measure frequencies up to 18 gc (kmc) with full counter accuracy. The counters are also useful with much other data-handling equipment and provide binary-coded decimal (BCD) outputs to facilitate such applications.

TIME BASE STABILITY

Of the many new measuring capabilities that the counters embody, one of great interest and assistance to engineers working in today's advanced technology is the increased measuring accuracy provided by the high stability in the counters' time bases. These time bases are rated to have stabilities of within $\pm 5$ parts in $10^{10}$ short term (1-second averaging) and an aging rate of within $\pm 3$ parts in $10^9$ per day. Such very high stabilities are extremely valuable since they permit precise measurements of up to 8 and 9 places in narrow-band VHF telemetry or communications work. Such stabilities also permit the counters to be used as an in-house frequency standard having a stability not commercially available until recently.

Actually, as might be expected on the basis of -hp- engineering practice, the measured stabilities of these time bases are typically considerably better than even the above specifications. This can be seen in Figs. 2, 5 and 6 which show the short- and long-term deviations measured on several production instruments. In the curves of Fig. 2 the short-term deviations of two of the counters are shown as measured against a standard of even higher stability, so that the curves show mainly the deviations of the time bases themselves. The measurements are made with 1-second averaging. The full vertical scale shown is the rated short-term stability; that is, the short-term deviations are rated not to exceed the vertical portion shown of the chart. The portion shown represents 5 parts in $10^9$. The curves show that these instruments exceeded ratings by more than 5 times.

In another interesting case, the stabilities of these particular production instruments were measured against one another (Fig. 5). Fig. 5 thus shows the sum of two deviations, usually considered to be $\sqrt{2}$ of the deviation of one frequency where the two frequencies have equal deviations. Here, too, the sum of the two deviations is far within the ratings of one counter.

LONG TERM STABILITY

The long-term stability also typically exceeds ratings by a considerable amount. While optimum utilization of any precision frequency instrument calls for a calibration program for the individual instrument, it is informative to examine the long-term curves presented in Fig. 6, since these are representative of the long-term stability experienced with the counters. The curves show the stabilities of the time base oscillators after the quartz crystals in the time bases have passed their initial several-week run-in period. It is plain that the time bases typically have an aging rate much below that specified. Also, since the data still indicate some run-in effect typical of a "green" crystal, the future aging rate can be expected to have the small slope exhibited by the final portions of the curve.

CIRCUIT ARRANGEMENT

The basic circuit arrangement of the new counters is indicated in Fig. 7. The frequency to be measured is...
passed through a time-base-controlled gate and then counted by decade counting circuits. Since the gate is held open by the time base for discrete, precise intervals of 10 seconds or a decade sub-multiple thereof, the count obtained by the counting circuits can be read out directly in frequency merely by appropriately positioning the decimal point. The counting circuits are followed by a digital readout system which directly displays the measured frequency and in which the illuminated decimal point is automatically positioned.

When the signal to be measured is low in frequency, improved measuring accuracy can normally be achieved (Fig. 11) by measuring the period of the signal instead of measuring its frequency as described above. For period measurements the basic measuring circuit is reconnected by the panel selector switch as indicated by the dashed lines in Fig. 7. The instrument then counts suitable clock signals from the time base for 1, 10, ..., or 100,000 periods of the low frequency. The readout is thus direct-reading in seconds, milliseconds or microseconds. Time intervals are also measured by this same basic approach of counting clock signals from the time base, although a plug-in is used to provide start and stop signals to the measurement gate circuit.

Frequency ratios are measured in a manner similar to that used for period measurements, except that the clock frequency from the time base is replaced by the higher of the two frequencies in question.

REMOTE CONTROL/PROGRAMMABILITY

While the above circuit arrangement is conventional, it embodies some new approaches that give the counters the ability to make measurements in previously troublesome applications. One of the circuit innovations, for example, is the use of AND gates to establish the signal paths in the circuit, where previously the selection of these paths was made with conventional mechanical switches. The arrangement of the gates is shown in Fig. 8. The AND
Fig. 9. All plug-ins can be used with either counter. Counter top and bottom plates are easily removed, being secured with coin-slotted screws.

gates pass a signal only when they see both a signal input and a control input. Since the control input can be, and is, a dc signal, the use of the AND gates has the advantage that the instrument's measuring functions can be remotely controlled by means of dc signals. To accommodate remote control operation, the instrument's time base signals also are selected by a group of AND gates.

