THE GENERAL RADIO
EXPERIMENTER

FREQUENCY STABILITY MEASUREMENTS OF STANDARD-SIGNAL GENERATORS

- FREQUENCY DRIFT
- RESIDUAL FM
- INCIDENTAL FM
- MICROPHONICS

INTRODUCTION

Present-day uses impose rather severe performance requirements on standard-signal generators, to a degree not predictable only a few years ago. The increasing crowding of the frequency spectrum has fostered the growth of narrow-band techniques, which in turn has drawn increased attention to some of the residual frequency instabilities in the generator output. Among these are (1) frequency change with time, usually called frequency drift, (2) short-period instability, usually called fm noise or residual frequency modulation, (3) incidental frequency modulation (resulting from amplitude modulation), and (4) microphonics, or frequency changes of mechanical or acoustical origin. For a signal generator to be most generally useful in today's technology, these quantities should be held to a minimum.

An example of the extreme stability requirements is found in the testing of crystal filters, which have very sharp cut-off characteristics, with slopes as steep as a few tenths db per cycle at frequencies of the order of 10 megacycles. Obviously any appreciable frequency instability in the test source will obscure the quantity under measurement.

MEASUREMENT TECHNIQUES

With an electronic digital counter one can set the frequency of the signal generator very precisely. Since the counter measures frequency directly and continuously, it can also indicate the frequency drift, but it cannot measure the short-period frequency instability. The shortest gating-time interval (in currently available counters) is about a millisecond, which corresponds to a large number of rf cycles, one thousand of them at one megacycle. The counter thus measures the *average* frequency within the counting-time interval. To measure frequency stability over much shorter intervals requires different techniques of measurement.

also in this issue

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A block diagram of a measurement system for the above quantities is shown in Figure 1. This equipment is suitable for measuring the frequency drift, the residual frequency modulation, and the incidental frequency modulation, and it can display microphonically induced frequency instabilities on the oscilloscope.

FM NOISE or RESIDUAL FM

A convenient method of measuring residual fm employs a pulse-count discriminator as used in the Type 1142-A Frequency Meter and Discriminator. This instrument can be operated directly up to 1.5 Mc; and, by means of heterodyne techniques, at higher frequencies. The output can be fed directly to a Type 736-A Wave Analyzer, which will selectively measure the various frequency components of the fm noise. Most of the residual frequency modulation occurs at power-supply fundamental and harmonic frequencies, which the analyzer can easily identify. FM arising from other sources, however, may require a wide-band measurement. A calibrated, high-gain amplifier covering the full audio spectrum will show up, for example, disturbances caused by variations in power-line voltage. The residual fm may consist of a dominant 60-cycle component, corresponding to a deviation of many carrier cycles from the average frequency, at a 60-cycle rate. However, owing to transients existing on the power line, this fm signal may fluctuate violently in intensity. A narrow-band analyzer cannot respond to these fluctuations and will simply average the results in accordance with its own bandwidth.

MICROPHONICS

Another capability of a wide-band fm test system is the measurement of mechanically induced frequency shifts,

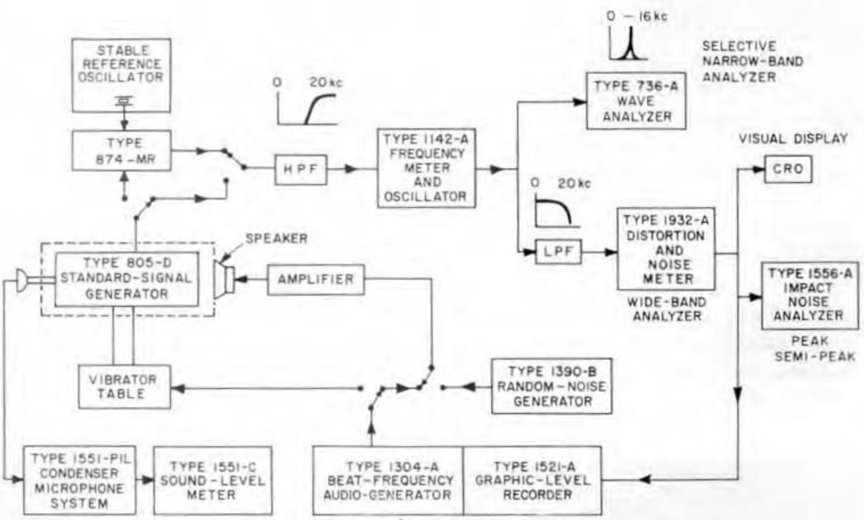


Figure 1. Block diagram of measurement system.

commonly referred to as microphonics. When one wants to reach the extreme limits of stability for a signal generator, microphonics and high acoustic noise levels may prove to be the limiting factors. When a signal generator is operated in acoustically noisy environments, it may exhibit carrier-frequency instability at frequencies related to internal mechanical resonances. It is of interest to know where these resonances are and how much frequency deviation they may be able to generate in a given environment, in order to minimize them where possible and to provide vibration isolation and acoustical insulation where practical.

