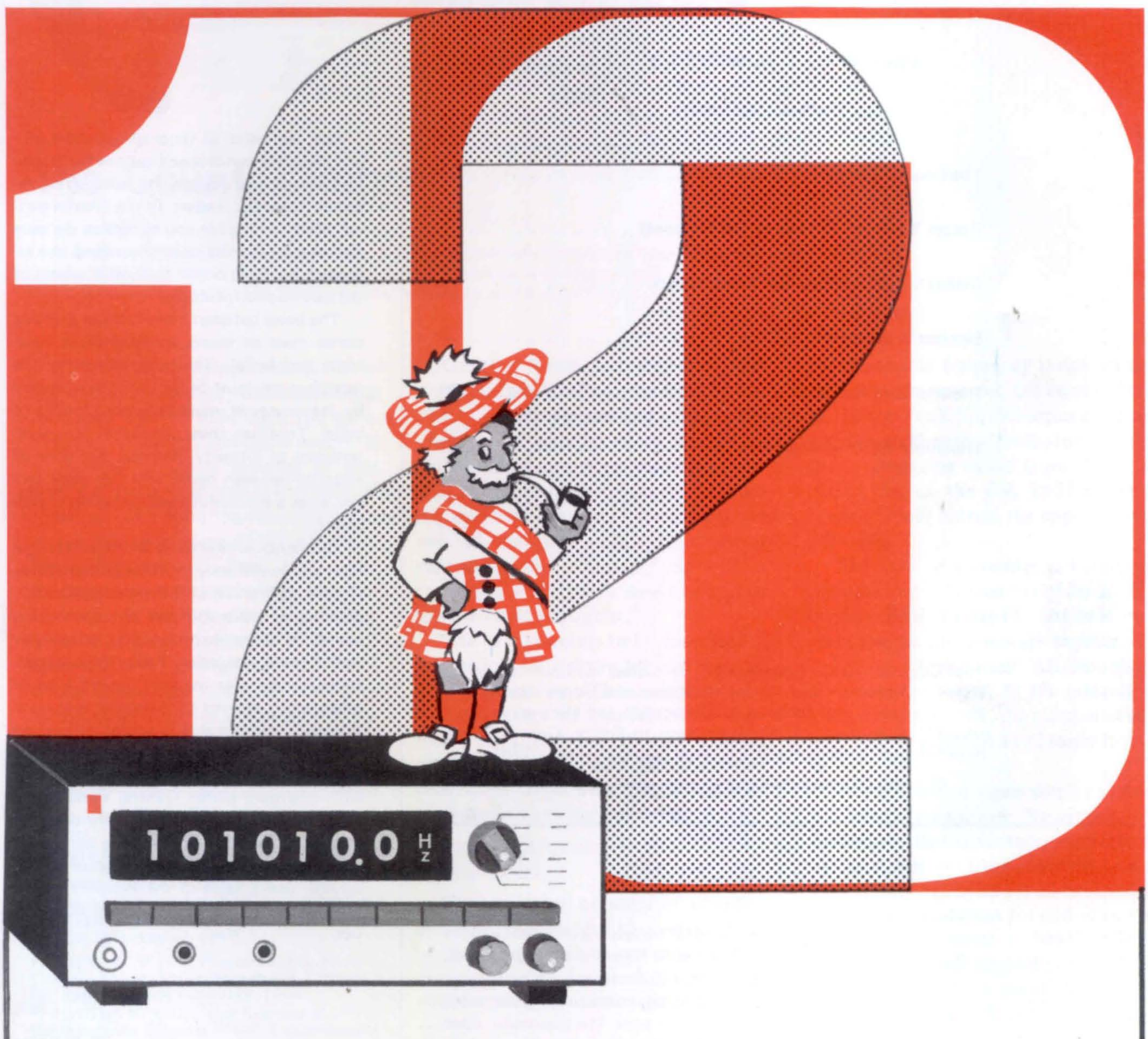
THE
GENERAL RADIO
Experimenter

VOLUME 43
NUMBERS 7, 8
JULY / AUGUST 1969



THE
GENERAL RADIO
Experimenter

VOLUME 43 NUMBERS 7, 8 JULY/AUGUST 1969

The *General Radio Experimenter* is mailed without charge to engineers, scientists, technicians, educators, and others interested in the instruments and techniques of electrical and electronics measurements. Address all correspondence to Editor, *General Radio Experimenter*, General Radio Co., West Concord, Mass. 01781.