The ability to remotely control the functions of the counters strictly by dc signals should prove valuable to many engineers working with systems. For example, the counters can be used for a sequence of measurements in a missile or other checkout system. Measurements of telemetry transmitter frequency, of a telemetry subcarrier frequency (or period), of the interval between two timing pulses (using time-interval plug-in) could be made in sequence under the control of a central console.

To facilitate remote control, connectors are provided at the rear of the instrument for operation of the AND gates. A dc supply voltage for operating the gates is also provided at a rear connector terminal so that it is only necessary for the application engineer to arrange for simple external contact closures to obtain remote and/or programmed operation of the counter. All functions of the basic counters are remote-controllable except for sensitivity and sampling rate.

**READOUT CONVENIENCES**

As shown in Fig. 10, the counting circuits feed storage circuits which in turn drive the readout system. This arrangement makes possible the -hp display storage feature which has two characteristics that are of assistance in making most measurements. One is that the displayed count is retained on the readout system while a new count is being made. The display is thus continuous, and changes only if the new count changes from the previous. If only the last places change from one count to another, the other places in

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**COUNTER**

To enable a variety of measurement problems to be solved with the counters, four plug-ins units have been designed. Two of these jointly permit measuring frequencies to above 500 megacycles. The third is an amplifier that increases the sensitivity of the counters to 1 millivolt over the full 10 cps to 50 Mc range. The fourth plug-in enables time intervals to be measured and can also serve as an amplitude discriminator, accepting for counting only signals that exceed a selected amplitude level.

Each of the plug-ins can be used with either of the counters. The plug-ins fit into a recess in the right side of the panels of the counters. When no plug-in is used, a panel plate covers the recess opening.

**FREQUENCY CONVERTERS**

Of the two frequency converters, one provides for measuring frequencies from 20 to 100 megacycles, and the second from 100 to 512 megacycles. Both converters have a high sensitivity and permit signals down to at least 50 millivolts to be measured at all frequencies. To assure the operator of adequate signal level, panel meters with a green-colored "go" area on their scales are provided. The meters also indicate proper settings of the mixing frequency selector control, the only operating control on the converters. In the lower-frequency converter this control is a selector switch. In the higher-frequency converter it is a continuous-tuning control, but one in which a mixing signal is obtained only at discrete frequencies.

The circuit arrangement of the converters is indicated in the accompanying diagram. Using the precise 10-mc frequency from the counters' time bases, the converters generate harmonics at 10-Mc intervals. The harmonic lying immediately below the frequency to be measured is then selected by a tuned circuit and subtracted from the frequency to be measured. When the appropriate harmonic is used, the difference frequency will lie within the range of the counter itself and will be measured by it. The frequency being measured is thus the sum of the harmonic frequency, as shown by the panel control, and the

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the display remain fixed and only
the changed numbers change. Such a
storage type display is obviously
much easier to read and less suscep-
tible to reading error.

The display storage feature, in
turn, leads to the second measure-
ment convenience which is that the
readout time is independent of the
gate (counting) time. This is espe-
cially convenient when the longer
gate times of 1 and 10 seconds are
used, because it is not necessary to
await the completion of a "display
time" before a new measuring time
can begin. If the Sample Rate con-
trol is turned to its maximum set-
ing, a new count will begin as soon
as (100 ms) the previous count is
completed. A higher sampling rate
is thus achieved.

Gating of the instruments is in-
dicated by a panel lamp.

(Continued on page 6)

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**PLUG-INS**

reading on the counter. Since the har-
monic frequency is always an integral
multiple of 10 megacycles, it is an easy
number to add mentally to the counter
reading, which will lie in the range be-
tween 0.1 and 12 megacycles. The over-
all measurement has the same accuracy
as the rating for the counter itself, since
the subtracted frequency is obtained
directly from the counter time base.

