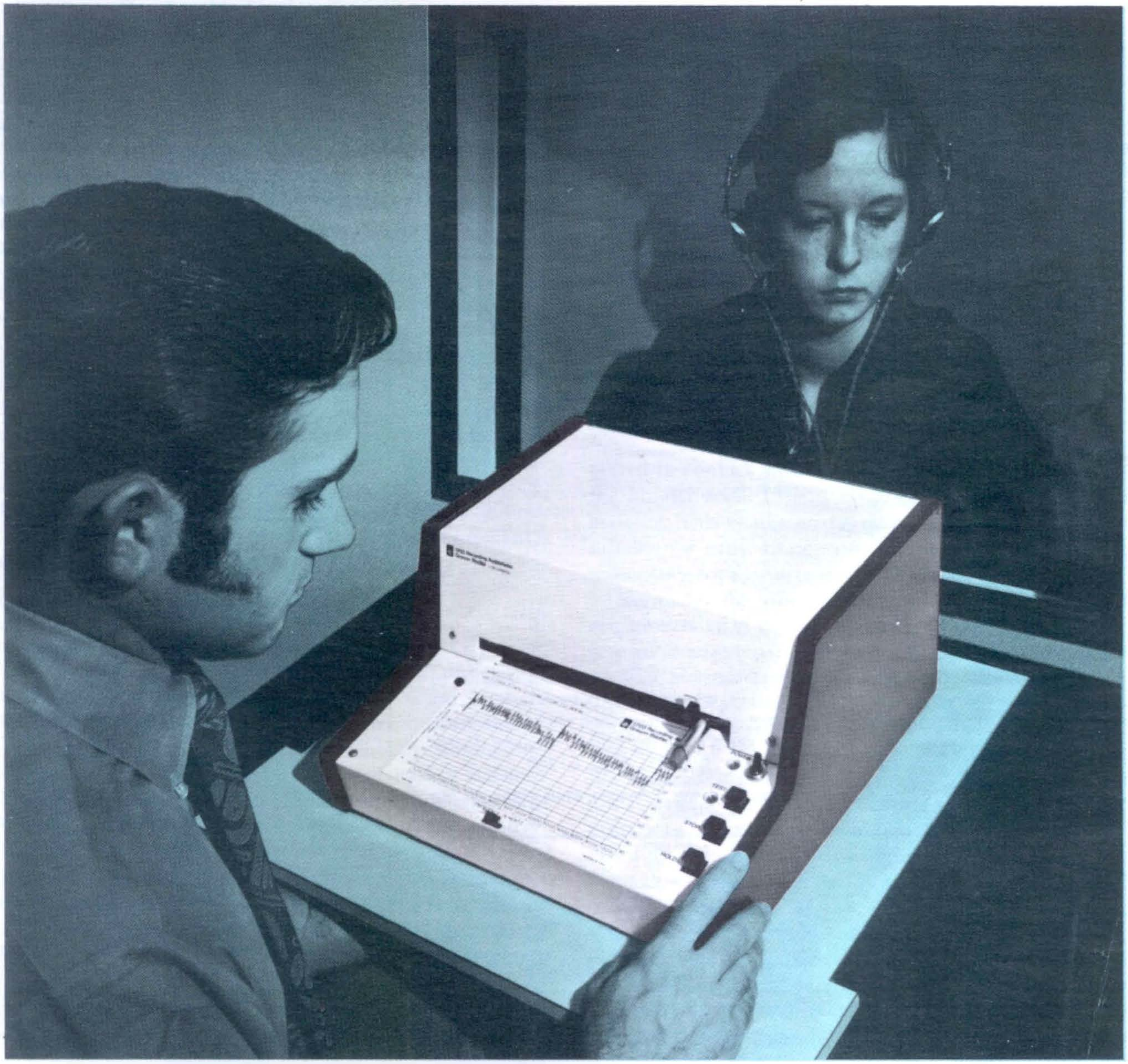
THE
GENERAL RADIO

Experimenter

VOLUME 44
NUMBERS 10,11,12
OCTOBER/DECEMBER 1970



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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., Concord, Mass. 01742.

Our Cover is an illustration of industry in action - with a G-S 1703 Audiometer. This picture is being repeated in many plants these days. The subject is undergoing a hearing test to detect any deviation from the normal response.

Inevitably, as time goes by, we awaken to the fact that our hearing is not as good as it used to be. If we are lucky, Nature will proceed **slowly**, but surely, to steal this sense from us. If we are unlucky, Nature will receive much help in ***hastening*** the process from the trappings of civilization - the noises of machinery, jet engines, rock and roll, etc. The tragedy of the latter case lies in the insidiousness by which we are consigned to that quieter world.

Deafness was recognized in the practice of medicine from its inception but comparatively little was known about how to measure the loss until the early part of this century. In line with Lord Kelvin's axiom concerning measurement and knowledge, the medical profession has contributed much data since 1900 to establish degree and type of deafness in patients. These data were derived from the **audiometer**, an instrument which has become increasingly familiar as industry has been alerted to one of its responsibilities — the well-being of the worker.

In this issue, Rufus Grason, president of GR's subsidiary, Grason-Stadler, describes the foundations of audiometry and the development of the audiometer.

Audiometers can be complex or simple, as established by their applications in hearing research or for clinical studies. But they are indispensable in this era of an alerted public and a benevolent judiciary, determined to prevent man from helping Nature's relentless but slow progression toward an awesome, silent world.

C E White

C. E. White
Editor

Another year draws to a close. Perhaps it has not been the best of years to many of us but it is a part of our lives. Looking forward optimistically, we at GR hope to share with our readers a Holiday Season filled with happiness and a New Year of growth and prosperity.

Season's Greetings!

Audiometric Measurement: 150 Years of Applied Research

One of the many considerations influencing the recent merger of Grason-Stadler with General Radio was the former's expertise in life-science instrumentation. Of particular interest was G-S's leadership in the design and distribution of acoustic and audiometric instrumentation—an area which significantly complements that occupied by GR's acoustic measurement devices. In the past year, Grason-Stadler has introduced two new major models, the G-S 1701 Diagnostic Audiometer and, more recently, the G-S 1703 Recording Audiometer. Adding to an already extensive line, these models represent two extremes of a continuum of devices whose applications range from relatively simple automatic screening to highly sophisticated research. This article describes these two units, how they came to be and their significance in the audiometric field.

WHAT IS AN AUDIOMETER?

In simple terms, an *audiometer* is an electronic instrument used to measure an individual's hearing acuity. The simplest units perform this function by providing to the listener (usually through earphones) an audio signal (commonly a pure tone) of known intensity and frequency. More sophisticated instruments offer the listener a variety of signals, pure tones, white noise, and speech, through a variety of output transducers—earphones, bone vibrators, or loudspeakers. These audiometers often will record, for several frequencies, the intensity level at which the listener just hears the signal.

The audiometer is usually operated under the auspices of an *audiologist*, a professionally trained individual interested in the measurement of the hearing function, its relationship to normative data, its assessment and, where appropriate, its treatment. As a formal discipline, the field of audiology plus the instrumentation that accompanies it is slightly more than 20 years old. Both were precipitated during the post World War II era when thousands of service personnel with varying degrees of hearing impairments returned to civilian status. Then, more than ever before, there was need for equipment, trained personnel, and accepted, proven techniques.

ROOTS OF AUDIOMETRY

The earliest attempts, in the beginning of the 19th century to establish techniques for the measurement of hearing involved little or no instrumentation as such. On the simplest level were live-voice tests, which typically required the tester to maintain a fixed-intensity speech level while varying the test distance until he could just be heard by the listener. Although this type of test yields some information regarding how an individual handles speech communication, it requires well-practiced testers, is subject to great test-retest variability, and is, at best, adequate only for screening purposes.

G-S 1701 Audiometer

Other early hearing tests involved the tuning fork, whose prongs vibrate when struck lightly, producing a pure fixed-frequency tone. The tuning fork provided a convenient means of generating a precisely repeatable fixed frequency, even though it was a greater problem to control the sound level at the subject's ear with the tuning fork than with live speech. Moreover, it also manifested the ability to transmit its signal by means other than air conduction, for, if its base is placed in contact with any solid material – wood, metal, or the human skull—it induces sympathetic vibrations in that material. This characteristic made the tuning fork uniquely suitable for early attempts to determine the anatomical site responsible for a given hearing loss.

Normally, the vibrating fork would be held outside the ear, air serving as the initial conductive medium. If the tone generated were heard by the listener, it was only because the ear was "normal" and the tone had been transmitted successfully through the entire auditory chain, including the outer, middle, and inner ears. If this test were unsuccessful, the next step might be to place the base of the vibrating fork behind the ear on the subject's mastoid bone, which serves as the initial conductive medium. For the tone generated by this process to be heard, it would only have to excite, by direct conductive vibrations, the inner-ear neural mechanisms through which acoustic stimuli are transmitted to the higher centers in the brain. If this step successfully elicited a response where air conduction had failed, it would seem to indicate some blockage or discontinuity in the outer or middle ear. This mode of determining any differential sensitivity to air-conduction and bone-conduction tests proved to be a viable diagnostic procedure. The basic technique pioneered with the tuning fork was subsequently refined and adopted as a standard procedure in the growing diagnostic repertoire.

EARLY INSTRUMENTS

For many years the tuning fork and live-voice test served as the most sophisticated means to measure human hearing. By the end of the 19th century, however, technology had advanced to a point where corollaries to these types of tests could be implemented by electro-mechanical instruments. The earliest instruments designed to test hearing were scarcely one step removed from the tuning fork, in some cases containing that very device as their central component. In at least one instance, the tuning fork's oscillations were used to modulate an electrical circuit and to produce an alternating current in a secondary circuit. Part of this secondary circuit was a telephone receiver that reproduced the frequency of the vibrating fork at the listener's ear. This technique established a signal source with repeatable frequency characteristics. Popularly called an "Acoumeter," this tuning fork audiometer served as the basic auditory-test instrument until the alternating-current generator made possible the production of a signal with a wider frequency range than that of a tuning fork. The availability of the vacuum tube, in the early 1920's, made electronic audiometers commercially feasible.

By the early years of the 20th century, then, an electro-mechanical replacement had been found for the purely mechanical tuning fork in air-conduction threshold tests. It was only a few years later that an electro-mechanical successor was found for the tuning fork in its second application – tests of bone-conduction hearing. To reproduce the effect of the vibrating base of the tuning fork, the diaphragm of a telephone receiver was replaced by a strip of metal to whose surface was attached a metal rod. This device, driven by the same auditory signal used in the air-conduction tests, could now serve as the vibration source.

The electronic successor to the earlier live-voice speech testing came about gradually through the early years of the 20th century. By 1927, the technique of recorded speech tests – implemented by a spring-wound phonograph – had reached a new peak of sophistication in the Western Electric 4A Audiometer. This unit permitted individual subjects, or even entire classes of subjects, to be given speech threshold tests.