THE COVER – The multiplicity of numbers is the seed for computing processes and the basis for science in general. In prehistoric times, with his 10 fingers as a group control, man counted by using twigs and pebbles. The Greeks and Romans supplied graphic control with their symbolic number-figures. Modern technology confounds the centuries-old use of 10 as a number base by adopting 2 as its number base. The conversion from decimal to binary system is the subject of our cover and, in a not-too-subtle manner, our little friend draws the attention of our readers to our line of new, inexpensive counters.

Our last editorial touched upon the subject of performance specifications for instruments and was designed to elicit some response from our readers. In the interim period, while waiting for you to receive the issue and to consider the questions raised, our attention has been drawn to another aspect of the specification problem.

The bond between manufacturer and customer must be based, in equal parts, upon *truth* and *belief*. The presentation by the manufacturer must be truthful; the reception by the customer must be with a feeling of belief. Together, these conditions denote attainment of integrity. Without that bond of integrity between maker and user there cannot exist a successful manufacturing organization.

Our personal sensitivity on this subject has been sharpened lately by a change in position. Recent assumption of the duties and responsibilities of editorship has not diluted our memories of, and experiences as, a customer rather than a supplier. From these experiences we are able to draw upon a fund of information related to customer problems. Formerly we were able to accept nothing we saw or heard in the manufacturing world without question. Our working relationship with engineers within General Radio, however, has been established upon the common ground of mutual respect and a continuing desire to give to our readers information, service, and a faith in the integrity of our engineering and in the quality of our product.

C. E. White
Editor

GR 1192 Counter

The Counter-Punch

Diminutive in size and cost, the GR 1192 Counters successfully match their bigger brothers in versatility, sensitivity, and immunity from noise. These instruments can interface with computers; they count up to 500 MHz (using the GR 1157-B Scaler) and offer precisions of 5, 6, or 7 digits.

The digital electronic counter is today a widely accepted, basic measuring tool used side by side with the oscilloscope, voltmeter, and signal source. It is also the youngest member of that family of tools inasmuch as we find first mention[1] of a counting-rate meter in a report from a meeting of the American Physical Society in April 1936. The development of the meter is an interesting study in evolutionary engineering, from its original application as an averaging device to register the output of a Geiger-Muller tube counter[2] to today's omnipresent tool for counting components and for measuring frequency and time. Performance, operability, and reliability have consistently improved while cost has steadily decreased.

General Radio has made notable contributions to this progress. The GR 1130 Counter was the first to apply the principle of parallel entry storage to prevent the intermittent read-in and display flicker of earlier counters.* Within the past two years we have introduced one of the first all-integrated-circuit general-purpose counters,[3] as well as creating a completely new concept in low-frequency counters.[4]

The new counters to be described in this article reflect the present state of device technology. These counters take full advantage of the latest developments in integrated circuits, display devices, packaging, and manufacturing procedures to produce a high degree of performance at a modest price.

Economics of Resolution and Number of Digits

The majority of users of counters apparently consider the measurement of frequency to be one of the counter's most important functions. They want a counter that operates over the maximum possible frequency range consistent with the cost and the current state of the art. The GR 1192-series of counters, designed with a recognition of this fact, covers the range from dc to 32 MHz. Use of the GR 1157-B Scaler (page 13) will extend the upper limit to 500 MHz.