**TIME INTERVAL PLUG-IN**

The Time Interval Plug-In enables
measurements to be made of the inter-
val between desired points on two sep-
arate signals or between two desired
points on one signal. Intervals from
10⁻⁴ to 10 seconds can be measured
at 0.1 microsecond resolution and to
10⁶ seconds at lesser resolution. The
plug-in has a "start" and a "stop"
channel with separate controls that
permit measurements to begin or end
on either positive or negative voltages
and on either positive or negative
slopes, as desired. In counting applica-
tions the input controls can also be
used to cause the plug-in to operate as
an amplitude discriminator where sig-
nals of a variety of amplitudes may be
present.

Remote operation of this plug-in is
also possible, i.e., the unit can be ac-
tivated or de-activated by means of ex-
ternal contact closures, as described in
the main text. The measurements will
be made in terms of the settings of the
plug-in's panel controls.

The time interval readout obtained
on the counter is given directly in time
units. Alternatively, the readout can
be obtained directly in other desired
units such as fps, mph, or rpm by ap-
plying an appropriate external fre-
quency for the counter to count in
place of the time base frequency. For
example, the phase difference between
two 10 kc signals will be displayed
directly in degrees if a 3600 kc signal
is supplied as the counted frequency.
For measuring phase difference, the
trigger level controls would usually be
set at the zero axis crossing of the in-
put waveforms for both the start and
stop channels.

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Fig. 10. Circuit ar-
angement used in new
counters to achieve
Display Storage fea-
ture which gives con-
tinuous display of
readouts with no in-
terruption during
measurement.

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The video amplifier plug-in in-
creases the input sensitivity of the
counters over the 10 cps to 50 Mc
range. At the same time the amplifier
raises the input impedance of the am-
plifier-counter combination to a high
value of 1 megohm shunted by 15 pf.
If desired, this impedance level can be
further increased to 10 megohms
shunted by 10 pf by using the hp-
AC-21M oscilloscope probe. This in-
crease will change the sensitivity of the
amplifier to 10 millivolts, however.

The amplifier has two outputs. One
of these operates the counter, and the
second is available at the amplifier
panel for other uses such as oscillo-
scope observation of the input signal.
The amplifier is also useful in this way
in non-counting applications as a high-
sensitivity pre-amplifier.

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MULTIPLE-PERIOD AVERAGING

A feature new in high-speed counters is the feature known as multiple-period averaging. This feature permits increased accuracy in measuring the period of a signal, because it averages the periods of from 1 to 10⁶ cycles of the frequency being measured. In cases where the signal has noise that obscures the precise duration of a single cycle, the resulting ambiguity in a cycle can be reduced by the number of periods over which the measurement is averaged. Similarly, the influence of instability in the signal or the ±1 count ambiguity inherent in a counter can be reduced by this same factor.

SCALING

Another provision new in -hp- counters is the provision for scaling input signals, i.e., providing one output signal for, in this case, each decade multiple count of the input signal. The signals can be random or periodic and can have any repetition rate up to the maximum counting rates of the counters. This results in much faster scaling capabilities than are found even in most specially-designed scaling equipment. The scaling capability is often convenient in many measuring situations for such purposes as frequency-dividing or obtaining accurate time intervals which can, if desired, be very long, such as 1000 seconds or more.

The counters are arranged to scale in selectable decade steps between 10 and 10⁶ for the 20 Mc counter or 10⁻¹⁰ to 10⁻¹⁰ for the 50 Mc counter. To facilitate scaling, the dc-coupled inputs on the counters can be used to prevent base-line shifting on aperiodic or unequal signals. The scaled output is provided in the form of positive pulses at the rear panel.

The double-pulse resolution of the 20 mc counter is about 40 ns for 15 ns-wide pulses. The 50 mc counter will resolve 5 ns pulses spaced 20 ns apart. (Continued on page 8)

SPECIFICATIONS

**-hp- MODEL 5243L**

20 MC ELECTRONIC COUNTER

Same as Model 5243L except as follows:

**FREQUENCY MEASUREMENTS**

RANGE: 0 to 20 mc.

