THE GENERAL RADIO Experimenter

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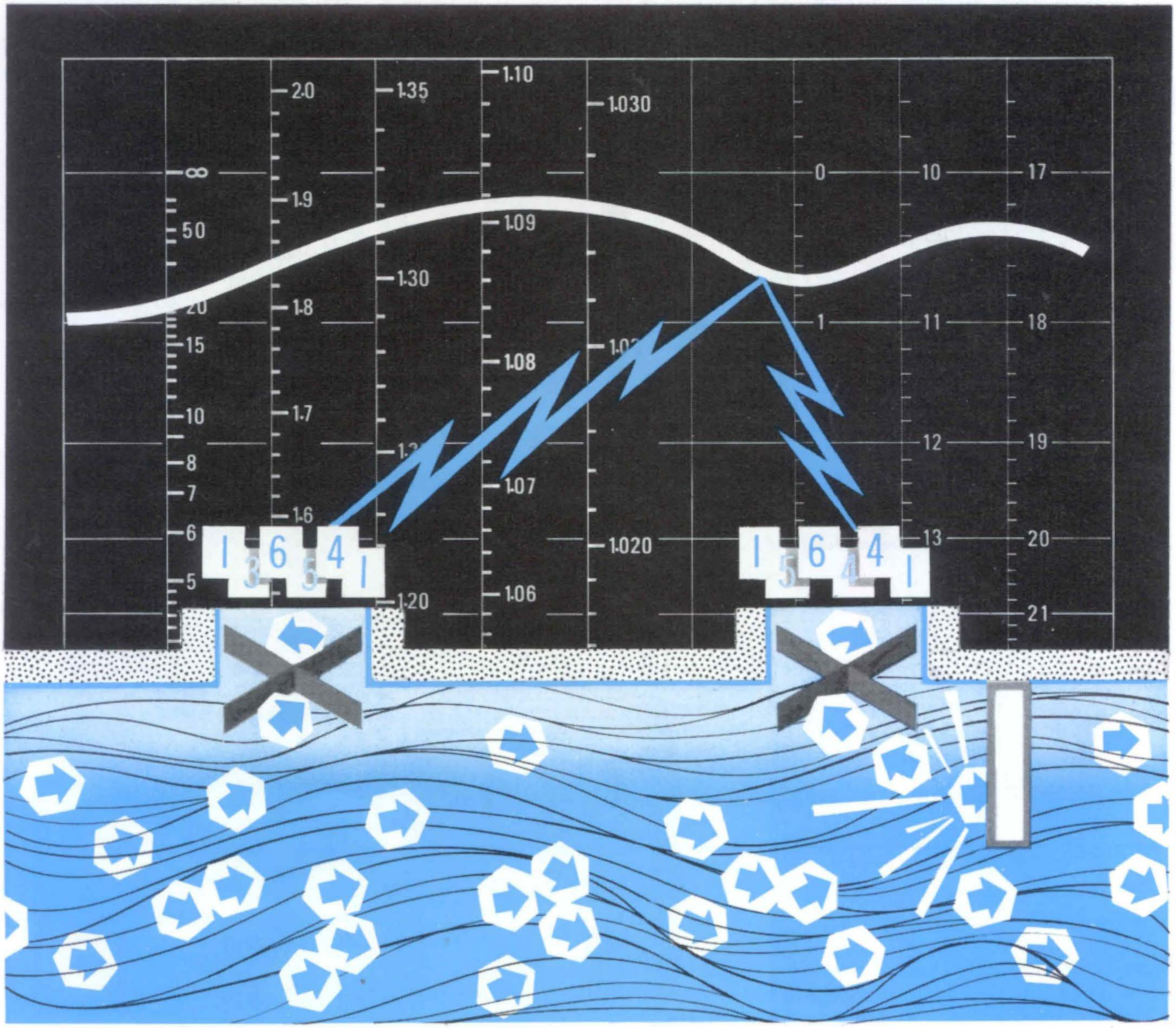

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The *General Radio Experimenter* is mailed without charge to engineers, scientists, technicians, educators, and others interested in the instruments and techniques of electrical and electronics measurements. Address all correspondence to Editor, *General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

THE COVER Broadband testing, using sweep-frequency reflectometry techniques, has been accepted as a time-saving, cost-reducing tool in research and industry. Our cover illustrates, in an abstract way, the ease of applying reflectometry techniques, the simplicity of the directional coupler which transmits the basic information, and the clarity of the observed parameter in the form of an oscillogram upon the graticule.

THE NEW LOOK

We hope you were pleasantly surprised at the look of the new *Experimenter* when it arrived at your desk in February. The change in size and format is evidence that General Radio recognizes its obligation to readers of the *Experimenter* to present information related to new measuring instrumentation, or improvements in previously issued models, in a form both provocative and attractive. An obligation exists also to supply technical information that is worthy of retention in your files.

Looking back through the years and reading Vol. 1 No. 1 issued in June, 1926, I was pleased to note that the *Experimenter* was stipulated to be a new General Radio *service* to experimenters in home laboratories. Service still is our theme but the direction has changed from the home laboratory of the radio hams to the laboratories of science and industry, to the production areas serving commerce and trade, and to the several echelons of measurement accuracy represented by standards and calibration laboratories.

The *Experimenter* has a significant role to play in advancing the state of the art of measurement engineering. At GR we are aware that many of our readers are part of the task forces that generate so much of what is new, useful, and available in the measurement and control fields. We hope to draw upon the experiences of our readers for some of the source material from which editorials will be generated in the future. The Editor's office at GR is prepared to receive any comments you feel will be of benefit to our readers. Spring is here — let's get together as a team and "Play Ball!"

C E White

C. E. White
Editor

The New Sweep–Frequency Reflectometer

An integrated system for direct-reading reflectometry measurements, which is remotely programmable, capable of simultaneous dual-channel presentations, and easy to operate. Expandable SWR and loss scales permit in-depth exploration of resonance bandwidths, perturbations, and residual reflections. Use of GR900® components significantly reduces inherent system errors and establishes an extremely low residual SWR.

by T. E. MacKenzie, J. F. Gilmore, M. Khazam

INTRODUCTION

The GR 1641 Sweep-Frequency Reflectometer operates in the *frequency domain*. Using a sine-wave signal to the unit being tested, it measures total reflection (SWR) and transfer (insertion loss) as a function of frequency.

This method should not be confused with the pulse-echo method (time-domain reflectometry), originally used for detection and location of faults in cables. The pulse-echo method employs a visual display which presents individual reflection locations as *magnitude* versus *distance*. The frequency-domain-reflectometer display presents *net reflections* versus *frequency*.

The introduction of low SWR connectors and the advance in performance of directional couplers have encouraged the move from fixed frequency measurements in coaxial circuits to sweep-frequency techniques. Sophisticated systems now operate over broader bandwidths and to tighter specifications. Some complications remained, however, including the need to establish calibrated reference levels for each measurement and a lack of direct SWR readout.

The GR 1641 was designed to eliminate such faults. It provides broad frequency coverage, 20 MHz to 7.0 GHz, in two bands by means of two integrated rf units. Band changing is simple; no time is lost in dismantling or reassembling components. Initial self-calibration is not repeated for an ensuing series of SWR or loss measurements within the instrument's range. High order of accuracy is assured by directivity greater than 43 dB at 1.0 GHz and 37 dB at 7.0 GHz plus SWR (for equivalent source and for the detector) less than 1.03 at 1.0 GHz and 1.06 at 7.0 GHz. All this is available at moderate cost.

For test purposes, only two panel controls require adjustment by the operator – the functional DISPLAY switch and the RANGE switch. The former controls measurements of SWR, INSERTION LOSS, or both; the latter establishes SWR readings at full scale equal to ∞, 2.0, 1.35, 1.10, and 1.03 or full-scale losses of 0, 10, 17, 27, and 37 dB. The controls are programmable for remote operation.

Test data are read directly from the panel meter in the operational modes corresponding to fixed frequency, stepped frequency or slow sweep. In the continuous sweep mode, direct and simultaneous indications of SWR and loss are presented on an auxiliary oscilloscope.

The 1641 is shown in use in Figure 1 with commercially available auxiliary equipment types which are in the normal

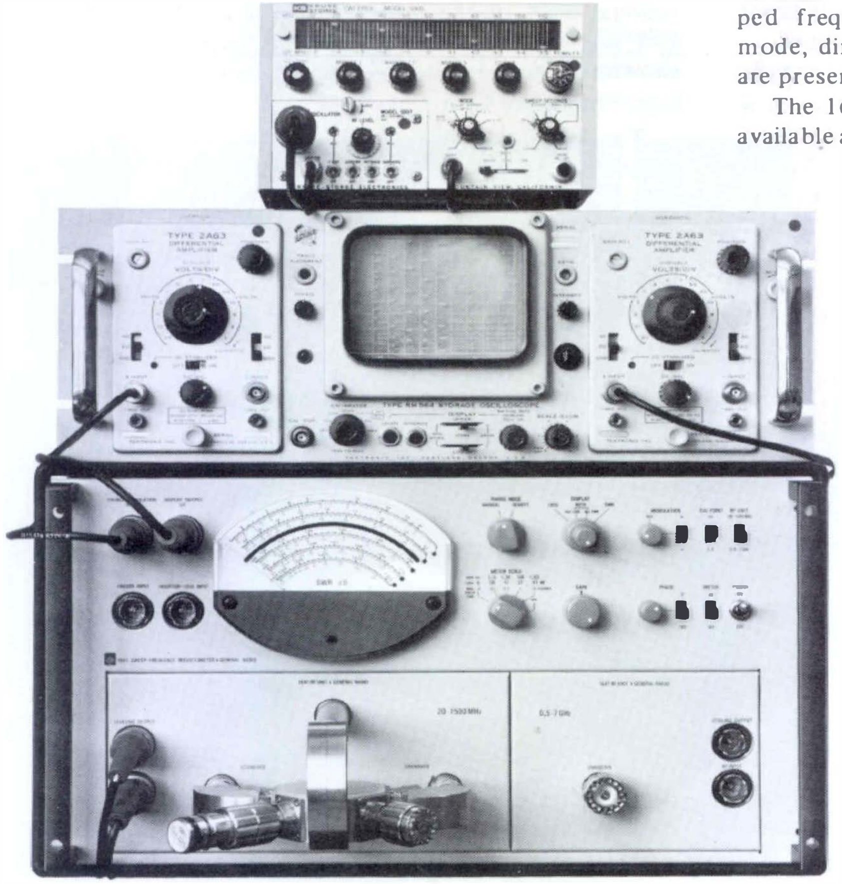

Figure 1. A test arrangement using GR 1641 Reflectometer.

Figure 2. Reflectometer panel.

complement of a testing laboratory. The assembly comprises the 1641, an external rf source, and an external oscilloscope. Figure 2 shows the panel of this reflectometer, with the low-frequency rf unit (20 to 1500 MHz) on the bottom left, the high frequency rf unit (0.5 to 7.0 GHz) on the bottom right; both are mounted in the main frame with the indicator unit. The transfer detector is separate for flexibility. The device to be measured is connected between the UNKNOWN port of the 1641 and the transfer detector, the detected output of which is connected to the 1641 through a cable.

SYSTEM DESCRIPTION

The interconnection of the various components of the reflectometer system for SWR and loss measurements is shown in Figure 3. The sweep source is modulated by a 10-kHz square-wave signal from the 1641. The detected return-loss and insertion-loss signals are fed to the indicator, basically a 10-kHz tuned amplifier, the output of which is displayed on the oscilloscope after rectification. The blanking pulse of the sweep source is fed to the indicator to provide a zero-retrace output level, and also to trigger the channel switch for an alternate display of return loss (or SWR) and insertion loss with each sweep.

Low-Frequency Unit *

The low-frequency unit consists of a balun and a summing junction, which together form a bridge circuit. Leveling is accomplished by means of a detector at the balun junction. A second detector provides the SWR information. Simple conversion of the bridge for comparison measurements is made possible by the external connection of the reference standard termination. The residual SWR of the bridge is less than 1.015 to 1.0 GHz and less than 1.02 to 1.5 GHz. A schematic diagram is shown in Figure 4a.

High-Frequency Unit

The high-frequency rf unit consists of two directional couplers, two detectors, and appropriate interconnecting transmission lines. A schematic diagram of this unit is shown in Figure 4b. The first directional coupler (the leveling coupler) couples part of the input signal to the leveling detector, which levels an rf source when the 1641 is

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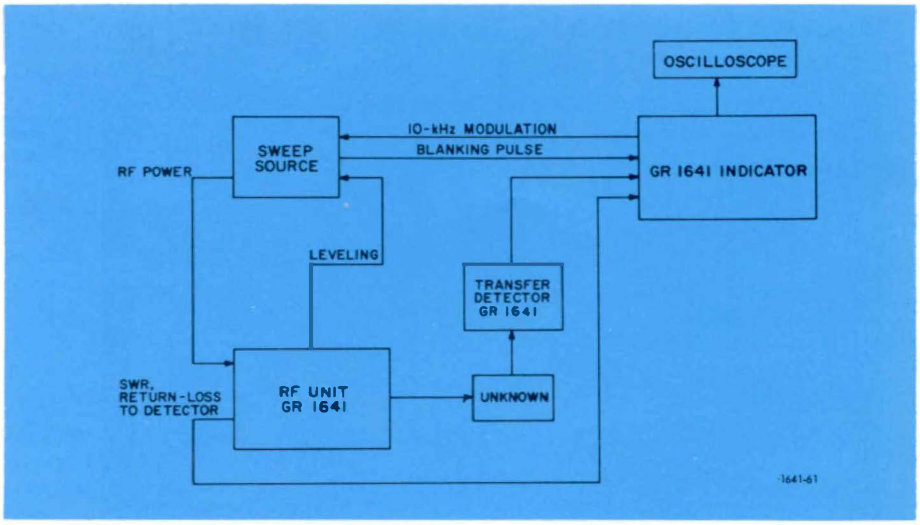
*Patent Pending.