Few really significant audiometric developments took place in the 30's and early 40's, prior to the outbreak of WW II. The field was growing, however, and commercial audiometers appeared in increasing numbers on the market, although their main characteristics were really quite similar. They were, without exception, vacuum-tube based. Several were equipped with sweep-frequency oscillators, though the majority provided only a limited number of frequencies, most of them the so-called "tuning-fork frequencies" of 128 Hz and its multiples. Output transducers generally included a variety of types of earphones and early renditions of the bone vibrator. An electric buzzer was included as a rough approximation of a masking source on many units, to "mask" or shield the ear not under test from signals conveyed by air or bone from the ear under test. Intensity was usually specified in terms of decibels of attenuation for each frequency used.

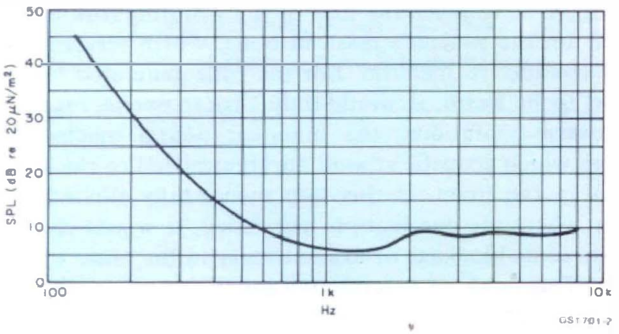


Figure 1. 1964 ISO threshold values for pure tone. Earphone reference based on measurements made on National Bureau of Standards 9-A coupler and Western Electric 705 earphone.

INSTRUMENTATION IMPROVEMENTS

In terms of the test equipment that had preceded them, the instruments described above reflected significant advancements in both audiometry and general electronic technology. The technology as a whole, however, was still in relative infancy.

Standards

When audiometers first were commercially manufactured, there were no accepted standards to specify either "normal" thresholds, acceptable signal parameters, or test techniques. Over the years, however, many organizations have been formed specifically to establish, revise, and maintain such standards.

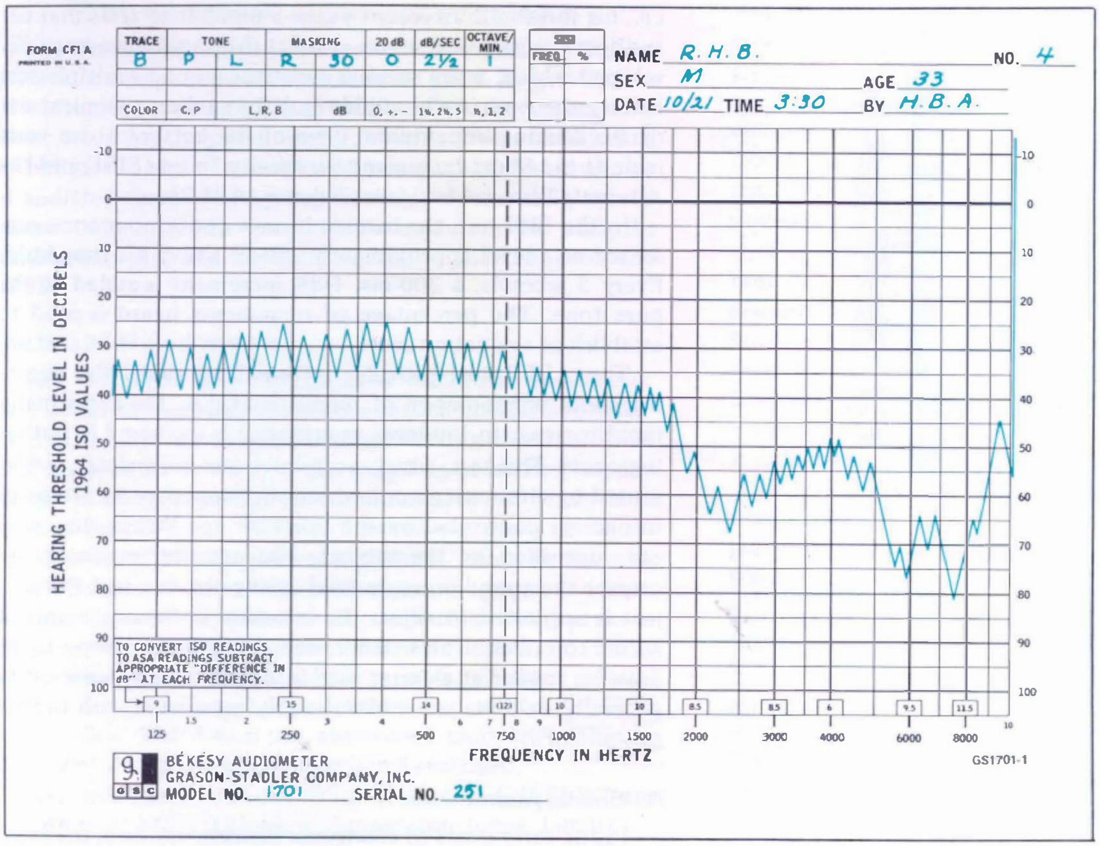
One of the most important standards, worked out over the course of several years, specifies the "normal" threshold intensities of the most significant frequencies in the audible continuum. These so-called normal absolute threshold values were obtained by screening large segments of the population to locate individuals without obvious hearing abnormalities, then by meticulous tests of these individuals' hearing. After further screening of the data, a statistical average was made and an absolute threshold value for each of several frequencies determined. Figure 1 shows the ISO pure-tone absolute threshold levels versus frequency.

On modern audiogram forms, such as that from the G-S 1701 (shown in Figure 2), an individual's hearing at several frequencies is plotted with reference to Hearing Threshold Level; 0 dB HTL is equivalent to the standard normal threshold values shown in Figure 1.

The G-S 1701, like most other audiometers, changes the intensity of the output as the frequency is changed and automatically references the signal to the accepted threshold standards. A subject with hearing acuity more sensitive than normal will show a negative HTL. A subject whose hearing is less sensitive than normal will show a positive HTL, i.e., he will require a signal more intense than normal to hear the same frequency tone.

Calibration

The American National Standards Institute, Inc. (ANSI) the National Bureau of Standards, and other regulatory groups also have tried to establish standards in the critical area of audiometer calibration. The output level of early audiometers, for example, was calibrated by the measurement of voltage produced across the earphones. While such an approach could accurately describe the adequacy of the signal



TRACE	TONE		MASKING		20 dB	dB/SEC	OCTAVE/ MIN.
B	P	L	R	30	O	2½	1
COLOR	C, P	L, R, B		dB	0, +, -	1¼, 2½, 5	½, 1, 2

NAME R.H.B. NO. 4
SEX M AGE 33
DATE 10/21 TIME 3:30 BY H.B.A.

TO CONVERT ISO READINGS TO ASA READINGS SUBTRACT APPROPRIATE "DIFFERENCE IN dB" AT EACH FREQUENCY.

BÉKÉSY AUDIOMETER
GRASON-STADLER COMPANY, INC.
MODEL NO. 1701 SERIAL NO. 251

Figure 2. G-S 1701 audiogram, illustrating possible inner-ear hearing loss.

within the system, it took into account neither the likely non-uniformity of the earphone response nor the effect on that response of the volume, resonance, and impedance characteristics of the ear into which the signal was directed.

The most significant improvement in this area came when couplers and, later, artificial ears were introduced into the audiometric calibration process. Both these devices, made with known volume and material, serve as substitutes for the human ear. The earphone of the audiometer to be calibrated is tightly fitted to the mouth of the coupler or artificial ear. The sound-pressure level of the earphone signal, introduced at a fixed input level, can then be measured and read through a microphone contained in the cavity.

Masking Sources

The importance of a masking source to mask, or block, transmission of the test signal to the ear not under test was recognized in the 1920's, and early audiometers contained an ordinary electrical buzzer specifically for this purpose. It soon became apparent that the precise nature of the masking agent – especially its frequency spectrum – significantly affected the pure-tone threshold being measured.

White noise, whose spectrum contains equal amounts of all audible frequencies, provides a more effective masking agent than the buzzer and continues to be used to the present day. White noise masks all frequencies equally, including that of the test signal, and with a minimum production of beats or harmonics. This major advantage of white noise, however, is also its main disadvantage. Because the white-noise spectrum is so broad, it introduces to the ear not under test a much higher over-all energy level than is required to mask any given pure tone. Ideally, most efficient masking would be accomplished with a very narrow band of frequencies centered around the test tone, which would concentrate the available energy in the vicinity of that tone.

As its latest approximation to an optimum masking signal, Grason-Stadler has incorporated into its 1701 Audiometer a variable narrow-band noise source whose bandwidth changes as a function of the frequency of the test tone. This variable bandwidth, which permits efficient masking to take place at all frequencies, is unique to the G-S 1701 and stands out as one of its most important features.

Speech Testing

The disadvantages of live-voice tests have already been mentioned. It became apparent at a relatively early stage, however, that whatever the advances in sophistication of pure-tone audiometry, speech material could not be abandoned entirely as an audiometric stimulus. Not only are there psychological advantages in tests with a speech stimulus, normally dealt with by average listeners, but there are certain common hearing disorders in which the subject manifests significantly less ability to understand speech than his pure-tone threshold would suggest. For these reasons, improved instrumentation and the standardization of testing materials were needed.

A variety of speech materials has been developed specifically for speech audiometry through the years. Much of the work originated at the Harvard Psychoacoustic Laboratory, the Bell Telephone Laboratories, and the Central Institute for the Deaf. Such material generally includes the equally stressed (spondee) and phonetically balanced lists whose

Rufus L. Grason received a very practical introduction to the field of psychoacoustics and its instrumentation by first working in, and later assuming responsibility for, the electronics shop at the Harvard Psychoacoustic Laboratory. His experience and training lead him in 1949 to form, with Steve Stadler, the Grason-Stadler Company, now a subsidiary of General Radio. As President and Director of Engineering, he has been intimately involved with design and development of the company's equipment, most recently the 1701 and 1703 audiometers. In the early 1960's, Mr. Grason served as a member of the American Standards Association writing group whose recommendations for audiometers resulted in the ANSI 1969 specifications. He is currently Secretary of a subcommittee of the International Electrotechnical Commission, preparing specifications for diagnostic and research audiometers.

phonemic make-up roughly matches that of American colloquial speech. This material is presented in standard speech tests either by an operator or through tape or phonograph inputs.

Modern audiometers such as the G-S 1701 include a VU meter that can be switched into the circuit to calibrate the input signal, either the speaker's voice or a recorded (tape or phonograph) input. To deliver a fixed-intensity speech signal to the subject in live-voice tests, the operator need only speak into the microphone and control the intensity of his speech with the aid of the monitor VU meter. Precisely repeatable intensity increments or decrements can then be made by a simple adjustment of the attenuator control.