**RATIO MEASUREMENTS**

RANGE: f₁ = 1 to 10⁶ in decade steps.

**SCALING**

RANGE: 0 to 20 mc.

**PERIODS AVERAGED:** 1 to 10⁶ in decade steps.

**ACCURACY:** ±1 count of f₁ ± trigger error of f₁ divided by number of periods averaged. One count of f₁ is 1/10⁶, while 1 count of f₁ divided by n counts is 1/10⁶ for n periods averaged. Accuracy of frequency is applied to counter by counting bi-naries (internal Time Base Ext. jack). When frequency is applied to decade counters (external Time Base Ext. jack), it is divided by number of periods averaged.

**READS IN:** Dimensionalized; decimal point is positioned for number of periods averaged.

**SELF CHECK:** Same as Period Average self check above.

**SCALING**

FREQUENCY RANGE: 0 to 50 mc.

**FACTOR:** By decades from 10 up to 10⁶.

**PRICE:** $2,590.

**-hp- MODEL 5245L**

50 MC ELECTRONIC COUNTER

**FREQUENCY MEASUREMENTS**

RANGE: 0 to 50 mc.

**RATIO MEASUREMENTS**

RANGE: f₂ = 0 to 50 mc, f₁ = 0 to 1 mc in single periods.

**PERIODS AVERAGED:** 1 to 10⁶ in decade steps.

**ACCURACY:** ±1 count of f₂ ± trigger error of f₂ divided by number of periods averaged. One count of f₂ is 1/50, while 1 count of f₂ divided by n counts is 1/50 for n periods averaged. Accuracy of frequency is applied to counter by counting bi-naries (internal Time Base Ext. jack). When frequency is applied to decade counters (external Time Base Ext. jack), it divided by number of periods averaged.

**READS IN:** Dimensionalized; decimal point is positioned for number of periods averaged.

**SELF CHECK:** Same as Period Average self check above.

**TIME BASE**

**FREQUENCY (internal):** 1 mc.

**STABILITY:** Aging rate: less than ±3 parts in 10⁶ per 24 hours, after 72 hours of continuous operation. As a function of temperature: less than ±2 parts in 10⁶ per °C from 20 to 55°C. As a function of line voltage: less than ±5 parts in 10⁶ for ±10% change in line voltage from 115v to 230v rms. Short term stability: better than ±5 parts in 10⁶ with measurement averaging time of one second under constant environmental and line voltage conditions.

**ADJUSTMENT:** Fine frequency adjustment of approximately 4 parts in 10⁶ available from front panel through plug-in compartment. Course frequency adjustment covering range of approximately 1 part in 10⁶ is available at rear of instrument.

**OUTPUT FREQUENCIES (rear panel):** 0.1 cps to 1 me in decade steps, selected by Time Base switch; availability as defined under Output Frequencies above; stability same as internal time base; 1 volt peak-to-peak.

**EXTERNAL STANDARD FREQUENCY:** 1 mc, 1 volt rms into 1000 ohms required at rear panel BNC connector.

**GENERAL**

**REGISTRATION:** 8 digits in-line with Nixie® Nixie® tubes and display storage; 99,999,999 maximum display; total width of 8 digit display including illuminated units, annunciator and auto-positioned decimal point indication is 7 inches.

**SAMPLE RATE:** Time following gate closing during which gate may not be reopened is adjustable from approximately 0.1 sec to 5 sec for any gate time. Sample rate of a single measurement may be held indefinitely.

**INPUT:** Maximum sensitivity: 100 mv rms. Coupling: ac or dc, separate BNC connectors. Attenuation: step attenuator provides ranges of 0.1, 1, and 10 volts. Impedance: 100K ohms/volt (10K ohms at 100 mv); approximately 40 pf on 0.1 v range, 15 pf on 1 and 10v ranges. Overload: 50 v rms signal on 0.1v range; 150 v rms on 1v range; 500 vms on 10v range; ac coupling capacitor, 1 µF, 600 v.