The cost of a counter is highly dependent upon the number of digits in its display. Each displayed digit calls for a counting decade, a storage register, and the display device itself. All these items are relatively costly. In the interest of maximum economy, the number of digits is varied in the GR 1192 series from 5 to 7.

The number of digits displayed does *not* affect resolution. Resolution for frequency measurements, determined by the duration of the counting gate, is a maximum of 0.1 Hz for all counters of the series. Resolution for period and interval measurements is determined by the internal clock frequency (10 MHz), corresponding to a maximum resolution of 0.1 μs for each of the 1192-series instruments.

[1] Gingrich, et al, "A Direct-Reading Counting Gate Meter for Random Pulses," *Review of Scientific Literature,* December, 1936.

[2] Bousquet, A. G., "A Counting-Rate Meter for Radioactive Measurements," *GR Experimenter,* July-August, 1947.

[3] Frank, R. W., "A Programmable 20-MHz Counter-Timer Using Integrated Circuits," *GR Experimenter,* June-July, 1968.

[4] Westlake, N. L. Jr., and Bentzen, S., "The Recipromatic Counter," *GR Experimenter,* June-July, 1968.

*U. S. Patent No. 3,328,564

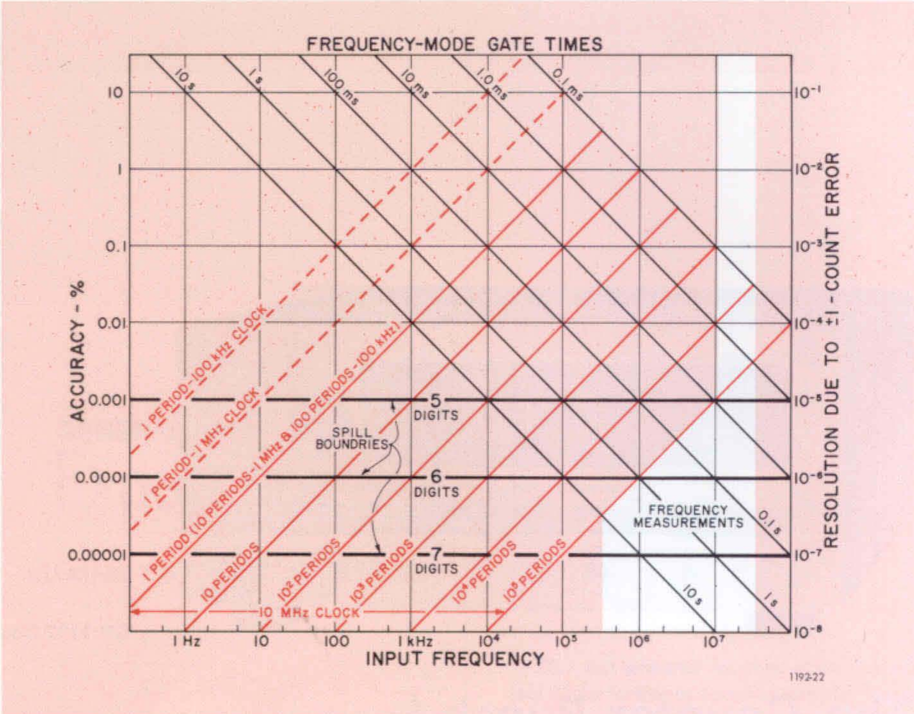


Figure 1. A summary of the GR 1192 resolution and display characteristics in its PERIOD and FREQUENCY modes. Within the white area resolution is highest in the FREQUENCY mode. The 1-ms GATE TIME prevents spill-over at the highest counting frequency; for period measurements, the 100-kHz counter clock permits up to 1-s periods to be measured without spill-over in the 5-digit counter, while the 10^5-PERIODS control permits parts-per-million resolution at an input frequency of 1 MHz.