A second method of implementing speech tests is to present the recorded material by means of either a phonograph or a tape recorder. To facilitate such an approach, most of the standard word lists are now provided by audiometer manufacturers on records, which have the advantage of providing a uniform speaking voice; this permits excellent inter-clinic data comparisons. At the beginning of these records a 1000-Hz calibration tone is generally included, which can be used to ensure that different testers present subsequent test materials under more nearly comparable conditions.

Suprathreshold Tests

One of the major disadvantages of the earlier audiometers was their exclusion of suprathreshold testing. Almost without exception, audiometers were used to determine the minimum audible intensity that could be detected by the listener, i.e., his threshold. In recent years, a number of tests that use auditory stimuli well above normal threshold have been developed which, when used as constituents of a multiple-test battery, become useful as aids in defining the anatomical site of the hearing impairment. Two of the better-known tests include the Short Increment Sensitivity Index (SISI) and the Alternate Binaural Loudness Balance (ABLB).

In the SISI test, the listener hears a continuous tone presented at a level approximately 20 dB above his threshold. Every 5 seconds, a 200-ms, 1-dB increment is added to the pure tone. The percentage of increments heard is used to establish an evaluation score.

The ABLB test provides information about the suprathreshold phenomenon of recruitment, i.e., the abnormally rapid increase in loudness as intensity is increased in pathologic ears. This test, which postulates one normal ear, is presented by alternating a pulsed tone between ears, its intensity in one ear controlled by the operator and that in the other ear controlled by the subject. The operator gradually increases the sound-pressure level in the one ear, and the subject is requested to adjust the intensity in the other until it seems to match. The listener who perceives the tone to be growing louder at a faster rate in one ear than in the other generally exhibits some abnormality associated with the organ of Corti.

Automatic Audiometers

In the early years of electronic instrumentation, the audiometer was manually operated. Intensity and frequency changes, and any timing of signal duration, were implemented by the operator. The responses of the subject, usually a verbal "yes" or "no" or a hand signal, were also manually recorded by the operator.

In recent years, especially since WW II, an increasing number of these functions have been automated. In addition to the obvious benefit of operational ease, such automation has resulted in increased reliability by presenting standard test sequences, free from operator intervention and the consequent possibility of error. On the automatic G-S 1701, for example, standard tests that employ short auditory signal presentations are automatically timed. The G-S 1701 also varies intensity and frequency parameters, and it records the subject responses to these stimuli. The technique through which this is accomplished is generally referred to as the Békésy technique, after Georg von Békésy who developed the procedure in the 1940's.

Békésy's technique requires that the subject's threshold be recorded continuously at several test frequencies. While the test is being administered, a recording pen is moved along the horizontal axis of the audiogram form, on which frequency is plotted. In the absence of a subject response, an automatic attenuator associated with the subject switch increases the sound level and simultaneously moves the recording pen down along the HTL (vertical) axis of the form. In the presence of a subject response, the attenuator decreases the sound level and moves the recording pen up along the chart's vertical axis. The end result of this procedure is that a record is made of the subject responses in the region between audibility and inaudibility.

THE GRASON-STADLER AUDIOMETERS

Grason-Stadler has been designing and manufacturing audiometric equipment for more than 20 years. Its present line of audiometry-related instrumentation includes a speech audiometer; a psychogalvanometer, which utilizes conditioning techniques to elicit a change in skin resistance as an indicator of auditory threshold; a group hearing aid, essentially an amplifier used in group situations to communicate with the hard-of-hearing; and two audiometers – the G-S 1701 and 1703.

The G-S 1701 Audiometer

The G-S 1701 is a sophisticated diagnostic audiometer used under the auspices of professional audiologists to measure and assist in the evaluation of the hearing function. Since it is designed to be used in the diagnosis of hearing impairments – which requires the administration of whole batteries of related tests – the instrument is extremely versatile. Signal sources include pure-tone, white, narrow-band and speech noise, as well as microphone, phonograph, and tape recorder inputs. Output transducers include loudspeakers for sound-field tests, earphones for air conduction, and a bone vibrator for bone-conduction tests, all three advantageous for reasons mentioned above. Suprathreshold tests such as SISI and ABLB are automated and can be implemented by changes of a few front-panel switches.

Intensity output of both channels of the G-S 1701 is from −15 dB to +115 dB HTL for mid-range pure tones. Timing for other tests can be implemented manually or automatically in a variety of switch-selected modes. To facilitate verbal communication with the listener being tested, a talk-forward/talk-back system with independent level controls is included with the G-S 1701.

Perhaps its most outstanding feature is the flexibility of its automatic control provisions. In addition to sweep-frequency Békésy, it can present fixed-frequency Békésy or automatic ABLB tests. Another distinctive feature is its variable bandwidth masking source, the first such masking source to appear on a commercially available audiometer.

The G-S 1703 Audiometer

The G-S 1703 Recording Audiometer is much simpler and less sophisticated than the 1701. It has been designed primarily for use in the early stages of a well-developed hearing program, to distinguish normal from hard-of-hearing individuals. Although the G-S 1703 will be used for a variety of applications, it will undoubtedly find wide-spread use in industrial and business situations where high ambient-noise levels might adversely affect hearing.

The existence of noise-induced hearing loss has been recognized for a number of years; the first national conference on noise was held in 1952. Since then, numerous variables contributing to noise-induced hearing loss have been determined with some precision: over-all noise level, composition of the noise, duration and distribution of exposure, and total time of exposure. These inquiries have led quite recently to a series of Federal and State laws that specify permissible noise conditions and prescribe compensation for workers suffering hearing loss due to occupational noise exposure.

In recognition of these possible effects of noise, more and more companies are establishing their own in-plant hearing test centers. When fully operational, these facilities will be used to screen individuals before they enter the working environment and at various time intervals during their occupational careers. In this manner, both the worker and the employer can be assured of mutual protection against the undesirable effects of noise pollution.

The G-S 1703 is a pure-tone audiometer with an intensity range of −10 dB to 90 dB HTL. It is extremely simple to operate, having only three operator pushbuttons – Start, Stop, and Hold. Included as an integral part of the unit is a recorder that makes a permanent record of subject responses, first for the left and then for the right ear. At each of the seven discrete frequencies presented, the subject's threshold is determined and recorded via a modified Békésy technique.

The G-S 1703 has at least two unique features not incorporated in other units currently available. First, the subject-controlled intensity changes at a variable rate, rapidly at the start of each test frequency, then more slowly as threshold is approached. This technique means that less time is spent getting to the threshold region at each frequency and more time is spent defining the threshold precisely. This, in turn, means greater retest reliability and a more meaningful audiogram.

Second, the G-S 1703 automatically initiates a check of threshold at 1 kHz at the end of each test. This value, when compared to the previous threshold value of 1 kHz, gives the operator an immediate indication of the validity of the test.

CONCLUSIONS

These distinctive features of the G-S 1703, added to its ease of operation and its reliability of design, should give it, like its more sophisticated antecedent, the G-S 1701, a long and healthy life in a world which increasingly requires precise information about the human hearing function. In conjunction with GR's growing line of instruments for sound measurement, these two units and their companions provide one of the most comprehensive single sources for audiometric and acoustic equipment.

—R. L. Grason

The author acknowledges, with gratitude, the work performed by Carol W. Hetzel in assembling and coordinating much of the material in this article.

For Further Information:

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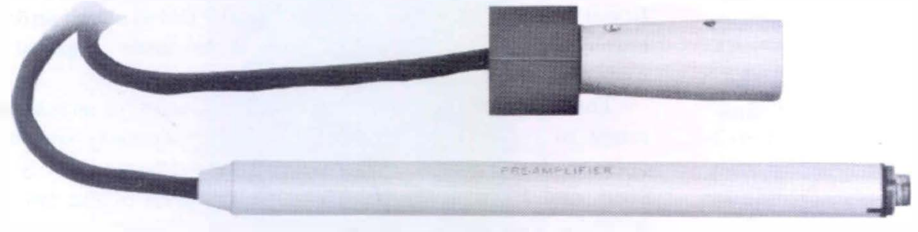
Condensed specifications for the G-S 1701 and 1703 Audiometers appear elsewhere in this issue.

Catalog Number	Description
1701-9700	**1701 Manual Diagnostic Audiometer,** 117/234 V 50 to 60 Hz
	1701 Automatic Diagnostic Audiometer,
1701-9710	117 V 50 to 60 Hz
1701-9720	234 V 50 to 60 Hz
1703-9700	**1703 Recording Audiometer**

A BIG LITTLE-BROTHER PREAMPLIFIER



GR 1560-P42 Preamplifier

1-in. microphone

1/2-in. microphone

1/4-in. microphone

1/8-in. microphone

The GR 1560-P42 Preamplifier is a bridge between most test microphones (ceramic or condenser) or ceramic transducers and the GR analyzers and sound-level meters. It is similar to the GR 1560-P40 unit but incorporates several improvements in its design.

Some Details

The -P42 unit is of smaller physical size (1/2-inch diameter by 6-inch length); incorporates switch-selected polarizing voltages, derived from an internal 65-kHz (approximate) oscillator, for condenser microphones; and has larger output current. Its three-wire output transmission system has a separate signal ground and a shield that does not carry signal current, thereby reducing hum pickup.

The standard front-end connection is readily adaptable to most test-measurement condenser and ceramic microphones. The input connection is guarded by a signal-driven shield, which reduces capacitive loading for low-capacitance microphones. Provision has been made, as an integral part of the preamplifier output jack (Figure 1), for insert-voltage calibrations, typically required for laboratory standard microphones such as the WE 640AA, and for remote checks of systems.

The preamplifier class AB output stage can provide up to 10 mA peak and > 1 V rms to feed full audio-range signals through cables as long as one mile; with no signal it draws less than 1 mA at +15 V, when used with ceramic microphones, thereby promoting longer supply battery life. Gain of the -P42 is switch-selected as unity (0 dB) or x 10 (20 dB). The FET input-stage design provides diode protection against input surges.

Connection between the preamplifier and transducers is by means of the accepted 0.460-60 thread, to fit present condenser microphones and their adaptors. Most other microphones and accelerometers are connected by use of simple GR adaptors.

Power for the -P42 unit is available from most of GR's sound analyzers and sound-level meters. For use with other instruments or for long cable runs, the GR 1560-P62 Power Supply will provide the required power. The power supply includes NiCad batteries, charging circuitry, an automatic low battery-voltage sensor to prevent excessive discharge, load-current limiting, and remote-switch control capability to turn off the power.

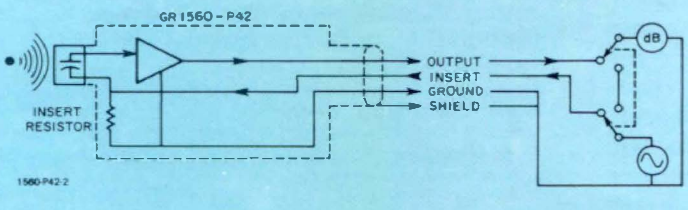


Figure 1. Schematic of 3-wire and insert-voltage connections in -P42 preamplifier.