Figure 3. Interconnections of test equipment.



operating in a sweep-frequency mode. The remainder of the input signal goes to the measuring coupler where part is coupled to the UNKNOWN connector and the rest is absorbed by the built-in termination.

The directivity of the measuring coupler is greater than 40 dB from 0.5 to 4.0 GHz, and greater than 37 dB from 4.0 to 7.0 GHz. The coupling characteristics of the measuring and leveling couplers are identical so that the magnitude of the signal reaching the UNKNOWN connector follows the frequency response of the leveling detector.

The high directivity, wide-band directional couplers are the heart of the rf unit. These directional couplers have an asymmetric coupling region of three sections. The theoretical design of such units to achieve a desired coupling characteristic is well known and results have been tabulated.[1]

While achieving a desired coupling response is a relatively simple matter, the high directivity of these coupler units requires the utmost care in design and fabrication. The wide bandwidth covered by these units makes it inevitable that any characteristic impedance errors or discontinuities will add at some frequency, so all components must be designed and made properly. Thus the built-in termination, support beads, connector and line-size transition must all have extremely low SWR's, and the coupling-region dimensions must be nearly perfect to achieve this level of performance. These characteristics have been attained in the 1641, resulting in a measuring coupler with substantially higher directivity than is available in any other commercial multi-octave coupler.

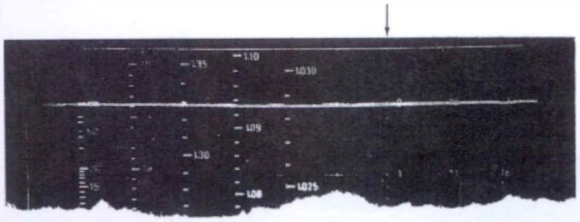


Figure 5. Typical calibration curve for insertion-loss measurements in 2.0- to 4.0-GHz range, full scale = 0 dB

Transfer Detector

Both the external transfer detector, used for insertion-loss measurements, and the built-in SWR detector are selected to have the same frequency response as the leveling detector. Both have a 10-dB attenuator built in to improve impedance match. The maximum power level at the detectors for an on-scale indicator reading is approximately −10 dBm. It is impossible, while maintaining an on-scale reading, to drive the detectors outside the square-law region. The leveled power required from the source is −10 dBm plus the dB-coupling factor of the directional coupler.

Data Presentation

A typical calibration curve for insertion-loss measurements is shown in Figure 5. The flatness of this curve depends mainly upon the similarity of the coupling characteristics of the leveling and measuring couplers and upon the tracking of the leveling and the transfer detectors.

Typical calibration curves for SWR measurements are shown in Figure 6. The over-all flatness of these responses

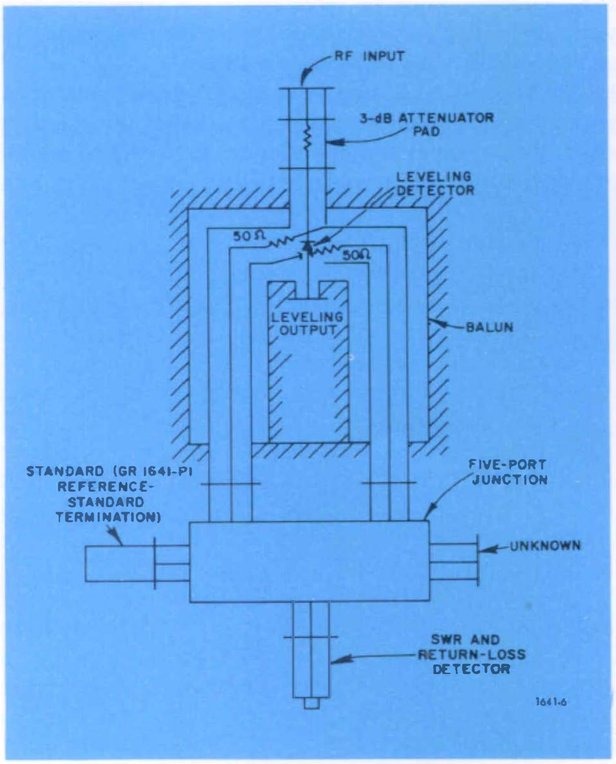


Figure 4a. Schematic diagram of low-frequency rf unit.

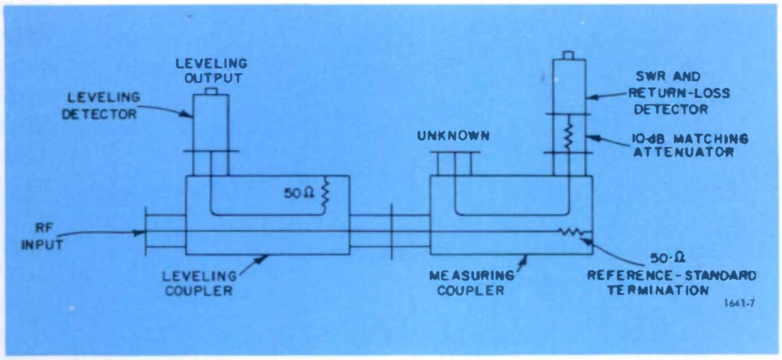


Figure 4b. Schematic diagram of high-frequency unit.

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[1] Levy, R., "Tables for Asymmetric Multi-Element Coupled-Transmission-Line Directional Couplers," *IEEE Transactions on Microwave Theory and Techniques*, May 1964, pp 275-279.

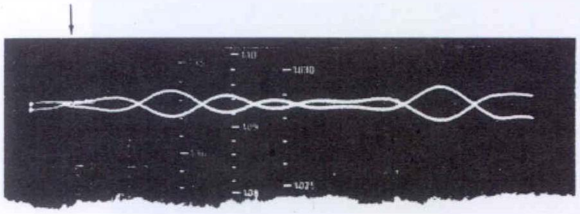

Figure 6. Typical calibration curves for SWR measurements in 2.0- to 4.0-GHz range. full scale = ∞

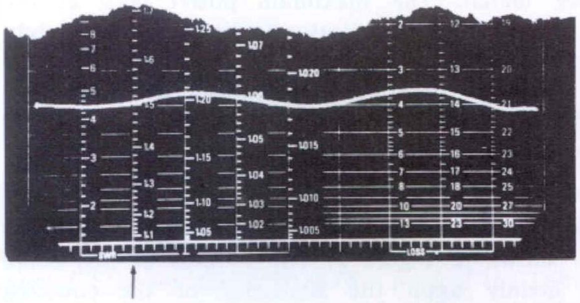

Figure 7. SWR measurement of 1.5:1 mismatch in the 2.0- to 4.0-GHz range; full scale = 2.0.

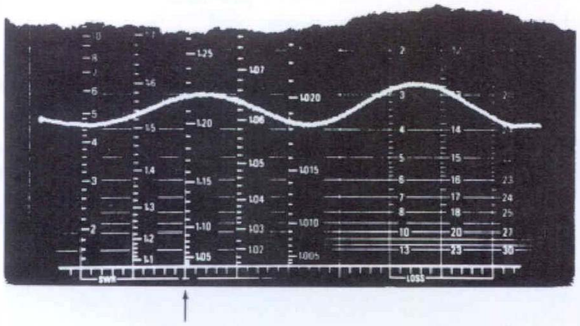

Figure 8. SWR measurement of 1.2:1 mismatch in the 2.0- to 4.0-GHz range; full scale = 1.35.

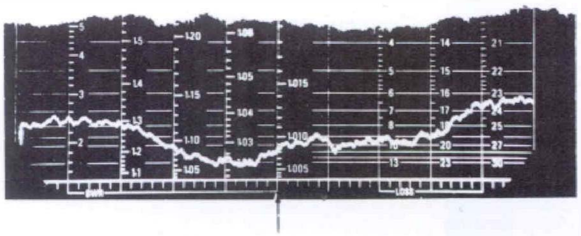

Figure 9. Residual SWR of typical rf unit from 2.0 to 4.0 GHz; full scale = 1.03.

depends upon the similarity of the coupling characteristics of the two couplers and upon the tracking of the SWR and the leveling detectors. The ripple in these traces and the difference between the open- and short-circuit curves depend mainly on the equivalent source match which, at the UNKNOWN connector, is less than $1.01 + 0.007 f_{GHz}$.

SWR measurements of typical standard mismatches are shown in Figures 7 and 8. These curves illustrate typical system performance at SWR levels of 1.5 and 1.2 respectively. The extremely low residual SWR of a typical high-frequency rf unit is shown in Figure 9.

Design

Figure 10 shows a block diagram of the GR 1641 Indicator. Two identical preamplifiers are connected to the main amplifier chain through the channel switch. The channel selection is accomplished through the DISPLAY switch, which has three positions: SWR, LOSS, and BOTH. In the BOTH position, the channel-switching circuit controls the channel switch; blanking pulses from the sweep generator cause alternate presentation of the preamplifiers to the main amplifier chain. The result is an alternate display of the SWR and LOSS functions with subsequent sweeps.

The detector is a synchronous detector of the sample-and-hold type. Gate pulses, derived from the 10-kHz oscillator, connect a charging capacitor to the output of the final amplifier for a duration of approximately three microseconds. A phase-shift network in the amplifier chain is adjusted so that the gate pulses coincide with the positive peak of the 10-kHz signal at the final amplifier. The value of the charging capacitor determines the response time of the detector and the over-all bandwidth of the indicator, since this is a synchronous detector. The value of the charging capacitor must be selected for an acceptably low noise-output level; the sweep speed must then be limited to a value compatible with the response time.

The METER SCALE switch controls the attenuator in the main amplifier chain and also the value of the charging capacitor. This relieves the operator from having to search for the optimum compromise between output noise and sweep speed; it is only necessary to set the sweep time to a value greater than or equal to the minimum recommended sweep time indicated by the meter-scale control.

Usually in systems that use diode detectors, for example, the 1641, the operator must take special precautions to prevent the detectors from functioning outside the square-law regions, thereby introducing gross errors. This is not so with the 1641 indicator. The indicator's sensitivity range is selected so that, for on-scale meter readings, the source output power must be set to a level compatible with that required for detector square-law operation. If excess power is available, the measurement range can be extended by this amount by recalibrating the instrument for SWR, with a standard mismatch other than an open or short, or for insertion loss, with a precision attenuator. For recalibration with a standard mismatch of 2:1 SWR ratio, a switch is provided that modifies the attenuator switching sequence of the indicator to maintain the meter SWR calibration for extended range operation.

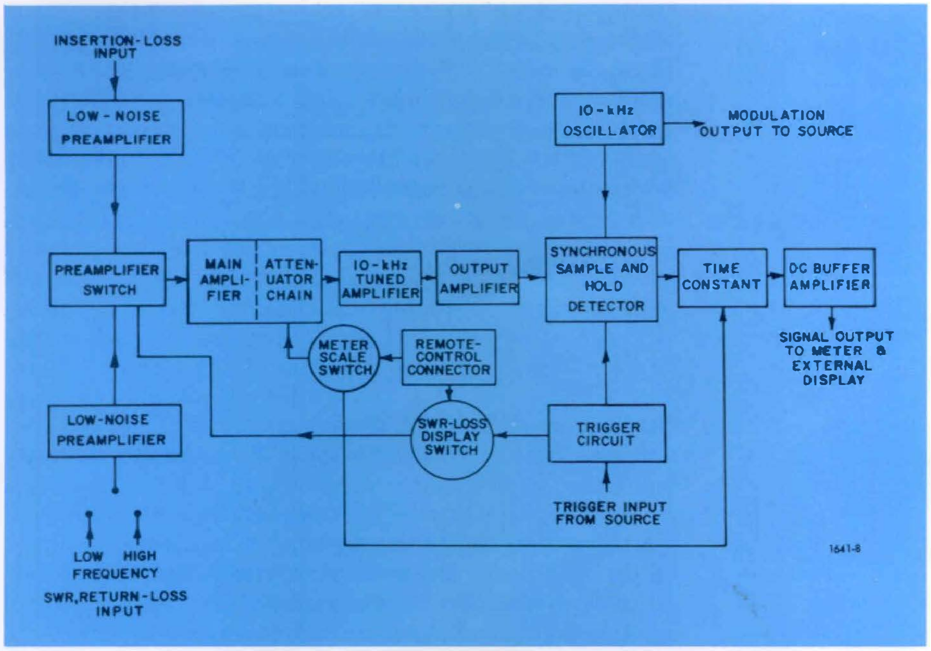

Figure 10. Block diagram of 1641 Indicator.