More About Resolution

The wide range of counting-gate times (100 μs to 10 s) and period-measurement clock frequencies (0.1 μs to 10 μs) permit even the 5-digit counters to display the most significant figures of a measurement without spill-over (Figure 1). All the counters incorporate a lamp indicator to warn that, in the interest of increased accuracy, the more significant figures have been spilled-over from the register.

Since the best time resolution of a counter is established by a maximum counter-clock rate, period measurements become less accurate as the input frequency is increased. For example, in a single period, a 1-MHz signal will produce a reading of 10 counts. In order to increase the accuracy of time measurements, up to 10^5 periods of the input signal may be averaged. This time-averaging process has the side benefit of reducing the effects, in the displayed data, of noise on the input signal by approximately the amount of the averaging (20 dB per decade of averaging).

The resolution of the GR 1192 for measurement of different input signals of good waveshapes, using frequency-, period-, or multiple-period measurements, is shown in Figure 1. The figure is relatively complex; fortunately, all the complexity is in the figure because the GR 1192 has both an automatically-positioned decimal point and a display of the dimensional unit of the measurement. Note that the same resolution is obtainable whether you measure with the 5-, 6-, or 7-digit counter because the largest numbers are displayed by using sufficiently short gating times. Conversely, the smallest numbers are displayed by using relatively long gating times. Since each counter in the 1192 series has identical gating-time controls, resolution is identical from one counter model to another.

Other Characteristics

In addition to making single- or multiple-period frequency measurements, the GR 1192 performs the other basic counter functions of serial accumulation or time-interval measurements, or it can establish non-decimal time-base ratios. As with the measurement of frequencies, the wide range of clock ratios (and time-base scaling) permits full resolution while accommodating even the least-costly 5-digit display.

- In serial accumulation or simple counting, a measure is continuous as long as the operator permits the counting-gate in the instrument to remain open. In the GR 1192, control of the gate is either manual or remote by means of start and stop pulses, or by a remote signal. Often it is desired that the counter present a total count over an extended interval, rather than the repetitive short interval counts. Such requirements exist in production control, or when intervals such as pulse duration are measured. A total count can

S. Bentzen received his BSEE degree from Indiana Institute of Technology in 1962, joined General Radio the same year, and completed work for his MSEE degree from Northeastern University in 1966. Presently he is a development engineer in the GR Frequency Group. He is a member of IEEE.

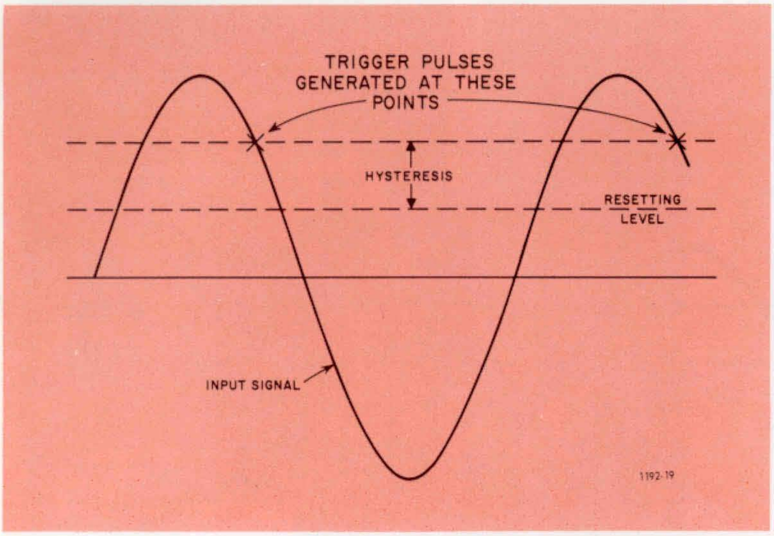


Figure 2. Illustration of hysteresis applied to trigger pulses.

be retained by the counter memory until the counter is directed to present it or to erase the memory.