Other Necessities

Since no single type of microphone satisfies all test requirements, GR has made available as sets a group of microphones to supplement the preamplifier unit. The 1-inch ceramic and 1/2-inch condenser microphones are useful for measurements of low or moderate sound-pressure levels at normal audio frequencies. The 1/2-, 1/4-, and 1/8-inch condenser microphones are required when measurements are made at high sound-pressure levels or high frequencies. Each set includes all necessary adaptors to mate microphone, preamplifier, and GR 1562 Sound-Level Calibrator. In addition, an adaptor is available to mate the -P42 unit and standard 1-inch condenser microphones such as the Western Electric 640AA; another adaptor is supplied to mate to Switchcraft-type A3 audio-type connectors.

The GR 1560-9580 Tripod accommodates both the -P42 and -P40 preamplifiers, the GR 1560-P5 microphone, and all sound and vibration instruments having a 1/4-20 threaded tripod mount.

Development of the GR 1560-P42 was by E. R. Marteney.

Complete details of the GR 1560-P42 Preamplifier, microphones, and adaptors are available in GR Catalog U.

Catalog Number	Description
1560-9642	**1560-P42 Preamplifier**
	Ceramic Microphone Set
1560-9531	1-inch
	Condenser Microphone Sets
1560-9532	1/2 inch
1560-9533	1/2 inch
1560-9534	1/4 inch
1560-9535	1/4 inch
1560-9536	1/8 inch

Turn To Page 19 To Learn About Reduction Of Wind Noises

The Greeks Had A "Word" For It - Stroboscope

A coined word of deep impact in the field of illumination, derived from strobos (whirling) and skopeo (I look at)


GR 1542

Years ago man discovered that the eye could perceive rapidly moving objects by observing them only intermittently, as through a slit in a whirling opaque disc. A similar "miraculous" phenomenon familiar to early western-movie fans was commonly termed "wagon-wheel effect" and was due to the harmonic relationship between the information-sampling (camera-framing) rate and the rotational rates of the thousands of wagon wheels that thundered across the silver screen. But it took the introduction of Dr. Harold Edgerton's electronic stroboscope by General Radio Company some 38 years ago to bridge the gap between a novelty principle and a widely-useful tool. Intense microsecond flashes of light produced by the many improved general-purpose instruments introduced over the years provide the ultimate in motion-stopping capability to observe visually, to measure the speed of, or to photograph events and objects that would otherwise be but a blur.

Customer requests indicated a need for several additions to the GR strobe line such as the GR 1540 Strobolume® electronic stroboscope,[1] which produces extremely high light output, and the GR 1541 Multiflash Generator,[2] an accessory for photographic applications. New, less-expensive light generators also were requested for "single-use" applications that demand less versatile light sources, such as a simple basic stroboscope designed only to "freeze" motion for visual study. One answer to these needs is the GR 1542 Electronic Stroboscope.

Small But Mighty

Simplicity in itself, the GR 1542 is a small, rugged, inexpensive and simple-to-operate stroboscope that puts the magic of frozen motion at your fingertips. Its stable wide-range oscillator produces steady stopped- or slow-motion images.

Most stroboscopes produce an image that appears to the operator to decrease in brightness as the flash rate is decreased. Usually this undesirable situation is overcome by switching additional capacitors into the discharge circuit at reduced oscillator frequencies. The GR 1542, however, uses a novel electronic circuit to provide an essentially constant sub-

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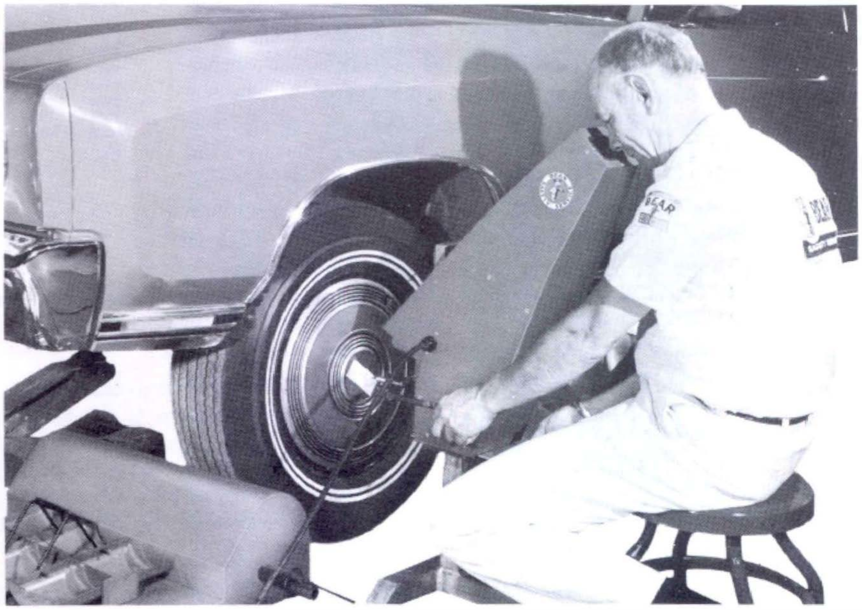
[1] Miller, C. E., "Detailed Viewing in Ambient Brightness," *GR Experimenter*, September/October 1969.

[2] Miller, C. E., and Rogers, W. F., "New Shoes for an Old Workhorse," *GR Experimenter*, July/September 1970.


The Bear Corporation's portable automobile wheel-balancing machine incorporates GR 1542 stroboscope.

Photograph courtesy of Bear Corporation, Rock Island, Illinois.

C. E. Miller was graduated from Yale University in 1960 with a B. Eng. degree and received his MS degree from Massachusetts Institute of Technology in 1966. He joined General Radio in 1960 and is an engineer in the Component and Network Testing Group. He is a member of IEEE, AOA and ATI and holds a patent for a constant offset frequency-generating device to produce slow-motion images.

jective image brightness over a wide speed range without switching, resulting in greater operational simplicity and lower over-all cost!

In education, the GR 1542 is well suited to student use in experiments that demonstrate the principles of stroboscopy and harmonic motions. Industrial uses for the GR 1542 abound in development, test, and maintenance areas. Careful electrical and mechanical design assure that this hand-held instrument will perform faithfully under severe industrial environmental conditions.

A particularly interesting application involves the use of a slightly modified GR 1542 in a new-type automobile wheel-balancing machine (Figure 1) invented by Bear Manufacturing Corporation of Rock Island, Illinois – long the foremost manufacturer of automotive brake and wheel alignment equipment in the USA. The stroboscope is an essential component in the "Telabalancer." With this machine the operator quickly makes extremely accurate balances of wheels with all parts, including the hubcaps, in place and at road speeds of 120 mph! Bear chose to use the GR 1542 for the critical illuminator in the Telabalancer because of its high, relatively-constant light output, oscillator stability, and ease of adjustment – important factors to the operator often working rapidly in areas of high ambient illumination. High reliability is also a prime requirement as the Telabalancer must function day after day. The stroboscope package provides the rather unique advantage that the entire strobe is bolted into the Telabalancer as a completely enclosed component. In the event service is required, the user simply unbolts and easily removes the stroboscope and returns it to his distributor for an exchange unit.

Some Background

Realization of the GR 1542 involved an unusual degree of cooperation among the industrial design, mechanical, and electrical engineers. The package was to be compact, neat in appearance, and the controls convenient to operate. It is physically rugged and thermally and electrically compatible with the high-performance strobe "innards," assuring operator safety and low cost. These criteria were met by use of a variety of tough plastics and a novel, symmetrical "clamshell" injection-molded case, amazingly resistant to physical abuse.

A single-range uncalibrated oscillator provides flashing rates from approximately 180 to 3800 flashes-per-minute, or a speed ratio of approximately 20 to 1. Stability of the oscillator is of prime importance to produce steady, stopped, or slow-motion images. Accuracy of calibration, of course, is not a factor since the instrument is not intended for speed measurements. A five-turn continuous control provides vernier action for smooth speed adjustment throughout the oscillator range, and motions to above 50,000 rpm may be viewed by use of harmonics.

User response indicates the GR 1542 provides good performance and a truly economical capability to "stop" high-speed motions for visual study or analysis.

–C. E. Miller

The GR 1542 was designed by the author; W. A. Montague and P. A. d'Entremont contributed to the mechanical and industrial designs respectively.

Flash Rate: ≈ 180 to 3800 flashes per minute (3 to 63 flashes per second), continuously adjustable by uncalibrated 5-turn control
Flash Duration: ≈5 µs at 63 fps, ≈25 µs at 3 fps
Beam Angle: ≈ 40° at half-intensity points
Power: 105 to 125 V, 50 to 60 Hz, 9 W.
Mechanical: Molded plastic case with face plate to protect lamp, high brightness reflector, standard 0.25-20 threaded hole for tripod mounting. DIMENSIONS (w x h x d): 4.2 x 2.16 x 7.52 in. (107 x 55 x 191 mm). WEIGHT: 1.8 lb (0.8 kg) net, 2 lb (0.9 kg) shipping

Catalog Number	Description
1542-9700	**1542 Electronic Stroboscope**
1530-9400	**Replacement Strobotron Flash Lamp**

Information Retrieval

An article edited by L. J. Chamberlain, Executive Vice-President of Time/Data (a GR company), presents the subject of time-series analysis in comparatively simple terms and illustrations. It is entitled "A Simple Discussion of Time-Series Analysis" and is available to any reader who would like a single copy. Address your request to the Editor – *GR Experimenter,* General Radio Co., Concord, Mass. 01742.

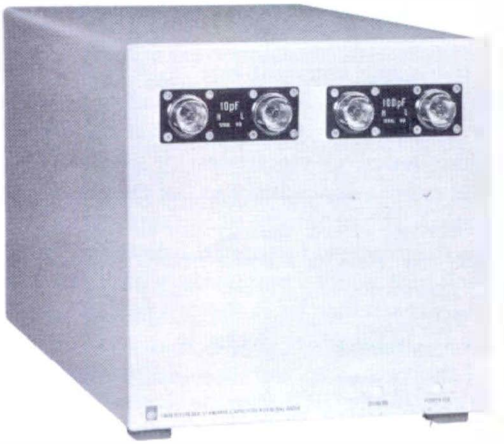
EXTRA!

Stability in Standard Capacitors, Precision in Capacitance Measurements

Our standard capacitors do change with time.

Even though these capacitors have remained satisfactorily stable over the years, the accuracy of the calibrations, Figure 1, shows an inclination to plunge into the region where the uncertainties are less than a part per million. The National Bureau of Standards has led the way with improved capacitors and measurements. We have followed them, not only with interest but with some new instruments[1] designed to bring to other laboratories the increasing accuracy of NBS calibrations.