The diode detector, as generally used with low-frequency tuned amplifiers, has a useful operating range of approximately 30 dB. This range is limited at low signal levels by the noise of the system and at high signal levels by the deviation from square-law operation. One method to extend the square-law range is to shunt the detector output with a properly chosen resistor. Figure 11 shows the measured deviation from square-law for a diode detector as a function of input power for three values of the load resistance. The optimum value of the load resistor is approximately $\frac{1}{2}R_d$, where R_d is the dynamic resistance of the diode. When a low resistance dc return path is present, as through a choke, the optimum load resistance is approximately equal to R_d. The advantage of an increase in dynamic range, brought about by this method, is offset somewhat by the disadvantage that there is a reduction in sensitivity caused by the addition of the shunt resistor.

In the 1641 indicator design, a dc return through a choke is presented at the input. The optimum load resistance is provided by the adjustable input impedance of the preamplifier. The disadvantage mentioned above is thus bypassed. The wide dynamic range of the 1641 indicator system is achieved by the extension of the detector square-law range at high signal levels and by the reduction of the indicator bandwidth to a very small value in the most sensitive measurement range. This narrow bandwidth is made possible through the use of the synchronous-detector technique previously described.

The SWR-loss display and meter-scale control functions can be remotely controlled by contact closures to ground

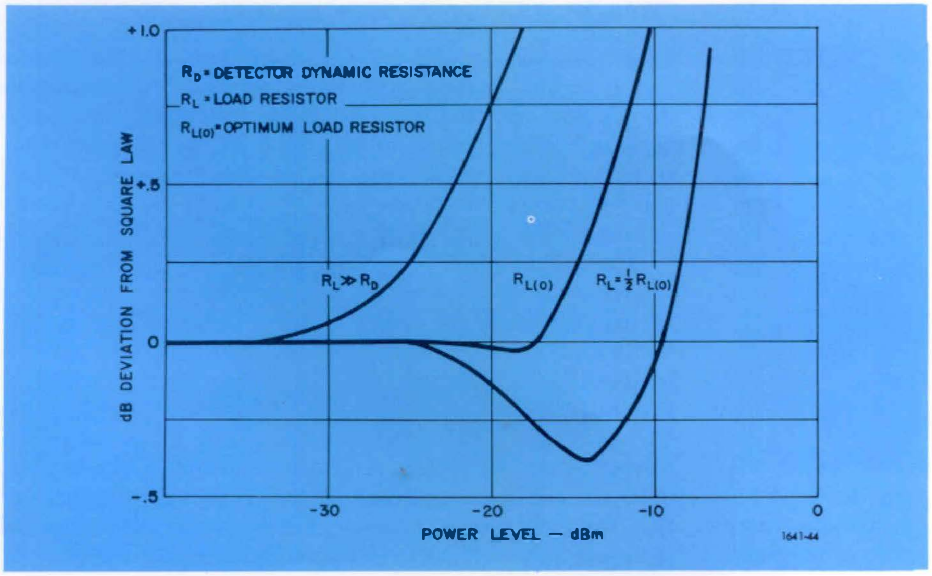

Figure 11. Diode detector — square-law range extension.

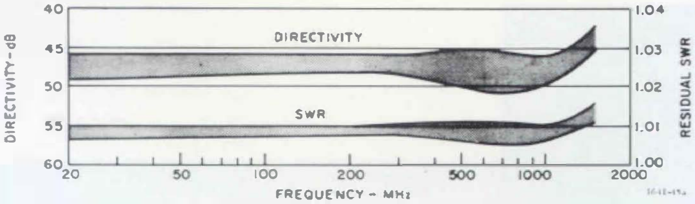

Figure 12a. Typical spread of directivity and SWR data for low-frequency rf unit.

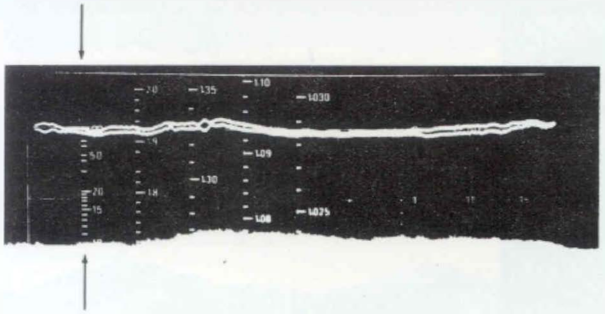

Figure 12b. Dual presentation of typical response data, using open- and short-circuit terminations in 0.5- to 1.0-GHz range; full scale = ∞.

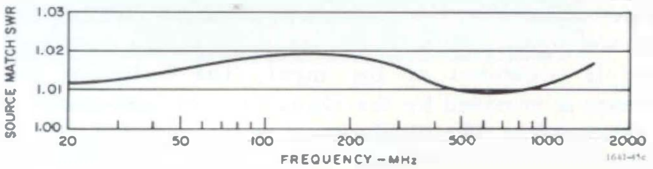

Figure 12c. Residual source match to unknown based on measurements of a unity reflection coefficient with varying reflection phase — low-frequency rf unit.

through electronic or mechanical switches. This allows the 1641 to be used in automatic measuring systems for sorting or qualifying devices.

The effect of ground currents in a measuring system that requires interconnections of several instruments had to be considered in the design of the indicator. Relatively large 10-kHz currents can flow through parts of the ground circuit, causing small voltage differences between various ground points. If the ends of the input cable shield are connected to two such points through low-impedance circuits, the resulting voltage difference between the ends of the input cable shield will appear in series with the measuring signal at the amplifier input. This can cause large errors in the measurement of low SWR or high insertion-loss values. This error is reduced to a negligible level in the 1641 indicator by connecting only one end of the input cable shield directly to the frame and by keeping the impedance between the other end and the frame high with respect to the shield resistance.

ACCURACY CONSIDERATIONS

The high degree of accuracy that has been obtained by use of the 1641 is a result of using components based on the precision of the GR900® connector. In fact, the total error of the 1641 system is no greater than the component error introduced by use of general-purpose connectors in other commercial systems. A consideration of the system errors, however, will provide illustrations of the limits of performance, as well as providing a greater insight into the 1641 system operation.

The main error contributions for reflection and transmission measurements with the 1641 are described approximately by:

$$|\Gamma_i| = k\,|\Gamma_x(1 + \Gamma_s\Gamma_x) + \Gamma_0 + \Gamma_\ell\,\tau_x\,\tau_x'| \qquad (1)$$

$$|\tau_i| = k\,|\tau_x\,(1 + \Gamma_s\Gamma_x + \Gamma_\ell\,\Gamma_x') + \tau_0| \qquad (2)$$

in which Γ_x is the true reflection coefficient.

τ_x is the true transmission coefficient of the measured device.

Γ_i and τ_i are the reflection and transmission coefficients indicated by the 1641 system.

Γ_0 and τ_0 are the residual reflection and transmission coefficients of the system respectively.

Γ_s is the equivalent source match and

Γ_ℓ is the transfer-detector match of the system, both expressed as reflection coefficients.

Γ_x' and τ_x' are the output reflection coefficient and the reverse transmission coefficient of the device being measured.

k is the frequency response characteristic of the system normalized to unity.

The relations above are based upon a two-port device, but they are easily expanded to apply for multiports. For a one-port device, the third term in equation (1) goes to zero and equation (2) is inapplicable.

The directivity or equivalent residual SWR of the system (Γ_0 when expressed as a reflection coefficient) is important to all reflection measurements; the residual detector match to the unknown (Γ_ℓ when expressed as a reflection coefficient) is important to low-reflection measurements on low-loss devices and to transmission measurements on high-SWR devices. (For the most accurate low-SWR measurements on multiports, auxiliary reflectionless terminations may be employed.) The equivalent residual source match to the unknown (Γ_s when expressed as a reflection coefficient) is important to both reflection and transmission measurements on high-SWR devices. Figures 12a, b, and c show typical data for the low-frequency rf unit (20 to 1500 MHz). Values of Γ_0, Γ_s, and Γ_ℓ are given in the published specifications of the 1641.

The residual-transmission coefficient (τ_0) is essentially the noise level of the system. It is dependent on the available source power and, for a source power of 30 mW, τ_0 is typically less than 0.005 (46 dB). The system flatness or leveling, characterized by k in equations (1) and (2) is dependent upon both the 1641 and the rf source employed. The principal causes of deviations in k from unity are distortion of the system modulation in the source leveling circuitry and tracking errors in the frequency responses of the 1641 detectors. Figure 13 shows a typical trace of system flatness for the low-frequency range.

The above discussion of accuracy assumes negligible harmonic content in the source signal. Presence of harmonics will affect the 1641 system in at least two ways; leveling across a band of frequencies is directly dependent upon the harmonic content and the leveling and measuring detectors respond to the net source signal (fundamental plus harmonics). The relative rf phases of the fundamental and of the harmonics at the two detectors may differ, however, and this can cause variations in a normally flat trace across the observed frequency band. The variations usually are not smooth but appear as an amplitude perturbation of the order of a few tenths of a decibel. The use of low-pass filters in the source-signal circuit, when necessary, will eliminate this problem.

A second effect of the presence of harmonics is apparent in the measurement of devices such as band-stop networks that have high loss at the fundamental frequency and low loss at the harmonic frequencies. The effect is also observed in the measurement of band-pass networks that have a low SWR at the fundamental frequency and a high SWR at the harmonic frequencies. The ratio of harmonic level to signal level, in these cases, is increased by the characteristics of the device being measured and results in a requirement for more stringent filtering of the source signal.

TYPICAL APPLICATIONS

The GR 1641 Reflectometer has wide application in production-test facilities; development, research, and calibration laboratories; incoming inspection and quality-control activities. It measures one-port, two-port and multiport devices, both passive and active, with bidirectional or unidirectional properties. With GR900 precision coaxial adaptors, accurate measurements can be made on devices equipped with a wide variety of connectors. Information can be obtained on a fixed- or swept-frequency basis from a meter, oscilloscope or recorder presentation, with go-no-go limits easily established. Since the 1641 is programmable, it can be controlled from a remote station, either manually or via a computer.

All the measurements made with the reflectometer fall into either the reflection-coefficient (SWR) or transmission-coefficient (insertion loss) category, but these two categories encompass an extensive list of characteristics. The reflection-coefficient or SWR category includes return loss and percent impedance deviation. The transmission-coefficient or insertion-loss category includes isolation, attenuation, coupling, directivity, gain, and frequency response. Most of the important characteristics of filters, antennas, isolators, circulators, switches, power dividers, couplers, amplifiers, attenuators, cables, and terminations are included in these two categories.

The 1641 provides a convenient means to measure the SWR of antennas, to search for resonances, and to characterize components or semiconductor devices. The following paragraphs describe some specific measurement examples and areas of application.

In 1962 T. E. MacKenzie joined GR's Microwave Group. Previous employment was with the Alford Manufacturing Company from 1954 to 1962. He holds degrees of BSEE (1958) and MS in Physics (1963) from Northeastern University. His work at GR has been primarily in the development of microwave instruments, components, and standards.

J. F. Gilmore joined General Radio as an engineer in the Microwave Group in 1963, after receiving his BSEE in 1961 and MSEE in 1963 from Northeastern Univeristy. He is presently engaged in microwave circuit and component design. He is a member of IEEE.

After receiving his EE degree in 1957 from the Delft University of Technology in Holland, M. Khazam was a project engineer with the Laboratory for Electronic Developments for the Dutch Armed Forces. He joined GR's Engineering Department in 1962 and presently is specializing in the development of uhf-vhf instruments and components.

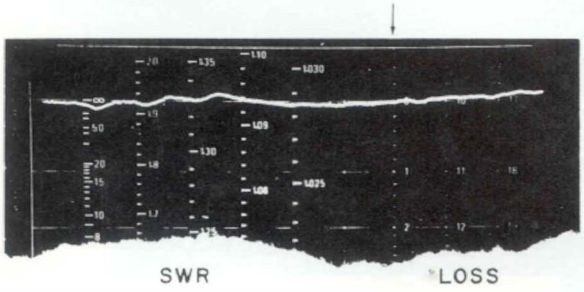

Figure 13. 1641 system-response flatness — low-frequency 0.5- to 1.0-GHz range; full scale = 0 dB.

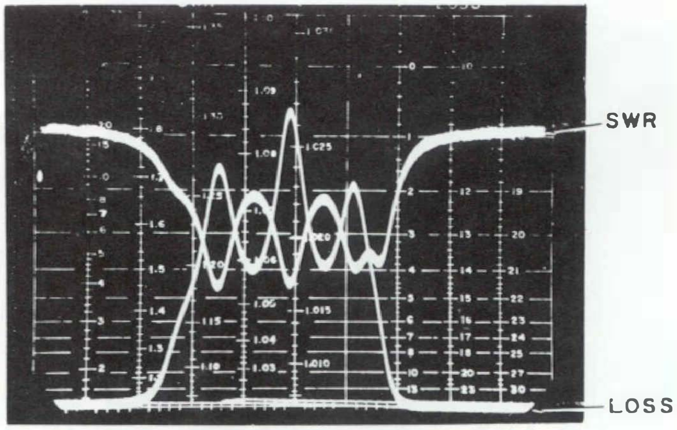

Figure 14. SWR and loss characteristics of a 5-stage bandpass filter in the 463- to 473-MHz range; full scale: ∞ (SWR) and 10 dB (loss).