**OPERATING TEMPERATURE RANGE:** -20 to +65°C.

**CONNECTORS:** BNC type, except for remote programming and BCD output.

**BCD OUTPUT:** Four-line BCD code output with assigned weights of 1-2-4-8 (128° state positive with respect to "0" state). This output is adjustable for point position and measurement units, suitable for systems use or output devices such as -hp- model 502A Digital Recorder, 590A, or 591A Digital-to-Analog Converter. Impedance is 100K each line with "0" state level approximately -8 v, "1" state level approximately +18 v.
Fig. 11. Typical measurement accuracy obtainable with new counters for frequency and period measurements. Curves assume a time base error of 1/100 s and a period noise-error of 3/10 V/N where N is periods averaged of a new counter.

Curves assume a time base error of 1/10 s and a period noise-error of 3/10 V/N where N is periods averaged of a new counter.

Fig. 12. Circuitry in counters is built up on removable computer-type circuit boards to achieve compact overall size and high accessibility.

**Fig. 13.** Typical measurement accuracy obtainable with new counters for frequency and period measurements. Curves assume a time base error of 1/100 s and a period noise-error of 3/10 V/N where N is periods averaged of a new counter.

Curves assume a time base error of 1/10 s and a period noise-error of 3/10 V/N where N is periods averaged of a new counter.

**REFERENCE LEVELS:** Approximately ±15 V, 300 ohm source; approximately ±6.9 volts, 1000 ohm source; print command step, +13 to 0 v, dc coupled, hold-off requirements from 1000 ohm source, chassis ground to +15 v (min) -15 v (max).

**REMOTE OPERATION:** All front panel functions may be programmed from remote location except for Sample Rate and Sensitivity control setting. Instrument provides all voltages necessary for remote control through rear panel connectors. Programming voltages for digital display are low level, −15 v dc maximum with approximately 5 K ohms looking into counter on signal control leads. Control may also be achieved by using external −15 v dc supply. Decimal point and measurement units may be illuminated from remote location at −170 vdc using internal or external supply.

**DIMENSION:** 160 in. wide, 5/4 in. high including plug-in, 161/2 in. deep. Hardware furnished converts unit to 19-inch wide by 5/4 inch high rack mount.

**WEIGHT:** Net, 32 lb. with blank plug-in; shipping 48 lb.

**PRICE:** $3,250.

**ACCESSORIES FURNISHED:** -hp- AC-16K cable, 4 ft. long, male BNC connectors, -hp- 8120-0078 Power Cord, 7Vz ft. cable, 4 ft. long, male BNC connectors.

**INPUT IMPEDANCE:** Approximately 50 ohms.

**INPUT VOLTAGE:** 50 mv to 1 v rms for optimum operation under worst-case conditions. Typical signal drop-out level is 10 mv rms.

**LEVEL INDICATOR:** Meter aids frequency selection; indicates acceptable voltage level.

**REGISTRATION:** Counter display is added to or subtracted from converter dial reading depending on whether mixing frequency is below or above measured frequency.

**ACCESSORY FURNISHED:** AC-16K cable, 4 ft. long, male BNC connectors.

**PRICE:** $500.00.

**INPUT IMPEDANCE:** Approximately ±1 period of standard frequency counted ± time base accuracy.

**OVERLOAD:** 50 volts rms, or ±150 volts peak, on X1 and X3; ±250 volts peak, on X10 and X100.

**ATTENUATOR RANGE:** 1, 3, 10, 30, and 100 mv rms; meter shows when signal to counter is within acceptable amplitude range.

**MAXIMUM AMPLITUDE:** Both channels continuously adjustable from −6 to +6 volts times multiplier position.

**FREQUENCY RANGE:** (When used as input signal discriminator) 0 to 2 mc.

**STANDARD FREQUENCY COUNTED:** 10° to 1 cps in decades from counter, or externally applied frequency.

**MARKERS:** Separate output voltage steps, 0.5 volts peak-to-peak from source impedance of approximately 7 k ohms, 100 pf available at rear panel of counter; negative step coincident with trigger point on input waveform for positive slope, and positive step coincident for negative slope.