The new GR 1408 10- and 100-pF reference-standard capacitors with the proven mechanical and electrical stability of a fused-silica dielectric have been constructed to provide higher accuracy in the transfer and storage of the unit of capacitance. The new GR 1616 transformer-ratio-arm bridge has also been built to meet the need for improved precision in the intercomparison of these standards and for high accuracy in the calibration and measurement of a wide range of other capacitors. This bridge provides extended ranges of capacitance and conductance and extended sensitivity, particularly when used with the complementary new GR 1238 phase-sensitive detector and GR 1316 power oscillator. The bridge, detector, and oscillator assembly (GR 1621) is of value not only in the calibration of standards but also in the investigation of the dielectric properties of materials, through measurements of small capacitances and conductances and of very small changes in these quantities.



GR 1408 standard, with temperature-controlled air bath.

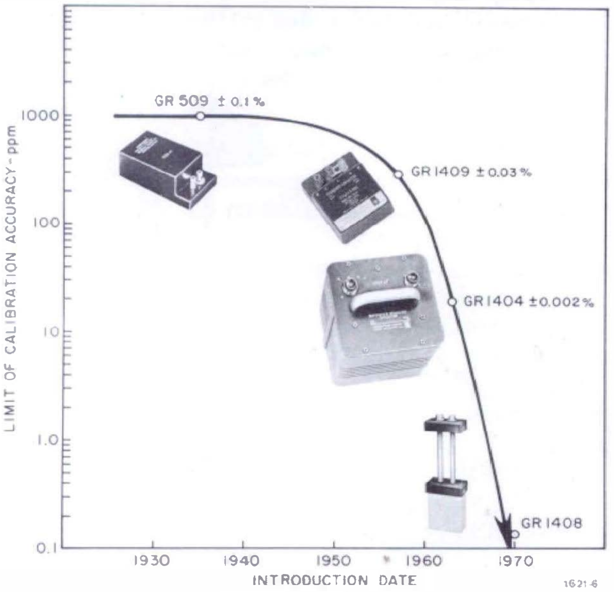


Figure 1. GR standard-capacitor calibration-accuracy improvement with time.

FUSED-SILICA CAPACITORS
GR 1408 REFERENCE STANDARD CAPACITORS

The fundamental design of the new 10- and 100-pF standards is based upon the development at NBS by Cutkosky and Lee[2] of a 10-pF capacitor with time stability and small variations due to voltage change or shock, which permit calibration to parts in 10^7. The dielectric material used for such stability is a special grade of fused silica. It has the further advantages of low losses and low frequency dependence of its dielectric constant in the audio frequency range.

GR Design

The two main considerations in the design of the fused-silica capacitors were the manner of applying the electrodes to the substrate and the manner of supporting the capacitor

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[1] Abenaim, D. and Hersh, J. F., "New Fused-Silica-Dielectric 10- and 100-pF Capacitors and a System for Their Measurement," *IEEE Transactions on Instrumentation and Measurement*, November, 1970.

[2] Cutkosky, R. D. and Lee, L.H., "Improved Ten-Picofarad Fused-Silica Dielectric Capacitor," *NBS Journal of Research*, Vol. 69C, July-September, 1965.

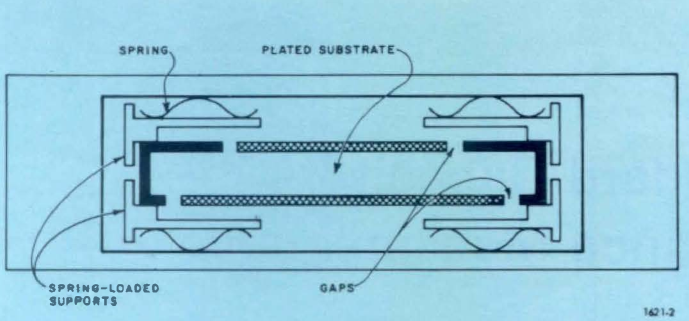


Figure 2. Substrate thickness
is the only difference between 10- and 100-pF units.

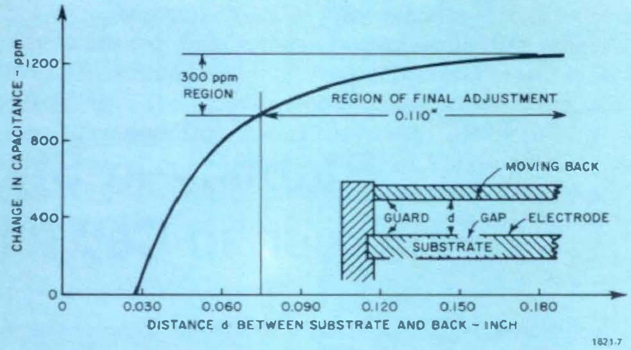


Figure 3. Effect upon capacitance
of changes in back-substrate separation.

in its cell. It became apparent very quickly that the gap between these electrodes was critical. It had to be well defined and free of isolated particles of metal that could be attracted to the plated guard or electrodes by electrostatic forces, which would cause a dependence of the capacitance upon the voltage applied. The geometry of the support in the vicinity of the gap is the principal factor in the design of the cell as the direct capacitance is not completely within the fused silica but includes capacitance from the top face of one electrode through the gap to the other electrode.

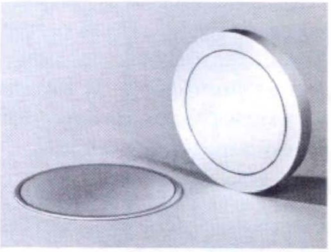
Figure 2 shows the configuration of the electrodes and the supporting cell. In the GR design the electrodes and guard are in the same plane on each face, and photo-etching techniques can be used both to generate the gaps and to adjust the capacitance by changing the area of an electrode. Fortunately, microelectronic techniques are available at GR for the deposition of electrodes and the generation of gaps. These techniques have proven more predictable and reliable than any grinding or masking technique investigated. Since the electrode areas are not equal and the capacitance is defined mostly by the area of the smaller electrode, only one gap is now crucial.

The substrate is held between spring-loaded supports which are shaped so that, even if the substrate moves, the guard in the vicinity of the gap stays the same. As the distance between the plane of the gap and the holder above it changes so does the direct capacitance. Figure 3 shows the magnitude of this effect. It appears from this graph that it is "unhealthy" to have the guard too close to the gap but, as the distance becomes greater than about 70 mils, the position of the guard is less critical. We take advantage of the last 300 ppm of change to provide for motion of the guard in the cell as a final capacitance adjustment.

Construction

Figure 4 shows two coated and etched capacitor substrates. The coating consists of 0.0005 inch of pure gold. Both the thin substrate (0.030 inch thick) for 100 pF and the thick one (0.300 inch thick) for 10 pF have a diameter of 2.727 inches. The element is placed in a brass holder, and the capacitance is adjusted to ±100 ppm of nominal values. Contact to the electrodes is made through gold-coated phosphor-bronze springs. Figure 5 shows the holder ready to be placed in a stainless-steel container, and also shows the assembled and sealed cell. This container is welded shut, evacuated,

Figure 4. 100-pF and 10-pF
substrate elements.



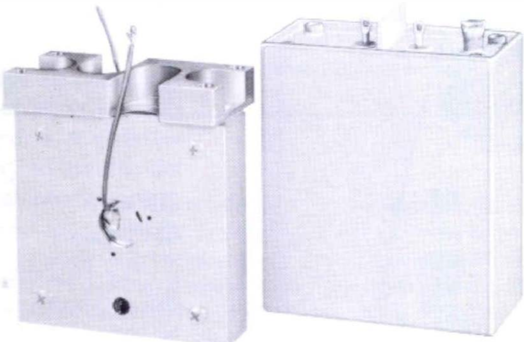


Figure 5. Capacitor brass holder
and assembled and sealed cell.

Figure 6. Oil-bath
version of GR 1408 capacitor.

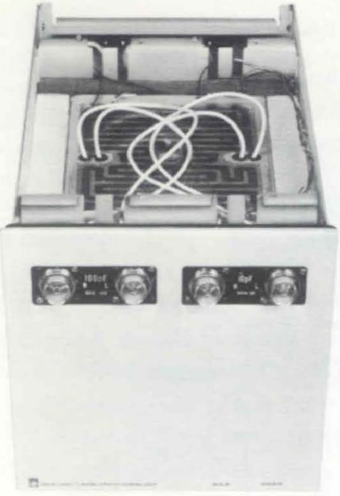


Figure 7. Air-bath version of GR 1408 capacitor.

baked, back-filled with dry nitrogen, and sealed; connections to the capacitor are made via glass-to-metal feedthroughs.

The dielectric constant of fused silica has a temperature coefficient of approximately 10 ppm/°C. To make meaningful measurements at a level of a part in 10^7, one has to know the ambient temperature to within 0.01°C. This can be accomplished in an oil bath; Figure 6 shows the oil-bath version of the capacitor. The GR 874® connectors, gold plated for lower contact resistance, are installed six inches above the capacitor to allow connection above the oil level. The normally simple measurement of this capacitor in an adequate oil bath is, however, complicated by the additional precision apparatus required to make the accurate temperature measurements needed to define the capacitance value. For that reason, an air bath was developed which can provide one or two capacitors with their own environment and, therefore, eliminate temperature measurements except in the case of highest accuracy. The air bath, Figure 7, is thermostatically controlled at a nominal 30°C. The bath has a long-term stability of 0.01°C; it changes by less than 0.01°C for a 6°C change in ambient temperature. Temperature control is by a 12-volt system; batteries can be used during transportation.

Performance

Evaluation of the fused-silica capacitors was difficult because standards and measuring equipment capable of the required accuracy and resolution were not available. We developed this equipment concurrently with the capacitors.

We found the voltage dependence of a fused-silica capacitor to be a good indicator of its quality, and it is the first test made on all new units. The capacitance change has to be less than a part in 10^8 when the voltage applied is changed from 50 to 150 V.

Frequency dependence and dissipation factor are directly related to the dielectric and were evaluated by comparison with two types of air capacitors. Our tests showed the frequency dependence to be a few ppm between 1 and 10 kHz; the dissipation factor was also a few ppm at 1 kHz. Measurement accuracy was 3 to 4 ppm.

The effects of mechanical and thermal shocks were investigated. Oil-bath versions were dropped at different angles: the capacitance did not change by more than a part in 10^7. Some 100-pF assemblies showed more shock sensitivity (1 ppm), attributed to bowing of the thin substrate. The capacitors were also cycled between 0 and 50°C and the hysteresis effect was less than 4 ppm; the cause of this change is questionable but could be due to temperature-measurement uncertainties of our oil bath.

As for long-term stability, it could only be checked indirectly. The difference between two capacitors in an air bath did not change by more than one part in 10^7 during a one-year observation period.