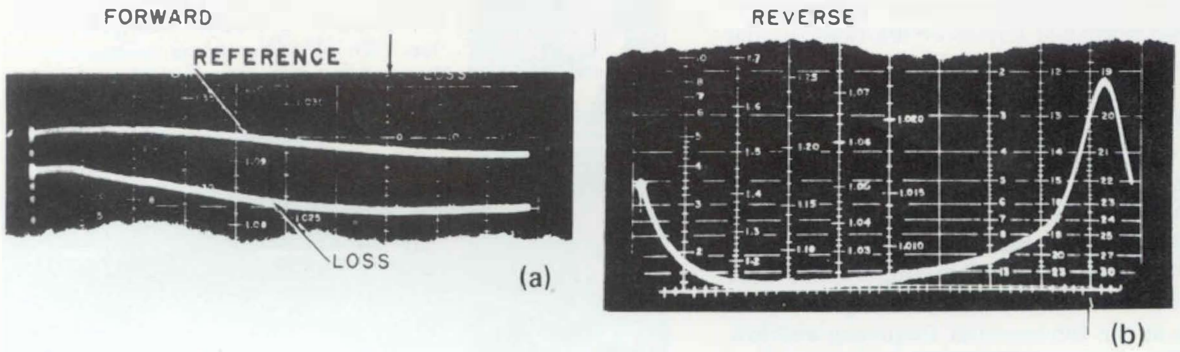

Figure 15. Insertion loss for isolator in the 2.0- to 4.0-GHz range; full scale: 0 dB in 15a and 17 dB in 15b.

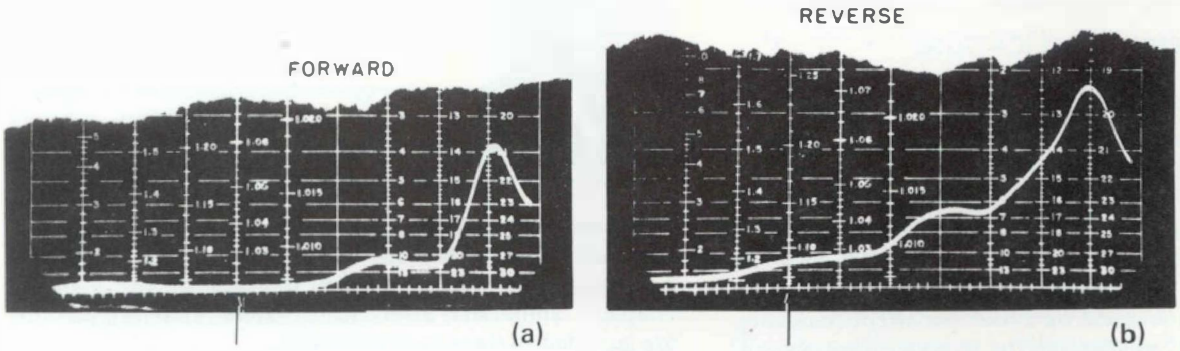

Figure 16. SWR for isolator in the 2.0- to 4.0-GHz range; full scale = 1.35.

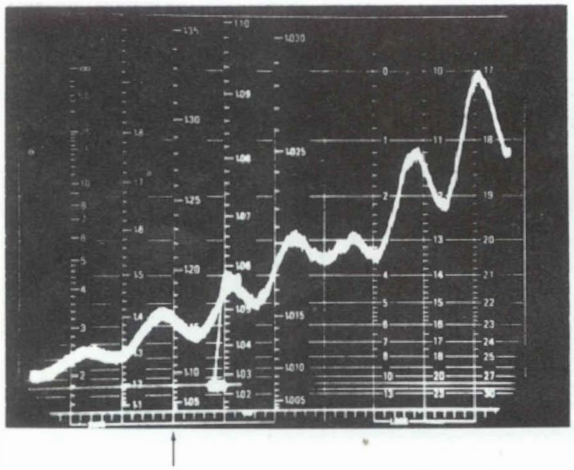

Figure 17. Video detector SWR in the 2.0- to 7.0-GHz range; full scale = 1.35.

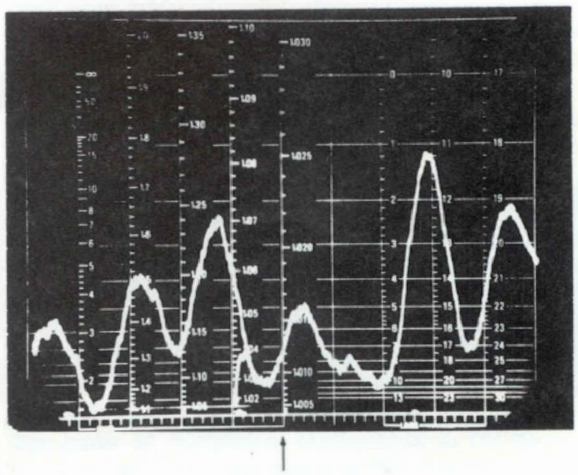

Figure 18. Termination SWR in the 2.0- to 7.0-GHz range; full scale = 1.03.

Microwave Components Measurements

Figure 14 shows the measured passband characteristics of a five-stage bandpass filter over the 463- to 473-MHz band. Since both the transmission-response and SWR characteristics can be displayed simultaneously, the effects of peaking in the individual sections can be quickly and easily determined.

Figures 15 and 16 show the measured characteristics of an isolator over the 2- to 4-GHz band. The forward characteristics were measured with the isolator input connected to the rf unit UNKNOWN port. The reverse characteristics were measured with the isolator output connected to the rf unit UNKNOWN port. These measurements are typical of those required on circulators, switches, power dividers and attenuators.

Figure 17 shows the SWR of a video detector over the 2- to 7-GHz range and Figure 18 shows the SWR of a termination over the same range. The full-scale SWR range in the first case is 1.35, in the second 1.03. The ripples in the traces indicate that the system residual SWR is less than 1.02.

Figure 19 shows the reject-band loss of a nominally 2-GHz strip-line low-pass filter. The spurious responses in the vicinity of 5 GHz are the result of leakage coupling. The full-scale loss is 17 dB.

The data shown in Figures 17, 18, and 19 were obtained using the system of Figure 20, which comprises the 1641, an Alfred Model 9510 Multi-octave Sweep Oscillator and a Tektronix Type 564 Storage Oscilloscope. The rf connections between the reflectometer and the oscillator plug-ins were made through a coaxial switch. To coordinate the triggering of the oscillator plug-ins and the rf switch with the horizontal-sweep voltage to the oscilloscope, the oscillator-blanking output was used (through a separate switching network). It was also used to switch the leveling connections. The modulation connections were made in parallel. The system was operated continuously with a sweep time of 10 seconds.

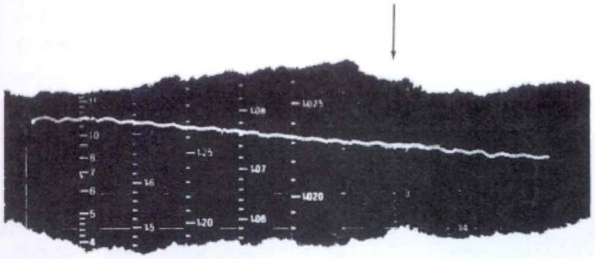

Figure 21. Insertion loss for 12.5 feet of RG-58/U cable; full scale = 0 dB

Cable Measurements

Figure 21 shows the attenuation characteristic of an RG-58/U cable assembly about 12.5 electrical feet long. Figure 22 shows the SWR characteristic. These measurements were taken by inserting the cable between the UNKNOWN port and the transfer detector of the 1641. The frequency range of measurement is 1 to 2 GHz. The attenuation characteristic decreases uniformly from 1.4 dB to 2.1 dB. The ripple in the SWR characteristic indicates that the main sources of SWR error are about 12.5 feet apart (a half wavelength at the ripple-rate frequency); in fact, the SWR is principally caused by the discontinuities at the cable-connector junctions.

In many instances, it is not possible to attach a detector to the far end of a cable – for example, if the cable or transmission line is long or passes through a bulkhead or is

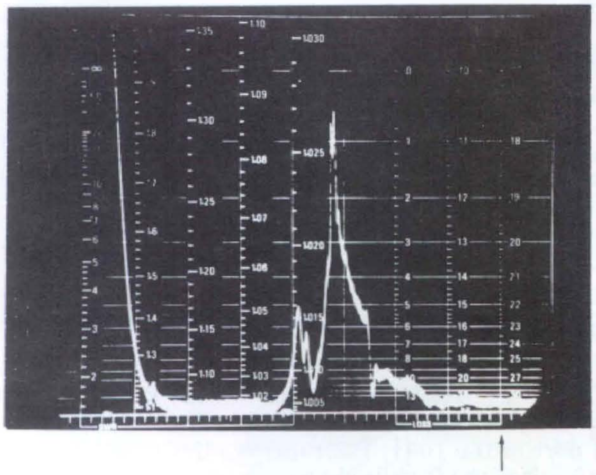

Figure 19. Reject-band loss of 2-GHz strip-line low-pass filter; full scale = 17 dB.

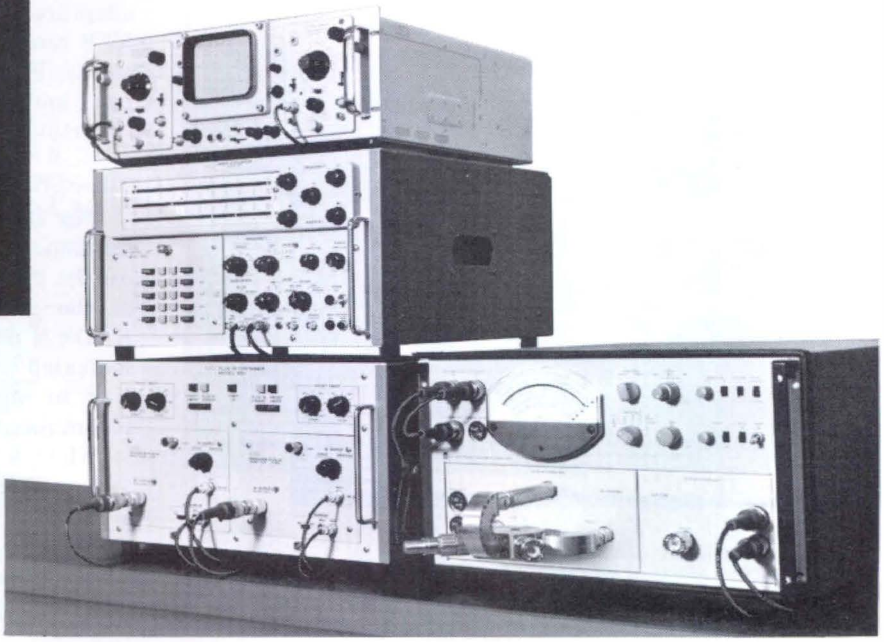

Figure 20. Test assembly for Figures 17, 18, and 19.

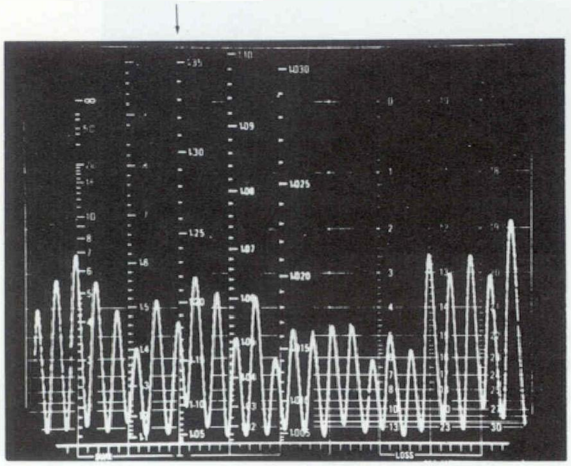

Figure 22. SWR for 12.5 feet of RG-58/U cable; full scale = 1.35.

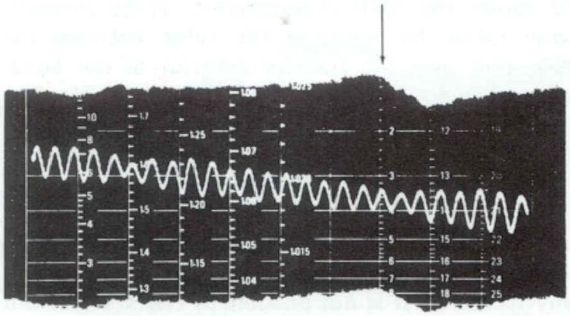

Figure 23. Return loss for 12.5 feet of RG-58/U cable open circuited; full scale = 0 dB

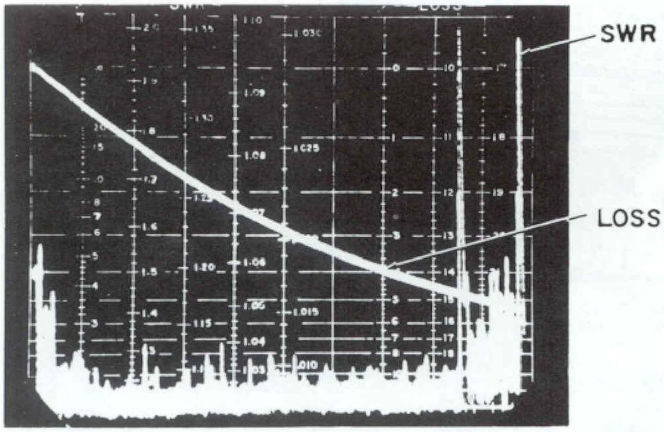

Figure 24. Insertion loss and SWR for 50 feet of RG-214/U cable in the 2.0- to 4.0-GHz range; full scale = 1.10 (SWR) and 10 dB (loss).

attached to an antenna mast. Measurements of the loss and SWR characteristics still are of interest. Such measurements can be accomplished by leaving the far end of the cable open-circuited (or short-circuited) and by looking at the return-loss or reflection characteristic only. This is illustrated in Figure 23 for the same cable as that of Figures 21 and 22.