- Measurement of a time interval can be defined by the duration of a single pulse. In the time-interval mode it is important that the internal clock frequency be high for good resolution, but not so high that a long time interval would cause register spill-over. The highest obtainable resolution in interval measurements is 0.1 μs in the 1192 series. In order to prevent loss of the more significant digits, the counter clock frequency can be reduced to 100 kHz, which permits the measurement of an interval as long as 100 seconds without spill-over.
- Another useful measurement mode is that of RATIO. The frequencies of two signals A and B are related: A/B. The B signal is used effectively to establish a new time base for the counter, as in these examples: A 100-Hz signal connected to the B INPUT can produce a gating time as long as 1000 seconds. Ratios of a non-decimal relationship, e.g., 60 ms, can be obtained when a stable input frequency of 16.6 kHz is fed into the B INPUT. Such a ratio is useful if you desire to display rpm. In a similar manner, it is possible to establish ratios that permit displays of flow in gpm, velocity in mph, and other parameters.

Some Design Notes

There are no panaceas in the design of counter input circuits. The thoughtful designer gives the user what he wants – high input impedance, good sensitivity, and low internal noise. It is necessary, however, that the user understand, and use intelligently, the input controls designed into the GR 1192 series.

The input circuit of the GR 1192 feeds a level detector that produces a pulse when the signal to be measured passes through a predetermined level. The level detector has a 10-mV hysteresis magnitude, referred to the input terminals, which effectively prevents

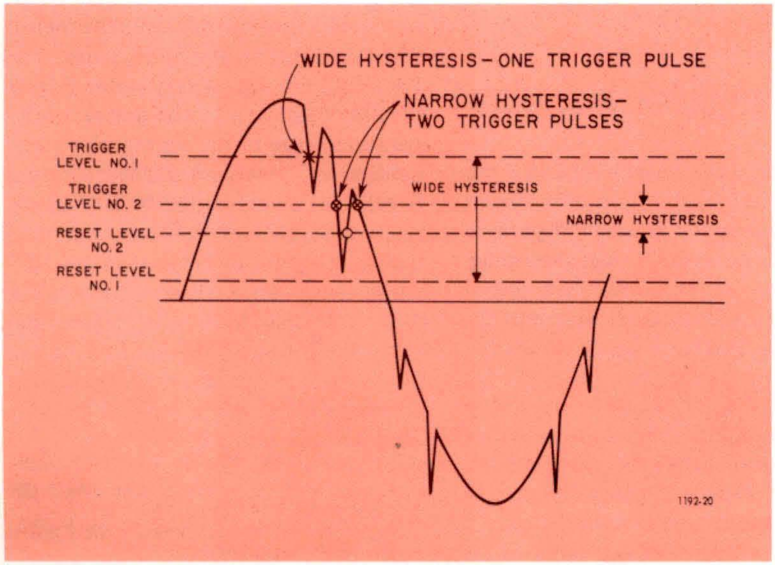


Figure 3. Example of hysteresis widening to reduce false triggering.