GR 1621
PRECISION CAPACITANCE-MEASUREMENT SYSTEM

One consequence of the improved quality of the new capacitors is that both the tests required to demonstrate their stability and the calibrations to be made in their ultimate use as standards require more precision than that to be found in the measurement systems of our laboratory and, indeed, of most laboratories. We met this need by developing the GR 1621 Precision Capacitance-Measurement System (Figure 8). The system is comprised of the GR 1616 Precision Capacitance Bridge, 1316 Oscillator, and 1238 Detector. A specific design objective of this system was to provide precision in intercomparison measurements of our new capacitors to parts in 10^8 near 1 kHz. An equally important design objective was to provide direct readings with high accuracy in measurements of a wide range of capacitance and conductance at audio frequencies.

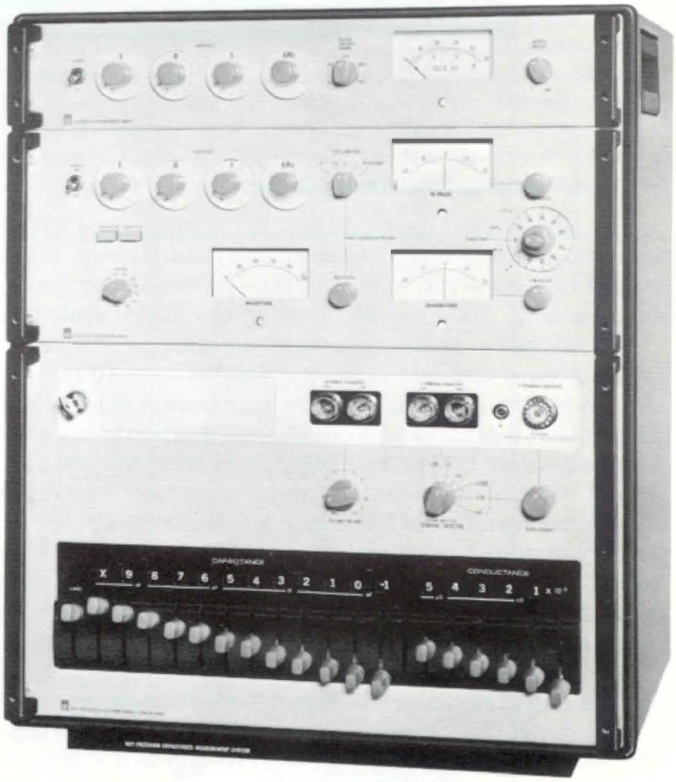


Figure 8. GR Precision Capacitance-Measurement System. Top to bottom: 1316 Oscillator, 1238 Detector, 1616 Precision Capacitance Bridge

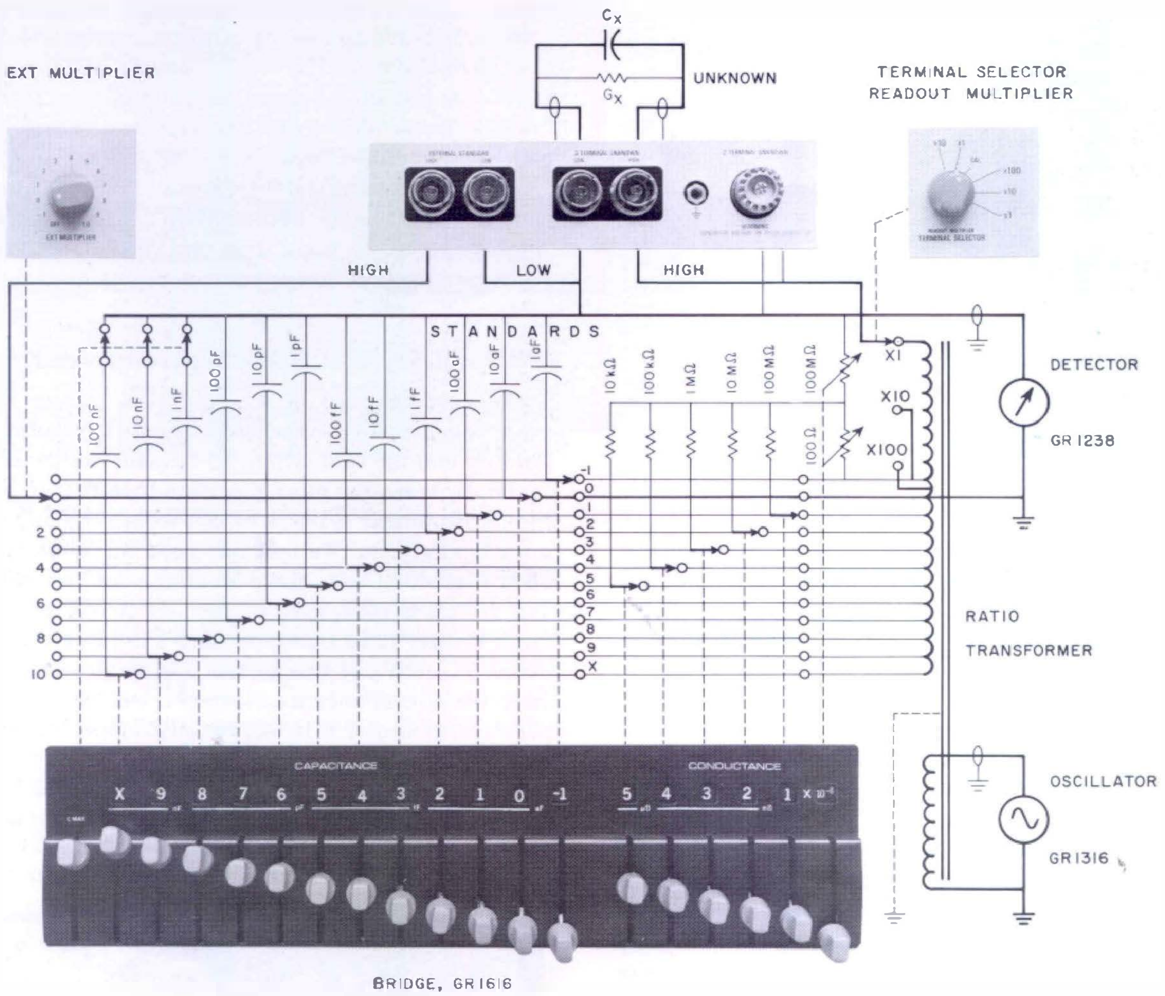


Figure 9. GR 1616 bridge: Basic circuits.

GR 1616 Precision Capacitance Bridge

The new bridge (Figure 9) uses the familiar transformer-ratio-arm bridge circuit.[3] Greater precision through higher applied voltages – 150 volts at 1 kHz – is obtained by use of a three-winding, 200-turns-per-winding toroidal transformer.

The bridge has twelve decades of capacitance provided by twelve internal standard capacitors ranging from 100 nF to 1 aF, and by the eleven taps on the transformer winding that give decade steps from 10 through 0 to -1. The three highest value capacitors can be disconnected in sequence when not needed, with a consequent reduction in detector shunt-capacitance loading and increase in bridge sensitivity. For the stability required in precision intercomparisons, the eight highest value capacitance standards are sufficiently insulated thermally to provide a time constant of at least six hours, for changes in the ambient temperature of the bridge.

Losses in the unknown capacitors are balanced by conductance decades, by use of five internal conductance standards – three metal-film precision resistors (10 kΩ, 100 kΩ, and 1 MΩ) and two carbon-film resistors (10 MΩ and 100 MΩ).

Some operational features are:

- Capacitance measurement range – 10 μF to 0.1 aF (10^{-5} to 10^{-19} F).
- Limits of capacitance measurement errors range from 10 ppm (1 nF, 100 pF, 10 pF standards) to 50 ppm from 1 kHz to below 100 Hz, measured at 23° ±1°C.
- Conductance measurement range – 10^{3} to 10^{-10} μmhos.
- Limit of conductance measurement error is 0.1% of reading at 1 kHz, over most of the range.
- Gold-plated GR874 coaxial connectors for low and repeatable contact resistance; GR900® connector for coaxial capacitance measurements.
- Terminals available for external-standard use.

GR 1238 Detector and 1316 Oscillator

The output of the GR 1616 bridge is only a few hundredths of a microvolt when the input to the bridge is 100 volts and the unbalance is a part in 10^{8} of 10 pF. The new detector developed to extract this small signal from noise, at the high impedance level of the bridge output, is a combination of a high-impedance, low-noise preamplifier, a tuned

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[3] Hersh, J. F., "Accuracy, Precision, and Convenience for Capacitance Measurements," *The General Radio Experimenter*, August-September, 1962.

amplifier with 130-dB gain, and two phase-sensitive detector circuits. The input impedance is that of 1 GΩ in parallel with 20 pF; the noise voltage at 1 kHz with a source impedance equivalent to the output impedance of the bridge in the measurement of 10 pF, i.e., 100 MΩ in parallel with 500 pF, is about 30 nV per root Hz.

A resumé of operating features of the oscillator and detector includes:

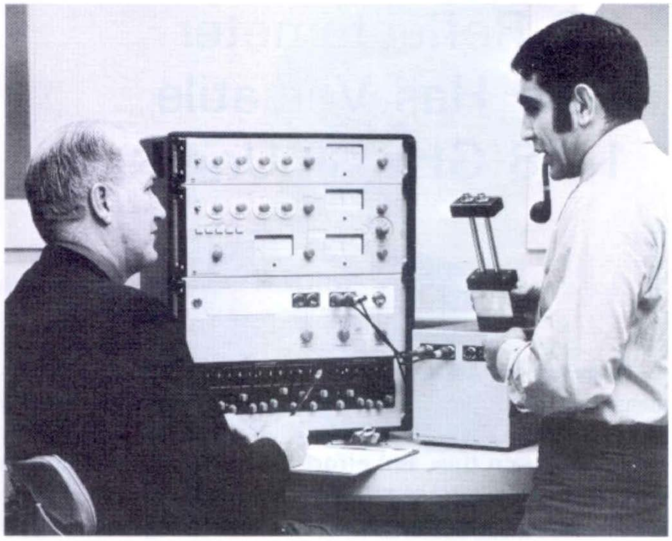
- Detector input is protected by diodes to the fullest extent of the oscillator's output of 150 volts.
- Matched decade switches tune the detector and set the oscillator frequency over the range 10 Hz to 100 kHz.
- A line-frequency notch filter is available in the detector, plus a choice of linear or compressed meter response.
- Detector bandwidth is narrowed by adjustment of the integration time constant from 0.1 to 10 seconds, to reduce noise.
- Bridge balance is speeded by the presence of detector panel meters that display magnitude of the unbalance signal plus the in-phase and quadrature components. The two phase meters can be made to respond to capacitance and conductance independently by adjustment of phase relationships. The phase reference voltages can be rotated from 0 to 360° to achieve any phase condition.
- The oscillator provides two 90°-displaced fixed-voltage reference signals to the phase sensitive detectors.
- Oscillator output is readily controlled and monitored by a 5-position range switch, vernier control, and panel meter.
- Oscillator signal distortion is typically less than 0.3% with loads ranging from short to open circuit.
- Amplifier output and meter outputs are available on the rear panel.