The attenuation is just one-half of the average indicated return loss because the measured signal travels down and back the length of the cable. The ripple in the return-loss characteristic is a measure of the cable input SWR, which is given approximately by the voltage ratio corresponding to the ripple excursion in dB. This measurement is limited to the degree that the value given by twice the cable attenuation must be at least 10 dB less than the terminated-cable return loss. If this is not the case, then the attenuation information is lost. For example, if the cable attenuation is 15 dB, twice the cable attenuation is 30 dB; the attenuation information therefore is submerged in the cable return loss. In fact, for long, lossy cables (20-dB attenuation or greater), the SWR can be read directly with the cable not terminated. In such cases, the cable attenuation can only be determined by utilizing the transfer detector at the far end of the cable.

Figure 24 shows the attenuation and SWR characteristics of a 50-foot length of RG 214/U cable over the frequency range of 2 to 4 GHz, measured directly with the transfer detector. The cable is equipped with GR900 cable connectors, and the SWR is very low except at the points of resonance. The resonances are caused by periodicity in the cable itself. The characteristics in the vicinity of one of the resonances are shown in detail in Figure 25. Long cables, such as this, exhibit SWR's that vary quite rapidly with frequency, and resonances such as the one illustrated are not uncommon.

Low-SWR Measurements

The SWR's of connectors, whether they are on cables, adaptors or air lines, are usually quite low, and appreciable SWR resolution is required to achieve meaningful measurements. Figure 26 shows a series of SWR curves of adaptor pairs and cables, all on the 1.03 full-scale SWR range. The frequency band is 250 to 500 MHz.

Tuned Reflectometry

For the most accurate low-SWR measurements at fixed frequencies, the system residual directivity or residual SWR can be tuned out with an impedance matching tuner (such as the 900-TUA or -TUB Tuner) attached to the UNKNOWN port of the 1641. The tuner is adjusted so a null is indicated on the 1641 while measuring a standard termination or while using quarter-wavelength or other air-line techniques.[2]

When a source is employed that delivers approximately 100 mW leveled power (into 50 ohms), additional SWR

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[2] MacKenzie, T. E. "Some Techniques and Their Limitations as Related to the Measurement of Small Reflections in Precision Coaxial Transmission Lines," *IEEE Transactions on Instrumentation and Measurement*, Vol. IM-15, No. 4, December 1966. (Available from GR as Reprint No. A133)

resolution can be obtained by calibrating initially at a 2.0-SWR level and utilizing a 1.01-SWR full-scale range. Under these conditions, the residual noise level is reduced to an equivalent SWR approximating 1.002. (Note – the 1.01 scale is obtained by using the 1.10 scale and manually inserting a zero after the test-data decimal point.)

If speed is required, in addition to the high accuracy described herein, pre-set tuners can be employed. In this manner, production measurements at discrete frequencies can be made with a minimum of set-up time, and with direct readout.

Active Devices

Use of the 1641 to measure the characteristics of active units, such as solid-state semiconductor devices, is illustrated in Figure 27, with measurements on a GR 1237 VHF/UHF Preamplifier. The gain and input SWR measurements of Figure 27a were obtained by connecting the amplifier input directly to the 1641 UNKNOWN port, and

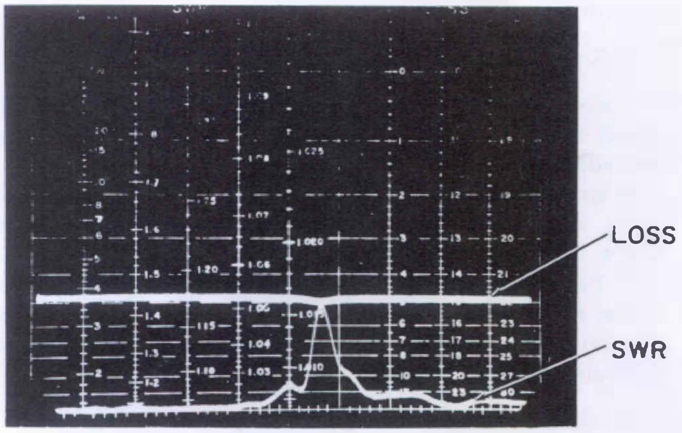


Figure 25. Detailed expansion of 3.75-GHz resonance in Figure 24; full scale = 1.35 (SWR) and 10 dB (loss).

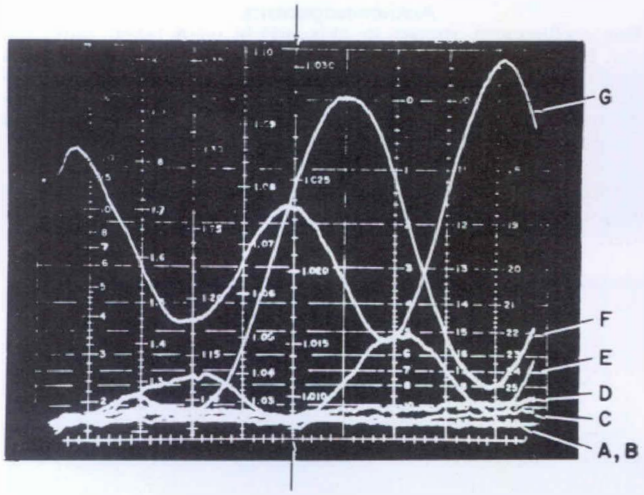
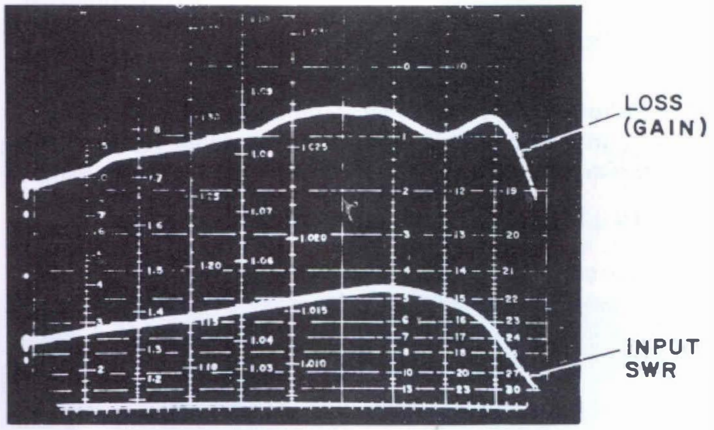


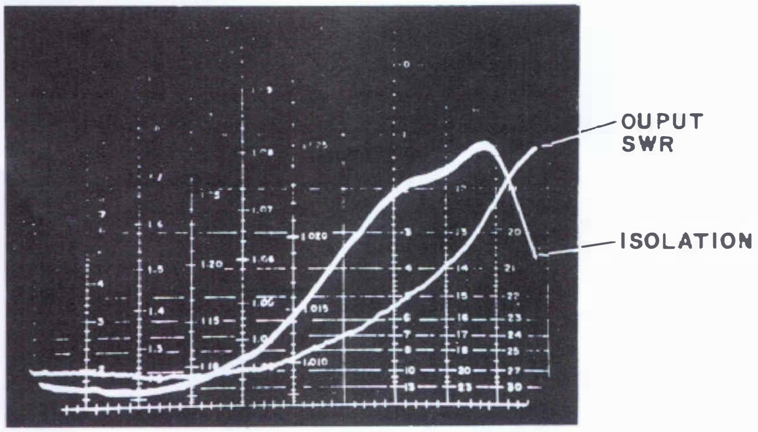
Figure 26. SWR curves for assorted adaptor pairs and cables in the 250- to 500-MHz range; full scale = 1.03. Curve A shows the response with 900-W50 Termination connected at UNKNOWN port of rf unit, curve B the response with a pair of 900-Q874 Adaptors inserted between termination and UNKNOWN port. Curve C indicates response after substitution of 900-QN Adaptors for 900-Q874 Adaptors, curve D after substitution of 900-QMM Adaptors for 900-QN units. Curve E shows the response of 3 feet of RG-214/U cable equipped with GR874® locking connectors, specially chosen to illustrate optimum response obtainable; curves F and G illustrate normal responses obtainable for 874-R20LA and 874-R22LA Patch Cords (3-feet) respectively, each equipped with GR874 locking connectors.

GAIN AND INPUT SWR



(a)

ISOLATION AND OUTPUT SWR



(b)

Figure 27. Measurements of an active device — GR 1237 Preamplifier — in the 0.5- to 1.0-GHz range. Figure 27a shows gain and input SWR (full scale: 0 dB — loss and ∞– SWR). Figure 27b shows isolation and output SWR (full scale: 37 dB — loss and ∞– SWR).

by inserting 13-dB attenuation between the amplifier output and the 1641 transfer detector. The attenuation combines with the amplifier gain to introduce a net loss that can be measured directly. The amplifier gain is determined from the measured loss by subtracting the amount of attenuation used. Thus, in this example, subtracting the 13-dB attenuation used from the measured loss of 0.5 to 2 dB across the band gives a −11- to −12.5-dB *loss* or a 11- to 12.5-dB *gain*. The attenuation was added behind the amplifier so the input SWR could be directly measured with no reconnections. The amplifier isolation and output SWR, as shown in Figure 27b, were obtained by reversing the amplifier connections end for end and connecting the amplifier input directly to the transfer detector.

The magnitudes of the s-parameters, $|s_{ij}|$, are obtained directly from the measurements described above and are expressed in dB as return loss ($|s_{ii}|$, $|s_{jj}|$) and insertion loss ($|s_{ij}|$, $|s_{ji}|$). Similar measurements can be made on transistors, diodes, etc, by the use of appropriate mounts and bias-insertion units. If dc bias is used with the device to be measured and no internal dc blocks are provided, a dc block is required between the device and the 1641 UNKNOWN port. The GR 1641 Transfer Detector is internally dc blocked.

ACCESSORIES REQUIRED

Although the 1641 depends on an external source of rf, the source requirements are not stringent. Specifically, the requirements are:

1. 10-mW minimum leveled rf output into 50 ohms

2. capability of being driven by external 10-kHz square-wave modulation, on-off, in the range of −15 to +15 volts and of presenting a minimum load impedance of 1 kΩ to the external modulation source (the 1641)

3. capability of being leveled from an external sampling detector that delivers a control signal with sensitivity in the 50- to 550-mV range for a 30-mW source power input

4. a blanking pulse of ± 3 to 50 volts into 30 kΩ.

Increasing rf output to 200 mW makes greater resolution possible. The modulation and leveling circuitry should not introduce appreciable differential distortion of the 10-kHz waveform. Use of the blanking pulse specified in (4) is required only for triggering alternate (simultaneous) measurements of SWR and insertion loss.

Specific requirements for the oscilloscope are:

1. both axes dc-coupled

2. vertical sensitivity of 0.1 V/cm or greater

3. horizontal sensitivity consistent with the sweep-signal output available from the source (0.1 V/cm is usually more than adequate).

A storage oscilloscope is not necessary for all measurements. It is particularly useful, however, for measurements of low SWR and high insertion loss where the sweep speed must be reduced below flicker speed to accommodate the system response time. The Tektronix storage oscilloscope is recommended, and the 1641 calibrated graticule fits this particular unit.

Design and development responsibilities for the GR 1641 Reflectometer were as follows:

T. E. MacKenzie — Project direction, general systems design, and low-frequency rf unit.
J. F. Gilmore — High-frequency rf unit.
M. Khazam — General-system, detectors and indicator design.

Acknowledgements

The oscillograms shown in this article were taken using the Alfred Electronics 650-series of sweep oscillators for frequencies above 0.5 GHz and the Kruse-Storke Electronics 5000-series of sweep oscillators for frequencies below 0.5 GHz. The oscilloscope used was the Tektronix Inc. Model 564 Storage Oscilloscope with two Type 2A63 Differential-Amplifier Plug-Ins.

Complete specifications and prices for the GR 1641 were distributed with the January/February 1969 issue of the *Experimenter*.

CONTINUING EDUCATION

In line with its policy of supporting the continuing education of technically inclined readers, General Radio has brought out another in a series of handbooks entitled *Handbook of Coaxial Microwave Measurements* intended for use by

- Students involved in academic laboratory experiments
- Technicians working the coaxial fields
- Scientists and engineers not indoctrinated in coaxial electronics, who may have research work involving coaxial techniques.