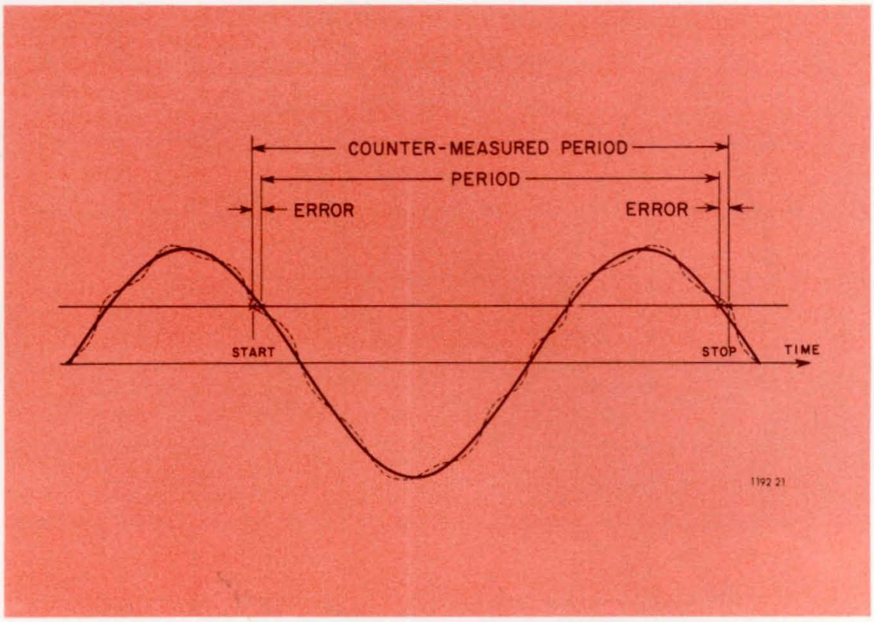


Figure 4. Effect of internal counter noise upon trigger point.

any false triggering actions by an input signal containing noise (Figure 2). Pulse triggering by noise may be prevented by expanding the hysteresis magnitude to such an extent that the hysteresis is greater than the superimposed noise (Figure 3).

Good practice indicates that the hysteresis magnitude should always be kept as wide as practical to overcome the effects of additive noise. In the GR 1192, hysteresis magnitude can be made great enough, by adjustment of the INPUT ATTENUATOR control, to overcome the triggering effects of unwanted noise levels from 10 mV to 10 V. If noise is superimposed on a waveform, the TRIGGER LEVEL control can be adjusted to move the triggering level to a point on the waveform which has less noise.

Optimum performance in the face of superimposed noise is obtained when the counter triggers on the maximum slope position of the input waveform. The TRIGGER LEVEL control, in combination with the INPUT ATTENUATOR control, permits threshold adjustment over a range of ±100 volts. Since the negative transitions are usually faster, we have chosen a negative triggering wave slope in our design.

The input impedance of a counter should be high enough so that very little loading of the input circuit takes place under operating conditions. The input impedance of the GR 1192 is 1 MΩ shunted by 27 pF. These values permit the operator to use an input probe such as the GR P6006 which has an impedance of 10 MΩ shunted by 7 pF.

In a good counter, the internal input noise should be very low and usually will be insignificant compared to the noise that has already been imposed upon the input-signal waveform. Internal noise adds to the signal and will cause the triggering point to vary in time (Figure 4).

Error in a period measurement due to noise impressed upon a signal can be expressed as:

$$\epsilon = \frac{N}{\pi S n} \times 100\%,$$

in which N is the noise level and S the signal level in the same units of measurement, and n is the number of periods averaged. If we assume a signal-to-noise ratio of 40 dB, the error in a single-period measurement is calculated to be: $\epsilon = 0.318\%$. This value is well within the resolution of the counter.

When the input signal is very, very clean, the limit of measurement accuracy is established by the noise in the input circuitry of the counter. The effective input noise of the 1192 counter typically is of the order of 50 to 100 μV. Thus the external triggering error in microseconds is less than $\frac{0.0002}{\text{signal slope in } \mu s}$. Interested readers can refer to the December 1962 issue of the *GR Experimenter* for a general article discussing error sources encountered in counter measurements, and to the February 1966 issue for an article specifically discussing noise-produced errors.[5, 6]

The accuracy of any counter is almost completely dependent upon the accuracy and stability of its time-base oscillator. Economical compromises involved consideration of low-cost ovens or crystals that operate over the instrument ambient-temperature range. The GR 1192 employs a very stable 5-MHz crystal, operating in the ambient-temperature range of the counter, for internal-frequency control. Its temperature coefficient is less than 3×10^{-7} in the range 0 to 55°C. Total frequency shift due to temperature is less than 4×10^{-6} while long-term drift is less than 2×10^{-6} per month. If higher stability is desired in the counter, it can be locked to an external frequency standard, with the attendant gain in accuracy and stability.