CONCLUSION

The new reference standard 10- and 100-pF capacitors, together with the new measurement system, make it easy for standards laboratories to improve their accuracy in the transfer and storage of the unit of capacitance. The new measurement system will also provide good direct-reading accuracy, to 10 ppm under limited conditions, in the calibration of a wide range of capacitors from 10 μF to much less than a picofarad, at audio frequencies. From our experience eight years ago with the introduction of new standards (GR 1404 capacitors) and a new measurement system (GR 1620), we can make two predictions: (1) Although this extended resolution will solve some measurement problems, it will also reveal some new ones when we try to make the sixth, seventh, or eighth figure significant. (2) Although we have provided more resolution in the system than most of us need today, we know you will be asking for more resolution tomorrow.

— D. Abenaim
J. F. Hersh

Condensed specifications for the GR 1408 Reference Standard Capacitor and the GR 1621 Precision Capacitance-Measurement System appear elsewhere in this issue.



D. Abenaim *(right)* graduated from George Washington University in 1965 (BSEE) and received the MSEE degree in 1967 from GWU. He joined GR in 1965 as a development engineer, principally concerned with standards and precision measurements. During a leave of absence in 1967, Dan was at the National Bureau of Standards, working with transportable voltage standards and fused-silica capacitors. He is a member of Tau Beta Pi and IEEE.

J. F. Hersh *(left)* graduated from Oberlin College with the AB degree (1941) and went on to Harvard University for his MA in Physics and PhD in Applied Physics (1942 and 1957). His doctorate work was in the field of electromechanical transducers. John's experience has involved work at Harvard's Underwater Sound Laboratory and teaching physics at Wellesley College. He joined GR in 1957 as a development engineer but shared time with the National Bureau of Standards that year, involved in bridge and capacitance research. His work since has been with inductance and capacitance bridges and the development of improved standards and techniques. He is a member of IEEE, Phi Beta Kappa, and Sigma Xi.

Catalog Number	Description
	1621 Precision Capacitance-Measurement System
1621-9701	Bench Model
1621-9702	Rack Model
	1616 Precision Capacitance Bridge
1616-9700	Bench Model
1616-9701	Rack Model
	1316 Oscillator
1316-9700	Bench Model
1316-9701	Rack Model
	1238 Detector
1238-9700	Bench Model
1238-9701	Rack Model
	Reference Standard Capacitor, air bath
1408-9700	1408, 10 pF
1408-9702	1408, 10/10 pF
1408-9703	1408, 100 pF
1408-9705	1408, 100/100 pF
1408-9706	1408, 10/100 pF
	Reference Standard Capacitor, oil bath
1408-9701	1408-A, 10 pF
1408-9704	1408-B, 100 pF

GR Reflectometer Now Has Versatile 1–18 GHz RF Unit

GR 1641 Sweep Frequency Reflectometer with the 18-GHz RF Unit.

There are definite advantages in providing the facility for measuring the reflection (SWR) and transmission properties of networks over the widest possible frequency bandwidth. First, the set-up time and effort for measuring components that have differing band-center frequencies are greatly reduced. Second, the equipment cost is lower when one high-directivity directional-coupler assembly can be employed in place of a number of octave-band couplers (in this case, about five).

It is, furthermore, advantageous to have the best possible directivity in a network-analyzer directional coupler because it means making a direct measurement without the need for computer correction. An accurate, continuous sweep-frequency measurement can be performed in contradistinction to the step-frequency measurement required for computer-correction.

The GR 1641-9603 RF Unit comes closer to meeting these and other requirements than any of its predecessors.

A Review of the System

The complete GR 1641 Sweep-Frequency Reflectometer,[1] a type of network analyzer, has distinct features that make it ideal for the measurement of microwave components. Its original concept was to provide the simplest, easiest-to-use instrument for measurement of the magnitude only of reflection coefficient (return loss or SWR) and transmission coefficient (insertion loss) of networks or microwave devices. If there is no need to measure the phase of these parameters, then considerable simplification of the set-up and operation of the measuring instrument results. The earlier GR 1641 offers this simplification with the result that, after a simple initial level-set adjustment, the instrument is completely calibrated and ready for use. The adjustment is stable; there is no perceptible drift. This approach necessitates the inclusion of all the directional-coupler "plumbing" within the package, and this alone offers an advantage to the user. He is not required to gather up a hodge-podge of couplers, detectors, and cables to make up a measurement system.

Some users, however, may prefer not to be bound by this concept. The fact is that the individual main-frame and plug-in units of the GR 1641 can be operated in other measurement systems. In particular the new GR 1641-9603 RF Unit, which covers the frequency range from 1 to 18 GHz, can be used in *any* network-analyzer to take advantage of the exceptional directivity, the wide bandwidth, and the 18-GHz operating frequency of this unique reflection-measuring device.

Alternately, the GR 1641 Main Frame and Indicator may be employed with whatever plumbing the user chooses. In fact, if transmission or insertion-loss measurements only are required, this plumbing is nothing more than attenuator pads and a detector. An example is the GR 1641-P3 Transfer Detector. With this unit, insertion loss as high as 60 dB can be measured.

The New 1-18 GHz RF Unit

The 1641-9603 RF Unit contains a newly-developed directional coupler that has unusually good directivity over a wide band. This coupler has directivity performance comparable to the best octave-band couplers. Also, the reflection coefficient or SWR looking back into the UNKNOWN terminals is quite low. Both these characteristics contribute to accuracy, a subject discussed below. The directivity is illustrated in Figure 1 in terms of both dB directivity and residual

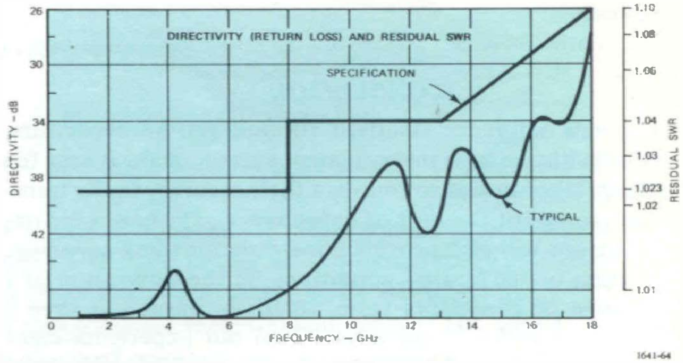


Figure 1. RF-unit directivity.

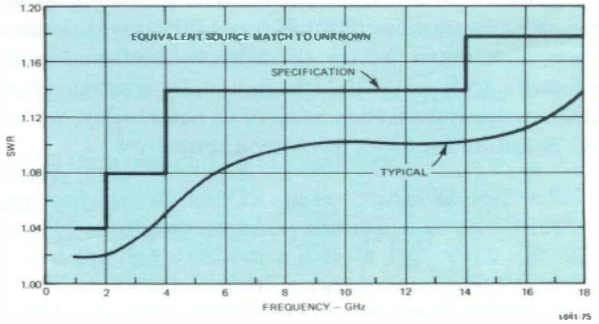


Figure 2. RF-unit equivalent source match.

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[1] MacKenzie, T. E., et al, "The New Sweep-Frequency Reflectometer," *GR Experimenter*, March-April 1969.

SWR; the equivalent-source-match SWR is illustrated in Figure 2. The UNKNOWN connector is an IEEE Standard No. 287, GPC-7mm. The instrument may be converted easily to N, SMA, TNC and other popular connectors by means of precision adaptors.

The rf-unit block diagram is given in Figure 3. One of the two identical directional couplers is used to sample the source signal and normalize it by leveling, so that the incident wave to the UNKNOWN is maintained constant. The tracking of the two couplers is important for this. An envelope or "video" detector is employed to provide the leveling signal. The second coupler is used to measure the reflection from the device under test connected to the GPC-7mm connector. The reflected signal is detected in a second envelope detector in front of which is installed a low-SWR, constant-attenuation, 10-dB attenuator. This attenuator provides an improved match not achievable with broad-band diode detectors.

The detectors are affixed by means of GPC-7mm connectors and can be removed for other applications.

The couplers have a nominal coupling value of 19 dB, ±1 dB approximately, from 4 to 18 GHz. At 3 GHz the coupling is 21.5 dB, at 2 GHz it is 25.5 dB, and at 1 GHz it is 32 dB.

The 1-18 GHz Transfer Detector

The GR 1641-P3 Transfer Detector is a well-matched envelope-detector assembly comprising a 10-dB attenuator and a diode detector. The attenuator is employed to improve the match to the diode detector. With the GR 1641 indicator system the assembly has a sensitivity of −65 dBm. The SWR specification is $1.02 + 0.005 f_{\mathrm{GHz}}$.

Accuracy

Although accuracy was described in detail on page 8 of the referenced *Experimenter*, a brief qualitative discussion is in order.

The significance of the directivity, Figure 1, and the source match, Figure 2, are illustrated in the following expression:

$$|\Gamma_i| = \Gamma_o + k\Gamma_x + k\Gamma_s\Gamma_x^2$$

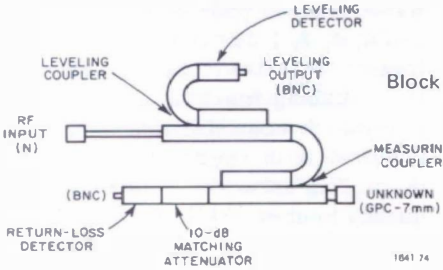


Figure 3. Block diagram of rf-unit.

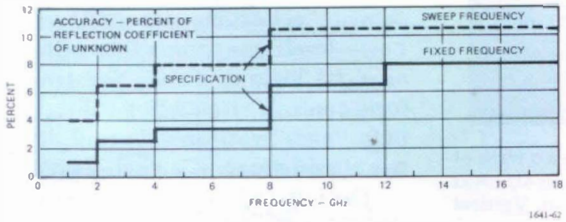


Figure 4. RF-unit accuracy.

John Zorzy received his BS-Physics degree from George Washington University in 1948 and his MS from Tufts College in 1950. His early experience was directly related to design and development of radar, antennas, and microwave devices. He joined GR in 1960 and presently is Group Leader of the Microwave Group. John is a member of IEEE, Sigma Xi, Sigma Pi Sigma, and serves as Chairman of the EIA/NCTA Task Group on 75Ω Precision Coaxial Connectors. He is a member also of the IEEE Subcommittee on Precision Connectors, of JEDEC Committee JS-9, and of the Department of Commerce Joint Industry Research Committee for Standardization of Miniature Precision Coaxial Connectors.

where:

Γ_i = Reflection coefficient indicated by the 1641 system.
k = Normalized frequency response of the 1641 system.
Γ_x = True, unknown reflection coefficient.
Γ_o = Residual "directivity" reflection coefficient (Figure 1).
Γ_s = Reflection coefficient looking into coupler (Figure 2).