Copies are available for readers interested in a publication which supplements the conventional text books. Send your order and check for $2.00 to General Radio Co., 300 Baker Avenue, West Concord, Mass. 01781.

THE VIABLE VHF/UHF PREAMPLIFIER

A low-noise, low-level, wideband amplifier operating in the frequency range 150 kHz to 1 GHz is as essential to the laboratory worker as bread to the growing child. In the home it could be used to boost the level of television signals, if a correct impedance match between antenna and receiver is established. The new GR 1237 transistor amplifier probably will not be used in the home but its place in the laboratory is assured by its simplicity and adaptability.

The GR 1237 amplifier was designed for general laboratory use in 50-ohm systems as an amplifier, preamplifier, or isolator. It finds application as part of a system to form a sensitive, broadband detector system such as that of Figure 1. Here, a demodulator, such as the GR 874-VQ, is operating as a video or envelope detector, employing a narrow-band, sensitive 1-kHz indicating amplifier such as the GR 1232 or 1234. The circuit suffers from lack of sensitivity and selectivity (or susceptibility to harmonics) as compared with a heterodyne system, but introduction of the 1237 unit improves the sensitivity, as evident in Figure 2, while use of a low-pass filter (GR 874-F) at the detector input reduces susceptibility to harmonics. The resultant system replaces the heterodyne as a null detector and eliminates need for a local oscillator.

Another use involves the familiar GR 1607 Transfer-Function and Immittance Bridge. The 1237, directly connected to the bridge terminals, effectively blocks the local-oscillator signal from the bridge and provides a means for connecting a mixer into the circuitry via the output terminals of the 1237. Bridge measurement errors, caused by local-oscillator feedthrough, are eliminated, sensitivity is improved and bridge performance enhanced, particularly below 100 MHz. Another advantage is assurance of small signal operation of semiconductor devices under test, because of the large reverse loss of the 1237.

Some operating characteristics of the 1237 amplifier are shown in Figure 3. Physical appearance is as shown in Figure 4, and specifications are detailed below for reader convenience.

SPECIFICATIONS

Frequency Range: 150 kHz to 1 GHz.

Gain: >10 dB (see typical curve, Figure 3).

Reverse Attenuation: >33 dB; below 700 MHz, >43 dB.

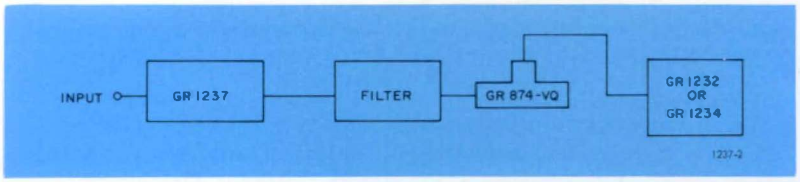
Noise Figure: See typical curve, Figure 3.

Terminals: Input and output, GR874® locking coaxial connectors.

Power Required: 100 to 125 or 200 to 250 V, 50 to 400 Hz, 1.5 W; or 9 V dc, 18 mA.

Catalog Number	Description	Price in USA
1237-9700	**1237 VHF/UHF Preamplifier**	**$195.00**

Figure 1. Detector system using the Type 1237.



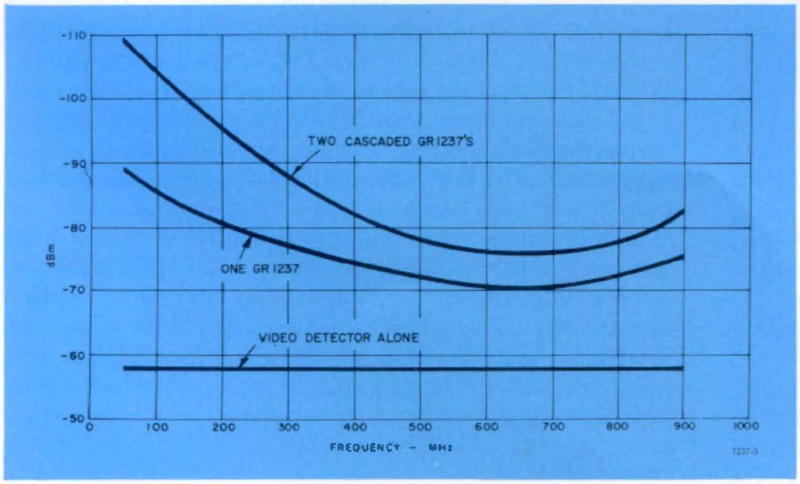


Figure 2. Relative improvement in sensitivity, using the Type 1237.

Figure 3. Typical noise figure, gain and reverse attenuation characteristics.

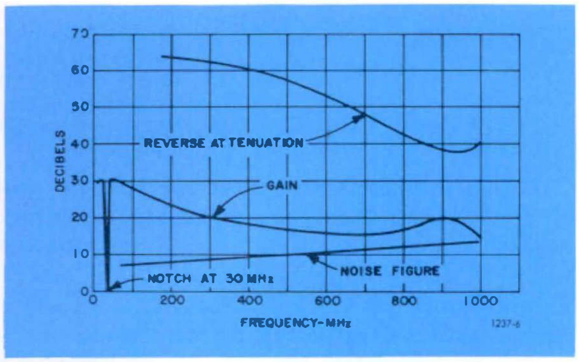
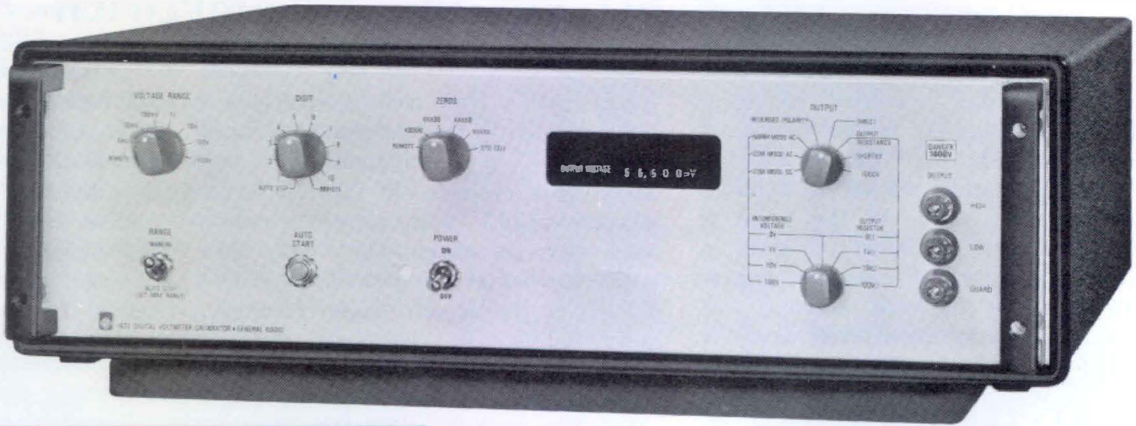


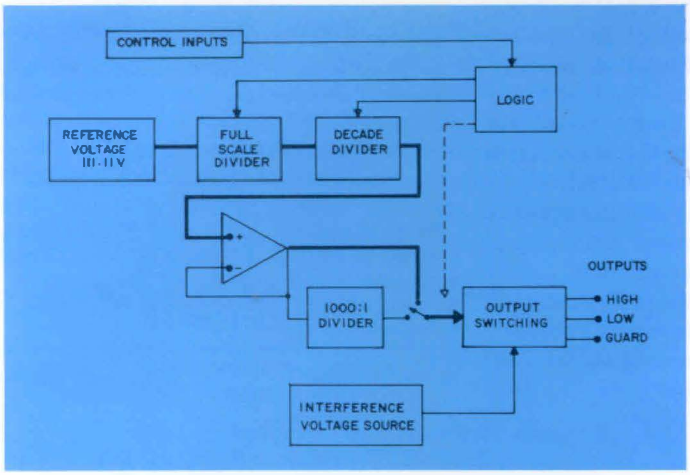
Figure 4. Type 1237 UHF/VHF Preamplifier.



Type 1822 Digital Voltmeter Calibrator.

The Semiautomatic DC DVM Calibrator

by Ralph P. Anderson



Block diagram of the calibrator.

Improvements in performance of digital voltmeters have encouraged increased use, with a correspondingly increased calibration work load. Standards being generated will specify calibration procedures to assure accurate performance of the meters. With these standards in mind, General Radio has designed the 1822 Digital Voltmeter Calibrator, which uses semiautomatic techniques to simplify calibration tests and to save calibration man-hours.

The Need

Digital voltmeters have taken the accurate measurement of dc voltages from the standards laboratory to the engineer's workbench and also to the production line, where relatively untrained personnel can make precision measurements quickly and accurately. Like any measuring instrument, digital voltmeters must be calibrated periodically to assure proper operation within published specifications. Increasing use of the DVM has strained the facilities of many calibration laboratories to the breaking point, because of the complexity, large number, and lack of uniform testing of the instruments involved. To standardize specification format and test methods, the USASI has created, and is in the process of accepting, a standard on automatic voltmeters and ratiometers.

Causes of error in digital-voltmeter measurements can be divided into two broad categories. The primary errors are those generated within the voltmeter, and they are independent of the character of the voltage source. These errors are caused by voltage offsets, reference-voltage drifts, hysteresis effects, nonlinearities, and range scaling errors. Traditional calibration methods, which have been developed to detect and to correct for these sources of error, require the generation of a large number of accurately known voltages.

Secondary errors are those that depend on the specific manner in which the voltmeter is connected or used and, to a large extent, upon the source characteristics in relation to the input characteristics of the voltmeter. The finite input impedance and input current of a DVM cause loading errors during the measurement of voltages with significant source impedances. Similarly, the finite isolation impedance can cause errors when common-mode voltages are present.

The traditional calibration of the DVM leaves these secondary sources of error undetected. It is in this area that the USASI proposed standard, C39.6, will have its greatest impact. It clearly defines these sources of error and preferred testing methods so both the maker and user can agree not only on what a specification means but also on how to verify it.

The Concept

The ideal digital voltmeter would have an infinite input impedance, zero input current and, of course, similar characteristics between each of its terminals and ground. In approaching these characteristics, digital voltmeter manufacturers have come very close to the ideal. The degree to which they have succeeded, however, may be easily defeated when the digital voltmeter is placed in a hostile environment. Insidious settlement of dust and grime onto even the best of insulators will eventually change them from high to low resistance and possibly into a current generator. Similarly, a small disturbance in the balance of the input circuits of the digital voltmeter can cause an offset current that is large with respect to that which the user might expect from reading the data sheet. Since the measurement accuracy of a DVM may well include the effects of these secondary sources of error, it is imperative that tests for them be included in every calibration cycle and that the users be kept informed of the results.

The Instrument

The General Radio Type 1822 Digital Voltmeter Calibrator has been designed to test for most of the sources of error as defined by the proposed USASI Standard. Basically the Type 1822 is a remotely programmable voltage supply, with an internal program. Its primary purpose is to make convenient and practical the tests indicated in the standard. It will automatically present a series of low source impedance, precision dc voltages (from 100 μV to 111.11 V) to the output terminals to check for the primary sources of error. Included also are means for checking the input characteristics, the common-mode rejection, the normal-mode rejection, and manual selection of voltages up to 1111.1 volts.

All precision voltages generated by the 1822 are ultimately referred to a single specially selected and aged reference diode, which is housed in a proportionally controlled oven with fast warmup characteristics. The reference voltage, 111.11 volts, is scaled up from the diode voltage by a resistive divider. The resistors in each of the dividers are precision wire-wound resistors, wound from the same spool, heat treated to relieve manufacturing stresses, and placed, uncoated, in a common oil bath to achieve, as nearly as possible, identical changes in temperatures. These precautions result in a ±1.5 ppm temperature coefficient for the division ratio and provide excellent long-term stability.

A photochopper-stabilized amplifier provides the voltage amplification needed for the kilovolt output range and, on the lower ranges, serves as a high-input-, low-output-impedance buffer isolating the dividers from the effects of varying loads.

The VOLTAGE-RANGE switch sets maximum values in decade ranges from 1 millivolt to 1000 volts; in each range the value set by a second control, the digit switch, multiplies the range by 0.11111, 0.22222, 0.33333,..... 1.11110. The ZEROS control permits the last 1, 2, or 4 digits to be replaced by zero to match the resolution of the DVM readout. An automatic stepping mode cycles the digit setting upward to maximum and then back down to one-tenth of full scale for a quick check of all the indicators and of linearity. After one cycle it can be set to step down one range and cycle through the same sequence. Direction of count, range incrementing, and stepping can all be remotely controlled. Because the voltages generated in these sequences have easily recognized numbers and are cycled automatically, the operator's attention can be focused on the DVM under test.

R. P. Anderson presently is Acting Group Leader of the Engineering Department's Industrial Group. He received his MS degree in Applied Physics from Harvard in 1962 after earning his BS in Engineering at Brown University in 1958. During the interim period 1958 to 1962, he served with the US Navy and worked for Ford Aeroneutronics, joining GR in 1963. He is a member of IEEE and Sigma Xi.

The output switching can reverse the output polarity, short the terminals, and modify the basic dc voltage by the addition of common-mode or normal-mode interference voltages or by a change in the output impedance. This switching also provides a safety interlock that prevents dangerous output potentials in the 1000-volt range from being selected or programmed accidentally.