[5] McAleer, H. T., "Digits Can Lie," *GR Experimenter*, December 1962.

[6] Frank, R. W., "Input Noise," *GR Experimenter*, February, 1966.

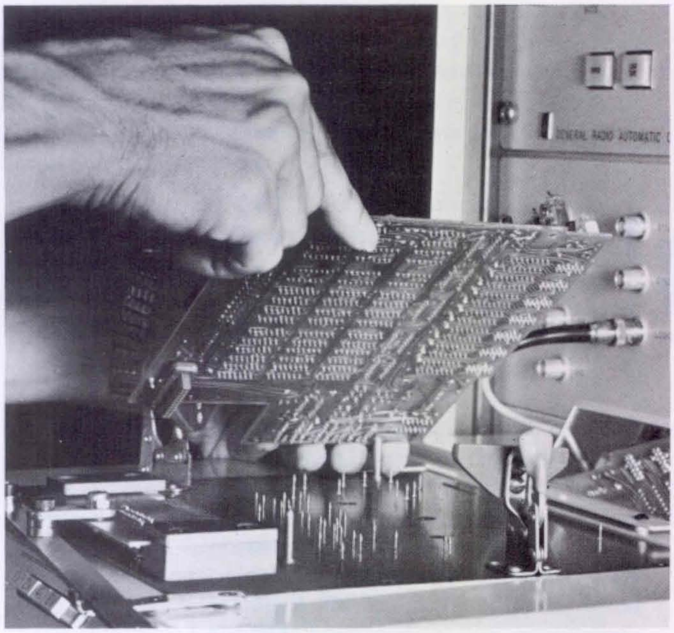


Figure 5. Automatic testing system for the GR 1192 etched-board subassemblies.

The physical size of counters has been decreasing steadily and this GR unit is no exception. In height, the progress has been from 16 inches to 3-1/2 inches, with a corresponding shrinkage to one-half rack width.

A Word About Production Control

The GR 1192 incorporates numerous computer-type integrated circuits mounted upon three etched-circuit boards. In order to test each circuit board, GR constructed an automatic computer-controlled test assembly that receives each type board in an individual test jig (Figure 5). A total of 90 points is tested on one board. The associated computer is programmed to perform more than 300 independent tests after it has first determined that the circuit has been conditioned for testing. The test assembly identifies failures and reports the failures in a printed record, using an associated teletypewriter. Upon completion of the automatic test program, the boards, okayed by the computer, are removed by the operator and installed in the instrument for a final over-all functional check.

—S. Bentzen

ACKNOWLEDGMENT

The author gratefully acknowledges the assistance of B. Sargent in the electrical design of this instrument and of J. McCullough for production engineering.

Complete specifications for the GR 1192 are available on the catalog page, included as a tear sheet inside the back cover of this issue, removable for insertion in GR Catalog T.

Recent Technical Articles by GR Personnel

"On Estimating Noisiness of Aircraft Sounds," R. W. Young and A. Peterson, *Journal of the Acoustical Society of America*, April, 1969.*

"Spectrum Analysis of Stationary Noise Signals," W. R. Kundert and A. P. G. Peterson, *Sound and Vibration*, June 1969.*

"High-Gain Phase Detector Circuit Uses No Transformers," C. C. Evans, *Electronic Design*, May 24, 1969.

"Microwave Tuners," T. E. MacKenzie, *Electronic Instrument Digest*, April 1969.

*Reprints available from General Radio.

A major instrument we employ to promote service to our readers is, of course, the *Experimenter*. Do not overlook, however, the existence of the supplementary handbooks, application notes, and reprints of technical articles, such as those above, available to our readers. A listing of these publications will be mailed to you upon request to the Editor. Other questions related to GR instruments or engineering are also welcomed.