When the UNKNOWN has low SWR ($\Gamma_x \simeq\!< 0.1$), the significant term is the directivity, Γ_o. When the UNKNOWN has moderate or high SWR, the significant terms are $k\Gamma_x$ and $k\Gamma_s\Gamma_x^2$. In this latter case, the specifications shown in Figure 4 are expressed as a percent of Γ_x for simplicity.

—J. Zorzy

Complete specifications for the GR 1641 are in the supplement to GR Catalog U, to be distributed shortly.

	Bench Models	Rack Models
1641 Sweep-Frequency Reflectometer		
20 MHz to 1.5 GHz	1641-9702	1641-9712
20 MHz to 7 GHz	1641-9701	1641-9711
20 MHz to 18 GHz*	1641-9704	1641-9714
20 MHz to 18 GHz	1641-9705	1641-9715
500 MHz to 7 GHz	1641-9703	1641-9713
500 MHz to 18 GHz	1641-9706	1641-9716
1 GHz to 18 GHz	1641-9707	1641-9717
1641-Z Sweep-Frequency Reflectometer, with display oscilloscope		
20 MHz to 1.5 GHz	1641-9902	1641-9912
20 MHz to 7 GHz	1641-9901	1641-9911
20 MHz to 18 GHz*	—	—
20 MHz to 18 GHz	—	—
500 MHz to 7 GHz	1641-9903	1641-9913
500 MHz to 18 GHz	—	—
1 GHz to 18 GHz	—	—
Transfer Detectors, included (where appropriate) with 1641 and 1641-Z; not included with RF Units purchased separately		
20 MHz to 7 GHz	1641-9606	
1 GHz to 18 GHz	1641-9604	
RF Units, to fill partially equipped models		
20 MHz to 1.5 GHz	1641-9601	
500 MHz to 7 GHz	1641-9602	
1 GHz to 18 GHz	1641-9603	
1641-9605 Accessory Kit	1641-9605	

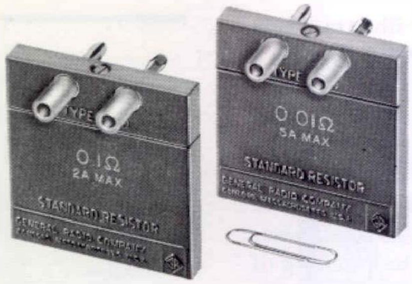
* Includes all three RF Units

other new products

EXPANSION IN THE RESISTOR FAMILY

The family of standard resistors designed by GR has been increased by two more members in the GR 1440 series. These are the 0.01-Ω and the 0.1-Ω resistors.

Principal uses for the new resistors are in calibrations of low-impedance systems, for use in substitution measurements, and as laboratory or production standards. Construction of the new resistors is somewhat different from resistors of higher values in the 1440 series. Previously, use was made of the card-type wire-wound technique. The new resistors are made up of a low-inductance meander-cut sheet element of well-aged Manganin,* connected to gold-plated copper terminals.



When completed, the resistors are adjusted, with relation to the nominal value, to 0.1% (0.01 Ω) and 0.05% (0.1 Ω) respectively. Both units are oil filled and sealed into oil-filled, diallylphthalate boxes for long-term stability and mechanical protection.

Development of these resistors was by W. J. Bastanier.

Complete specifications for the GR 1440 0.1-Ω and 0.01-Ω resistors are in the supplement to GR Catalog U, to be distributed shortly.

Catalog Number	Description
1440-9671	1440 Standard Resistor, 0.01 ohm
1440-9681	1440 Standard Resistor, 0.1 ohm

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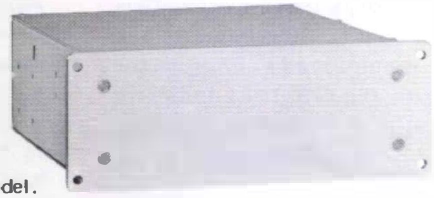
*Registered trademark of Driver-Harris Co.

SOLID-STATE, PROGRAMMABLE ATTENUATORS

Manual-remote model.



Remote only model.

Automated testing is a must for efficient high-volume production. If manually operated electronic instruments are involved, they have to be designed so that controls can be set and changed remotely by suitable electrical signals, often under computer control. Calibrated programmable attenuators are useful for a variety of tasks

- to extend and/or program the dynamic range of other test equipment such as analog or digital meters, level sensors, oscilloscopes, wave or spectrum analyzers, and counters
- as gain or loss standards for measurements using insertion techniques
- for level setting of signal sources for receiver testing of sensitivity, over-load characteristics, and selectivity
- for open- or closed-loop leveling of sources responding to a preset program or a detector with suitable analog/digital conversion.

Note that signal sources often have provision for frequency programming but remote level setting is limited or unavailable.

Calibrated attenuators now available are almost all electromechanically programmed. Relays, reed switches, and turrets of coaxial pads operated by motors or solenoids are in use. With this approach, excellent results in terms of accuracy, SWR, and broad coverage can be obtained, but switching time suffers and there are definite limits to operating life.

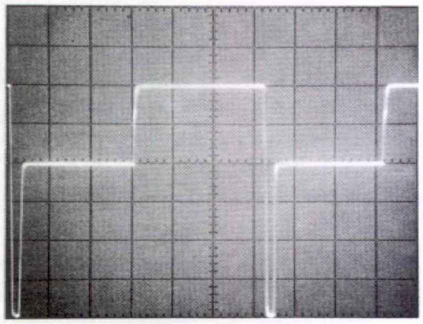


Figure 1. Programming pulse triggers trace of attenuation transition from 0 dB to 40 dB at 30 MHz. Horizontal scale: 1 ms/cm. Vertical scale: 10 dB/cm.

These are severe restrictions which would rule out applications in highly repetitive production testing or high-speed systems. The GR 1452 Attenuator was designed specifically for these requirements. Since it is all solid state, it is fast and not subject to the usual performance-life limitations. One-dB steps from 1 to 80 dB are produced by highly stable resistive pads of 40, 20, 10 dB and 8, 4, 2, 1 dB. These T and π-pads, together with the rf diodes performing the switching function, are assembled into pseudo-coaxial structures. Switching time is dependent largely on the decoupling networks; with a lower frequency limit of 10 kHz it is less than 0.5 ms. Operating frequencies are 10 kHz to 500 MHz.

As the choice of pad values suggests, remote selection uses BCD coding. Logic levels are compatible with common IC logic systems. Negative true logic controls attenuation values (all inputs "high" corresponds to 0 dB relative attenuation).

The GR 1452 is available in two versions. One model, for remote operation, is not packaged in an instrument case to save money and space. The second model offers both manual and remote operation (when the dials are set to the "R" position).

Figure 1 shows a transition in attenuation from 0 dB to 40 dB, at 30 MHz. A spectrum analyzer was used as the detector (with suitably wide bandwidth and not scanning frequency); the horizontal sweep is triggered by the switching signal applied to the attenuator.

Development of the GR 1452 was by G. H. Lohrer.

Complete specifications for the GR 1452 are available in the supplement to Catalog U, to be distributed shortly.

Catalog Number	Description
	1452 Programmable Attenuator
1452-9700	Manual-Remote Bench Model
1452-9701	Manual-Remote Rack Model
1452-9702	Remote-Only Model
	0480-9722 Adaptor Set, to rack-mount manual-remote model

WINDSCREENS FOR MICROPHONES

The GR windscreens for 1-inch diameter microphones (1560-9521) and 1/2-inch diameter microphones (1560-9522) have been added to the ever-growing list of small accessories designed to make the lot of the sound-measurement engineer a little easier. The two new windscreens are fabricated of reticulated polyurethane foam. They are especially helpful if one must make noise measurements outdoors when winds are of low velocity (30 mph or lower). Wind-generated noise is attenuated by a factor of 20 dB or more.

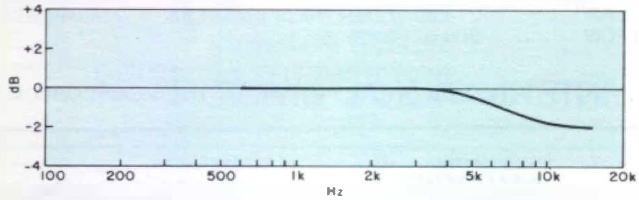


Figure 1. Effect of 1560-9521 Windscreen on response of 1560-P5 Ceramic Microphone.

These windscreens should prove to be useful also in industrial areas that may be oily or dusty. The use of a polyurethane windscreen will protect the microphone diaphragm and has only a very small effect on the microphone frequency response and sensitivity. As the windscreen becomes soiled it can easily be removed, washed, and reused.

The effect on the microphone sensitivity and frequency response is shown in Figure 1 for the GR 1560-9521 windscreen. Loss is essentially 0 dB below 3 kHz, then rises to about 2 dB at 12 kHz.

Development of the windscreens was by E. E. Gross, Jr.

Catalog No.	Description
	Windscreen, 4 per pack
1560-9521	1-inch diameter
1560-9522	½-inch diameter

A COUNTER IMPROVES

The GR 1192-B Counter is another answer from GR to consumer requests for economical instrumentation. It incorporates higher frequency response (50 MHz) than its predecessor, the 1192-A, without relaxing sensitivity specifications. With type-acceptance by the FCC as an a-m frequency monitor and as a monitor for fm and vhf-television broadcasts, the 1192-B (plus the 1157-B Scaler for approved operation to 216 MHz and to 500 MHz for normal tests) is available to broadcasters for use as a frequency monitor.

Obviously, we have no wish to restrict the use of our counter to the broadcast industry. Any reader interested in reading frequency, frequency ratios, time intervals, single and multiple periods, and many other electrical phenomena for which the electronic counter is suited, should refer to the article[1] that introduced the 1192-A to *Experimenter* readers. Many features of the 1192 counters are explained there in detail.

As in the previous model, data displays can be varied to suit test requirements; options are 5-, 6-, or 7-digit readout. Buffered data-output versions are available for each of the digit options.

Development of the GR 1192-B was by S. Bentzen.

Complete specifications for the GR 1192-B Counter are in the supplement to GR Catalog U, to be distributed shortly.

1192-B Counter (50 MHz) Bench Models
    5-digit readout
    6-digit readout
    7-digit readout
1192-Z Counter (500 MHz with scaler) Bench Models
    5-digit readout
    6-digit readout
    7-digit readout
Relay-rack mounting for 1192-B or 1192-Z
Option 2 BCD Data Output for 1192-B or 1192-Z

1158-9600 Probe, Tektronix P6006 (010-0127-000)
    not sold separately

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[1] Bentzen, S., "The Counter Punch," *GR Experimenter*, July/August 1969.

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