The 1822 can be completely calibrated against a primary voltage standard by conventional methods, and its inherent stability will permit a six-month recalibration cycle. For a simple check for changes in the internal reference, dividers, or output amplifier, a "simulated standard-cell output" is available that can be compared by a simple null measurement against a saturated standard cell.

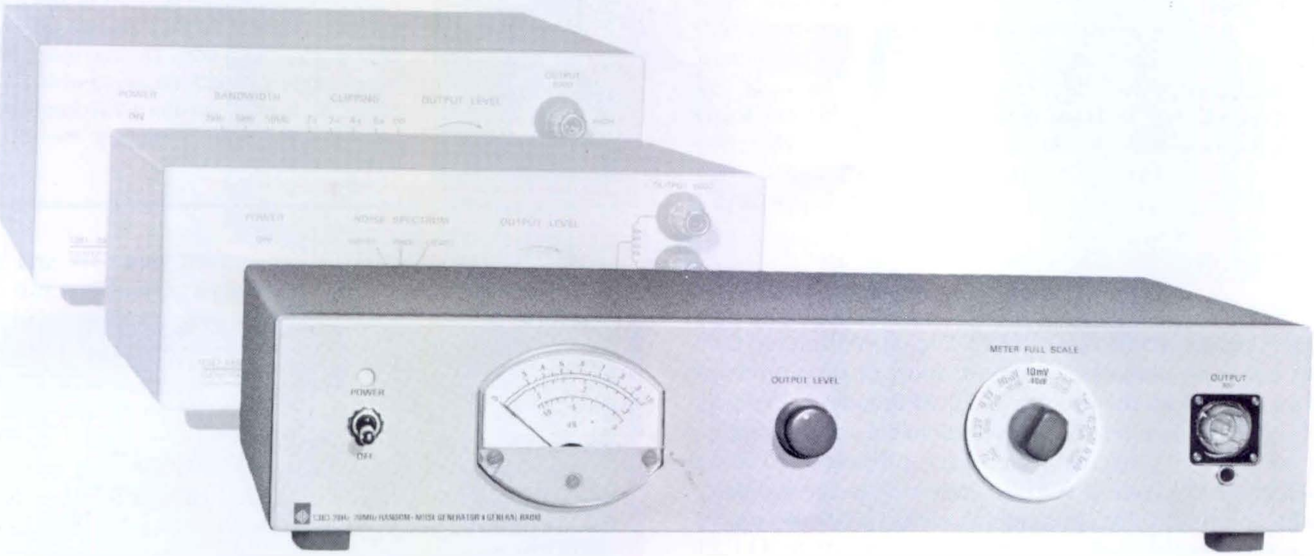
For voltages that are not generated in the sequences of similar digits and zeros, the user may easily substitute an external voltage divider in place of the internal, automatically switched dividers of the 1822. Either a simple resistive divider or a Kelvin-Varley Divider may be used to generate any voltage from microvolts to 1111.1 volts, with the divider itself varying only between 1 millivolt to 111.11 volts.

Its Applications

While the 1822 is ideally suited, because of its mobility, to calibrating DVM's on location in the laboratory, production line, or inspection department, it is not limited to this use. Any precision instrument that requires, transmits, or transduces analog voltages can be calibrated and its susceptibility to interference determined readily by the 1822. Analog-to-digital converters, telemetry systems, and analog voltmeters are typical examples.

As a component in the complete testing system, the 1822 can be programmed by the system to establish precise voltage levels for periodic calibrations of other sections of the system.

The 1822 is a convenient, stable transfer standard that moves easily from the standards laboratory to wherever the DVM's are used. Because of its flexibility, time savings, and ease of use, it can be used economically more frequently than conventional calibration instruments, thus assuring more reliable results from all voltmeters. With the 1822, testing for secondary error sources is more practical than ever before.



NOISE, NOISE, AND MORE NOISE!

- 20 Hz to 20 MHz, ±1 dB
- 30-μV to 1-V output, open circuit

The GR 1383 Random-Noise Generator is a white-noise signal source of contant spectrum level, operating in the frequency range 20 Hz to 20 MHz. Output level is at one volt into an open circuit, derived from a 50-ohm source impedance. Level is adjustable over a range of 80 dB. This instrument complements random-noise generators GR 1381 (audio frequency) and GR 1382 (sub-audio frequency), described in the *GR Experimenter* issued January, 1968.

What's It Good For?

Experimenters will use it as a source of controlled background noise while studying signal-detection and -reception systems. Measuring noise temperature or noise figure of the input stages of an amplifier, within the specified frequency range, is greatly simplified.[1] A simple reminder – the 1383 becomes a 50-ohm source of noise, whose equivalent temperature is the ambient temperature when the power is not turned on.

Use it for checking intermodulation distortions[2] – apply a noise spectrum to the amplifier input, remove a band of noise frequencies from the input by means of a band-stop filter; check the output of the amplifier, using a band-pass filter of the same frequency range as the band-stop filter to determine how much intermodulation product has appeared in the vacant band. This is a useful check for general quality of performance.

---

[1] Mumford W. W., and Scheibe, E. H., *Noise Performance Factors in Communication Systems*, Horizon House-Microwave, Inc., 1968.

[2] Icenbice, P. J. Jr., and Fellhaur, H. E., "Linearity Testing Techniques for Sideband Equipment," *Proceedings of the IRE*, Vol. 44, pp 1775-1782, December 1956.

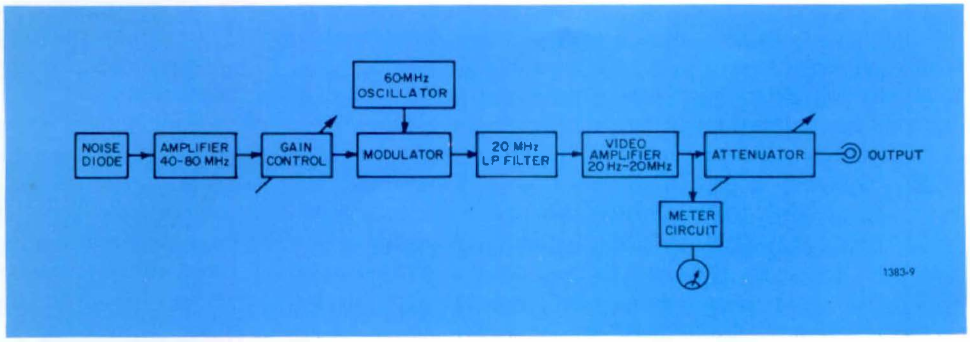


Figure 1. Block diagram of the GR 1383.

J. J. Faran, Jr. is a graduate of Washington and Jefferson College (AB-1943) and Harvard University (MA-1947 and PhD-1951). As a Research Fellow at Harvard, Dr. Faran worked on correlation techniques as applied to acoustic receiving systems. In 1952 he joined GR's Audio Group and has since developed a variety of instruments, including recorders, voltmeters, and analyzers.

Check interference in multichannel communication systems. The broad bandwidth of the 1383 encourages its use at intermediate and radio frequencies. Interference produced in channels adjacent to the test channel may be useful for investigating interference-mitigation methods.

How about checking effective-noise bandwidth of filters? Apply a noise of known bandwidth to the filter input, and compare noise amplitude at input and output. The reduction in level is proportional to the square root of the ratio of the effective noise bandwidths. Note – the bandwidth of the noise output of the 1383 is 20 MHz ±5%.

Do You Need Special Noises?

The noise from the 1383 can be used to modulate a signal generator to produce sidebands of noise at almost any frequency. The modulation bandwidth will, in most cases, be limited by the modulation amplifier in the signal generator rather than by the 20-MHz bandwidth of the 1383. If broader bands of noise are required, and the carrier frequency is undesirable, mix the noise with a sine wave from a signal generator in any one of several balanced mixer units which are commercially available.

Narrow bands of noise are easily produced by building tuned circuits into GR 874-X Insertion Units for insertion into 50-ohm lines; more complicated filters designed for operation in 50-ohm lines may be inserted in series with the output.

What Makes It Work?

The noise source is a temperature-limited thermionic diode, commonly accepted as a random-noise standard. A feedback system, shown in the block diagram of Figure 1, controls the filament current while maintaining a constant plate current. The generated noise voltage level is stabilized in this manner, since it is dependent upon the square root of the dc plate current. Noise current from the diode is amplified in the frequency range 40 to 80 MHz and heterodyned against a 60-MHz oscillator signal, producing noise in the dc to 20-MHz band. The "video" amplifier produces an output noise level of one volt rms, open circuit. The sharp cutoff filter following the mixer provides very accurate definition of the effective bandwidth of the generated noise and helps reduce oscillator leakage into the output.

For Old Friends

We have redesigned the high-frequency section of the old 1390-B Random-Noise Generator, extending the upper limit of the bandwidth from 5 MHz to 20 MHz; tightened tolerances on spectral flatness; made the amplitude distribution symmetrical; built in a constant and more practical output impedance; and restyled the cabinet. We believe you'll find the 1383 quite useful.

– J. J. Faran. Jr.

SPECIFICATIONS

Spectrum: Flat (constant energy per hertz of bandwidth) ±1 dB from 20 Hz to 10 MHz, ±1.5 dB from 10 MHz to 20 MHz.

Waveform: Table shows amplitude-density-distribution specifications of generator compared with the Gaussian probability-density function, as measured in a "window" of 0.2σ, centered on the indicated values:

Voltage	Gaussian Prob. Dens. Function	Amplitude-Density Dist of 1383	
0	0.0796	0.0796	±0.005
$\pm\sigma$	0.0484	0.0484	±0.005
$\pm 2\sigma$	0.0108	0.0108	±0.003
$\pm 3\sigma$	0.000898	0.000898	±0.0003

(σ is the standard deviation or rms value of the noise voltage.)

Output Voltage: Full output 1.0 V rms min, open circuit.

Output Meter: Indicates open-circuit output voltage ahead of 50 Ω.

Output Impedance: 50 Ω. Can be shorted without causing distortion.

Amplitude Control: Continuous control and 8-step, 10 dB-per-step attenuator.

Output Terminals: GR874® coaxial connector that can be mounted on either front or rear panel.

Accessories Supplied: Spare fuses, lamp, power cord.

Power Required: 100 to 125 or 200 to 250 V, 50 to 400 Hz, 40 W.

Catalog Number	Description	Price in USA
	1383 Random-Noise Generator	
1383-9700	Bench Model	$775.00
1383-9701	Rack Model	795.00

Figure 1. GR 1442
Coaxial Resistance Standard.

STABLE SERIES OF COAXIAL RESISTANCE STANDARDS

The GR 1442 Coaxial Resistance Standards (Figure 1) are the most recent addition to the line of General Radio impedance standards with coaxial connectors. As in the capacitors described previously,[1,2] the GR900® connectors make it possible to have two-terminal impedance standards for the radio-frequency range, which can be calibrated to a high degree of accuracy.

The GR 1442 resistor consists of two GR900 connectors with a short length of outer conductor forming the housing for the resistor. The resistance element, consisting of a cluster of metal-film resistors, is connected between the two inner contacts. The length of the assembly has been made as short as possible in order to keep both the inductance and capacitance low.

The two GR900 connectors permit use of the 1442 resistor in two different ways. One use is as an individual resistance standard, obtained by shorting one end with a GR 900-WN Short Circuit Termination and using the other end for the terminals. The other use is as a resistor in series with other impedance standards having GR900 connectors. This provides a wide range of combinations for calibrations and other measurement purposes.

The characteristics that make the GR900 connector so useful at microwave frequencies also make it a desirable means of connection for two-terminal devices at lower frequencies. The low resistance and the accurately defined reference plane, plus the precisely repeatable inductance and capacitance when connected to different instruments, make it possible to construct and to calibrate impedance standards for a wide range of frequencies and uses. Precision coaxial connectors are essential for the highest accuracy when radio-frequency resistance calibrations are made by the National Bureau of Standards.[3]

When shorted at one end, the 1442 can be used to calibrate high-frequency resistance bridges, such as the GR 1606-B, and similar instruments. It can be used also to calibrate a wide range of instruments for dissipation factor, conductance, or Q when connected in series with a coaxial capacitance standard. This can be particularly useful in materials laboratories and in similar activities that do not have immediate access to the services of a high-frequency electrical standards laboratory. A few 1442 resistors and GR 1405 or 1406 capacitors will provide a number of dissipation-factor combinations in the range of samples

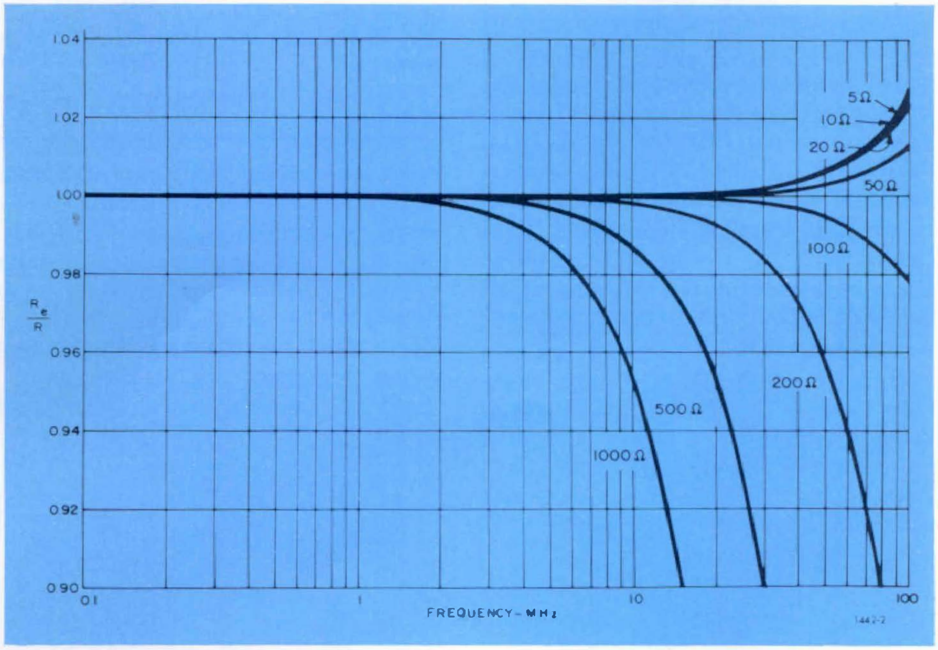


Figure 2. Typical ratios of effective series resistance
to dc resistance, with a
GR 900-WN Short Circuit at one end.