**READS IN:** ms, s, ms, or sec with measurements unit indicated and decimal point positioned.

**ACCESSORIES FURNISHED:** AC-16K cable, 4 ft. long, male BNC connectors.

**WEIGHT:** Net 2 lbs., shipping 6 lbs.

**PRICE:** $300.00.

All prices f.o.b. Palo Alto, Calif.

Data subject to change without notice
HIGH-READABILITY DISPLAY

Besides their compact size, perhaps the most conspicuous feature of the new counters is the ease with which their display can be read. This comes about because the previous wide spacing necessitated by tube diameter now has been considerably compressed as shown in the illustration. The numerals have the same large size as previously, but the spacing is reduced about 30%, which results in a display with a more readable span. The reduction is achieved by using new "rectangular" Nixie® readout tubes, which were developed by the Burroughs Corporation at the request of the Hewlett-Packard Company. Combined with the display storage feature which keeps the numerals visually readable at all times with no "count-time" effect, a very pleasing display indeed is obtained.

The display system includes an automatically-positioned and illuminated decimal point, as well as an automatic, illuminated readout of the units of measurement (kc, mc, µsec, msec and sec.).

The counters are also arranged to operate with recently-developed -hp- auxiliary equipment to provide a printed record of measurements on paper tape or to obtain strip-chart or X-Y recordings by use of the -hp- 580A Digital-to-Analog Converter. For such purposes, the counters provide a binary-coded decimal (1-2-2-4) output at special connectors at the rear panel. Using the -hp- printer Model 562A (with option 14), the printed record of measurements can be obtained complete with indication of decimal point multiplier and units of measurement.

The BCD outputs are also useful with Dymec equipment to permit the counter measurements to be fed into automatic systems.

TIME BASE OSCILLATOR

The heart of the time base circuitry is, of course, a crystal-controlled precision oscillator. To achieve an oscillator with the stability shown by the curves discussed earlier requires an excellent crystal operating in a stable environment and maintained by a constant-amplitude drive. The crystal is one that has a high Q of about 2,000,000 to 5,000,000 and is exceptionally free from contaminants for good long-time stability. To achieve the needed environment, the crystal is operated in an oven with proportional-type temperature control to avoid cycling effects. The oven holds the crystal temperature constant within approximately 0.01 °C over a -20° to +55° C ambient range. To keep the crystal's physical excursions at a constant amplitude, the amplifier that maintains the crystal is AGC-controlled.

The crystal oven circuitry is arranged so that the oven heater is always energized so long as the counters are connected to a power source and even though the panel power switch is turned to off. The crystal itself is thus kept at operating temperature which greatly reduces turn-on effects.

ENVIRONMENTAL DATA

It is part of their specifications that the new counters have an operating temperature range from -20°C to +65°C, i.e., to +149°F. This upper operating limit is well beyond the temperature where grasping the knobs will burn the fingers. Operation at such extremes will be unusual for most users, but a design that embraces this range of temperatures assures broad performance margins for the instrument.

Time base stability is specified from -20 °C to +55 °C (131°F), although the time base operates to +65 °C. The narrower temperature range for specified stability occurs because the oven for the quartz plate in the time base operates at a temperature between 60° and 75° C, depending on the turnover temperature of the individual crystal. To allow some temperature differential between oven and ambient, time base stability is specified only to +55 °C, although operation to +65 °C is permissible.

Prototype samples of the instruments have been satisfactorily stored at temperatures ranging from -65°C to +85°C with no reduction in subsequent performance.

Prototype samples of the instruments have also been subjected without damage to severe mechanical tests such as the vibration test specified in MIL-E-16400D.

DESIGN GROUP

The electrical design group for the new counters and plug-ins included Robert L. Allen, Larry A. Amsden, LaThare Bodily, John H. Gliever, Dexter C. Hartke, Edgar G. Stromer, Jeffery J. Wolflington and the undersigned. The mechanical design group included Alfred Low, Charles S. Lowe, Stephen D. Nemeth, and David D. Smith. Valuable contributions were also made by Francis Berry, Leonard S. Cutler, Glen E. Elsea, Lawrence Lim, Rolf K. Murchison, and Irwin Wunderman.

-Charles M. Hill and Tracy S. Storer