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[1] Orr, R. W., "Capacitance Standards With Precision Connectors," *General Radio Experimenter*, September 1967.

[2] Orr, R. W., and Zorzy, J., "More Coaxial Capacitance Standards," *General Radio Experimenter*, May 1968.

[3] *Calibration and Test Services of the NBS, Special Publication 250* – 1968 Edition, p 7.12 and 7.30.

normally measured. These can be used for routine calibrations or as a check when the results of a measurement on a sample appear questionable.

The change in effective series resistance with frequency for 1442 resistors is shown in Figure 2. The change in reactance with frequency is shown in Figure 3. Substantially, all the change in effective resistance for the range shown by the curves is due to the inductance and the capacitance of the resistor. This is explained by reviewing the equation for effective series resistance R_e of the resistor whose equivalent circuit is shown in Figure 4. For analysis, one end of the resistor is shorted.

$$R_e = \frac{R}{1 - \omega^2\,(2LC - R^2C^2 - \omega^2L^2C^2)}$$

The denominator has been rearranged somewhat from the usual form to make it easier to see the effects of the individual parameters. The value of L in this equation is 9 nH; the capacitance 3.4 pF, the sum of 2.5 pF across one end of the resistor assembly and 0.9 pF across the resistor proper. These inductance and capacitance values are substantially the same for all resistance values. At the lower values of resistance, R^2C^2 is less than $2LC$, making the denominator less than one, and the effective resistance rises as the frequency increases. In the higher resistance values, R^2C^2 is greater than $2LC$, making the denominator greater than one, and the effective resistance decreases with frequency. The term $\omega^2L^2C^2$ is relatively small for these resistors at the frequencies shown in Figure 3. A more complete analysis of resistor performance at radio frequencies is given in an article by D. B. Sinclair.[4]

– R. W. Orr

R. W. Orr received his BS in EE from Texas A&M in 1928. He held technical positions with General Electric Company, RCA, Erie Resistor Corporation, AMP Inc., and Aerovox Corporation prior to joining General Radio in 1964. Presently he is a member of the Engineering Department's Impedance Group. Mr. Orr is a member of IEEE and ASTM. He is Chairman of ASTM Committee D-9 on Electrical Insulating Materials, member of Committee D-27 on Electrical Insulating Liquids and Gases, and Associate of the NAS/NRC Conference on Electrical Insulation and Dielectric Phenomena.

SPECIFICATIONS

Initial DC Accuracy: ±(0.1% + 0.3 mΩ).

Stability: ±0.05% per year.

Dissipation: 1 W max.

Capacitance (Inner to outer conductor): 5 pF, typical.

Inductance: 9 nH, typical.

Temperature Coefficient of Resistance: ±50 ppm/°C, except ±100 ppm/°C for 1442-F.

Catalog Number	Description	Resistance	Price in USA
1442-9705	1442-F	5Ω	$65.00
1442-9706	1442-G	10Ω	65.00
1442-9707	1442-H	20Ω	65.00
1442-9708	1442-J	50Ω	65.00
1442-9709	1442-K	100Ω	65.00
1442-9710	1442-L	200Ω	65.00
1442-9711	1442-M	500Ω	65.00
1442-9712	1442-N	1000Ω	65.00

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[4] Sinclair, D. B., "Type 663 Resistor – A Standard for Use at High Frequencies," *General Radio Experimenter*, January 1939.

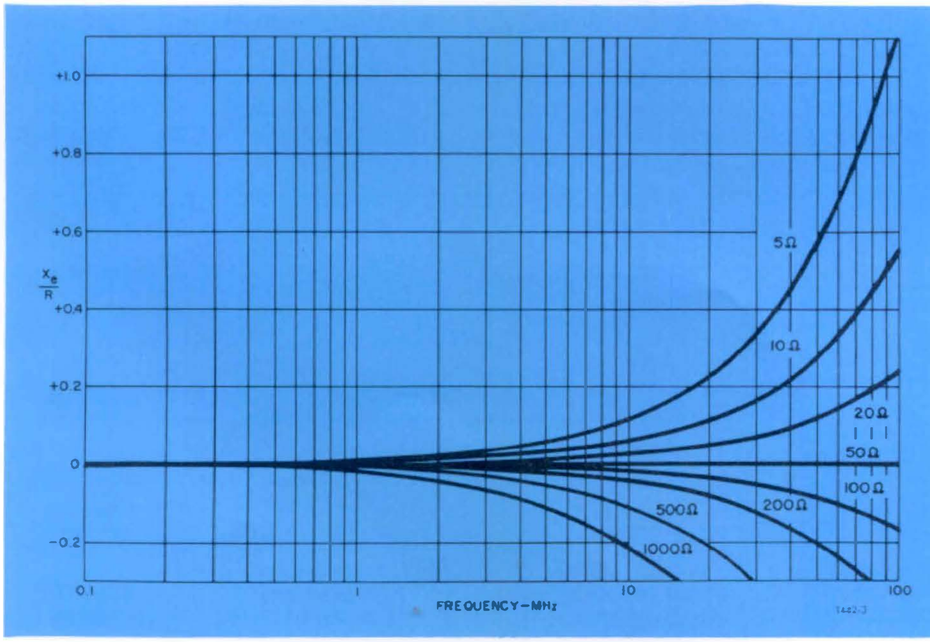


Figure 3. Typical ratios of effective series reactance to dc resistance, with a GR 900-WN Short Circuit at one end.

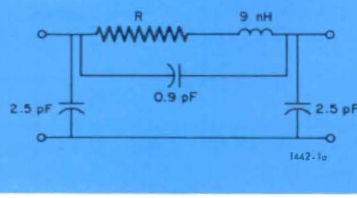


Figure 4. Equivalent circuit for GR 1442 resistance standards up to 100 MHz.

NEW


Type 1863 Megohmmeter — Inspection Model


Type 1864 Megohmmeter — Laboratory Model

A familiar standby for GR customers — the popular 1862-C Megohmmeter — has been replaced by *two* new units, Types 1863 and 1864, which require fewer adjustments and are easier to use.

The 1863 is recommended for production and inspection testing of insulation at five test voltages in the range 50 to 500 volts. Resistance ranges from 50 kΩ to 20 TΩ will cover most insulation specifications.

The 1864 will answer the need for a laboratory-type instrument; but also, its use is recommended for production testing at voltages not available in the Type 1863. This new instrument meets such requirements as 1000-volt checking, leakage testing of semi-conductors and capacitors to as low as 10 volts, and testing for reverse leakage of rectifiers. The highest range of the instrument — 200 TΩ — is most useful for research and development work involving insulating materials.

Leakage testing of paper, plastic, ceramic, and mica capacitors traditionally has been accomplished by measurement of insulation or leakage *resistance* of the capacitor. Testing of electrolytic capacitors of the aluminum- or tantalum-plate type usually is specified as a measurement of the leakage *current*, a method also employed in the inspection of semiconductor devices. Either megohmmeter, plus Ohm's Law, will accomplish the specified test.

Stability of calibration is maintained by use of a four-transistor unity-gain amplifier with FET input circuitry. In addition, no warmup drift is encountered, and high zero stability is maintained during operation. Human engineering has not been overlooked, as evidenced by the warning light that is activated by application of the test voltage. Also continued are use of the MEASURE-CHARGE-DISCHARGE switch and provision for performing grounded and ungrounded measurements. System engineering application of the instrument is encouraged by providing rear terminal access to an output voltage that is inversely proportional to R_x. This proportional voltage may be used to trigger a limit indication or an actuating mechanism in an automatic system. Its value varies from 0 to 4 volts when test voltages of 100 to 1000 are used; the value is proportionally less at lower test voltages.

SPECIFICATIONS

Voltage and Resistance Ranges:

Voltage	R_{min} Full Scale	R_{max} 10% of Scale	R_{max} 2½% of Scale	Useful Ranges
		Type 1863		
50, 100 V	50 kΩ	500 GΩ	2 TΩ	7
200, 250, 500 V	500 kΩ	5 TΩ	20 TΩ	7
		Type 1864		
10 to 50 V	50 kΩ	500 GΩ	2 TΩ*	7*
50 to 100 V	200 kΩ	5 TΩ	20 TΩ	8
100 to 500 V	500 kΩ	5 TΩ	20 TΩ*	7*
500 to 1000 V	5 MΩ	50 TΩ	200 TΩ	8

*Recommended limit.

Resistance Accuracy: ±2 (meter reading + 1)% on lowest 5 ranges (min reading is 0.5). For higher ranges add:

	sixth	seventh	eighth
1863	2%	4%	—
1864	2%	3%	5%

Voltage Accuracy (across unknown): ±2%.

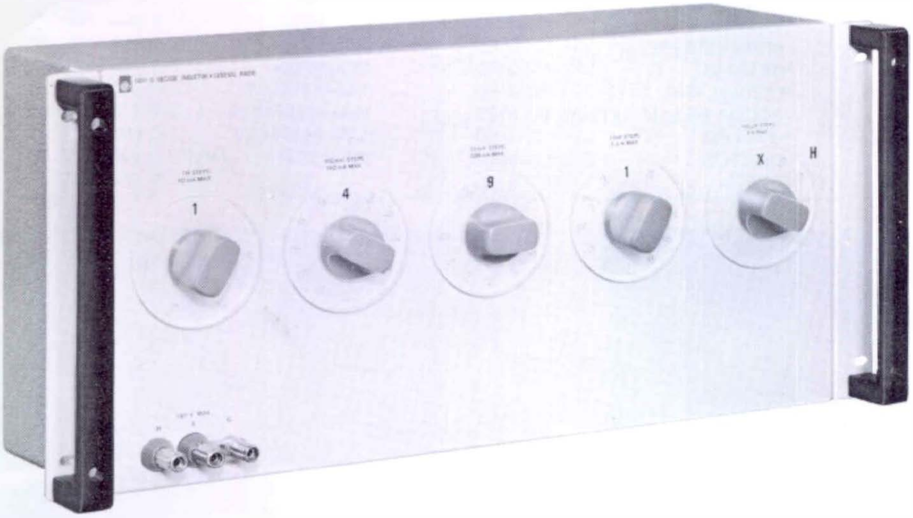
Short-Circuit Current: 5 mA approx.

Power Required: 100 to 125 or 200 to 250 V, 50 to 400 Hz, 13 W.

Catalog Number	Description	Price in USA
	1863 Megohmmeter	
1863-9700	Portable Model	$385.00
1863-9701	Rack Model	385.00
	1864 Megohmmeter	
1864-9700	Portable Model	485.00
1864-9701	Rack Model	485.00

NEW

The Type 1491 Decade Inductor incorporates several GR940 Decade-Inductor Units within, and insulated from, a single metal housing. The assembly offers moderately precise standards of inductance, with values of *Q* much higher than air-core coils at audio and low radio-frequency operation. Complete specifications are available from GR Catalog T.



Catalog Number		Description	Inductance		940's Included	Price in USA	
Bench	Rack		Total	Steps		Bench	Rack
		Decade Inductor					
1491-9701	1491-9711	1491-A	0.111 H	0.0001 H	DD, E, F	$615.00	$630.00
1491-9706	1491-9716	1491-F	1.111 H	0.0001 H	DD, E, F, G	795.00	815.00
1491-9703	1491-9713	1491-C	1.11 H	0.001 H	E, F, G	595.00	610.00
1491-9707	1491-9717	1491-G	11.111 H	0.0001 H	DD, E, F, G, H	995.00	1015.00
1491-9704	1491-9714	1491-D	11.11 H	0.001 H	E, F, G, H	795.00	815.00
1491-9702	1491-9712	1491-B	11.1 H	0.01 H	F, G, H	615.00	630.00

General Radio announces the first broadly applied quantity discount policy in the electronics industry; it applies for all customers and to all products.

Since it costs us less per unit when several, even two, items are ordered at a time, GR will share this savings with its customers. Anticipate your needs, consolidate purchases, and save your money. The full discount schedule shown below became effective March 2, 1969.

NEW

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