A bandwidth covering at least the audio spectrum is highly desirable in the test equipment. An oscilloscope provides a convenient visual display of the audio-frequency signal from the discriminator output. An approximate frequency analysis of microphonics can easily be made by use of a shake table to vibrate the generator under test. Dominant mechanical resonances can be quickly located by visual observation on the oscilloscope as the vibrator drive-frequency is varied.

Acoustical effects, which are similar to microphonics, can be examined by use of the speaker system shown in Figure 1. For most accurate results, the generator under test should be enclosed in an anechoic chamber, although very useful results can be obtained with very much simpler enclosures. A Type 1551-C Sound-Level Meter is recommended to monitor the sound level within the enclosure.

To determine the effect of white noise upon the generator under test, the speaker can be driven by the Type 1390-B Random Noise Generator. It is perhaps more significant to examine the response to single-frequency sound as the frequency is varied over the entire audio spectrum. This can be done conveniently by use of a combination of the Type 1304-B Beat-Frequency Audio Generator and the Type 1521-A Graphic Level Recorder, as shown in Figure 1. A chart of signal-generator fm deviation magnitude vs. acoustical-excitation frequency will be obtained. Such a chart is very useful in predicting generator performance in high-level acoustical environments and serves as a guide toward elimination of unwanted mechanical resonances within the generator.

Many systems are concerned with maximum peak-amplitude signals (as opposed to rms or average), which tend to overload them, sometimes to the point of complete loss of amplification for several seconds. In such cases, the knowledge of the peak amplitude is important. The amplitude corresponding to the peak deviation of a signal generator's carrier frequency is easily measured with the Type 1556-A Impact Noise Analyzer to indicate peak deviations of the signal. A choice of time-average, quasi-peak, or peak response is provided for either polarity of the signal being measured. This permits the measurement of transient deviations, such as may result from shock or vibration.

INCIDENTAL FM

When a signal generator is amplitude-modulated, some incidental frequency modulation also occurs. The measurement of this effect imposes severe requirements on the measuring apparatus, which must be capable of handling the rf input signal without phase distortion, at any modulating frequency within the capabilities of the generator under test. A variation of phase in the generator carrier frequency during the modulation cycle will result in incidental fm. Similar phase shifts can also occur in the test apparatus and can lead to erroneous results unless adequate design precautions are taken. Measurements at very low levels of incidental fm are usually limited by this effect, especially at the high audio modulation frequencies.

While a carrier signal can be examined visually on a panoramic display device, it is difficult to identify separately the am and fm sidebands when both are simultaneously present. For this reason, the system shown in Figure 1, which employs an fm discriminator, is recommended.

One of the most important factors in the measurement of incidental fm is the complex waveform involved. As pointed out previously, signals that represent the residual fm noise of a signal-generator carrier frequency are commonly complex waveforms, dominated by strong components related to the power-line frequency. Similarly, the signals that represent the incidental fm of an amplitude-modulated carrier will vary considerably in waveform. They will contain frequencies related to the amplitude-modulation fundamental frequency. Over a wide range in modulation levels and modulation frequency, the measured signal may change from nearly sinusoidal to a highly distorted complex signal.

Thus, either the bandwidth of the measuring system must be adequate, or corrections must be made for it. Correlation between various methods of measurement can be made where the response characteristics of each system are known.

MEASURED CHARACTERISTICS OF THE TYPE 805-D STANDARD-SIGNAL GENERATOR

The measurement system of Figure 1 was used to evaluate the performance of the Type 805-D Standard-Signal Generator, with results as detailed below.

Residual FM Noise

In tests on the Type 805-D Standard-Signal Generator for frequency stability, measurements were first made of the residual-fm-noise characteristics over the entire carrier-frequency range (16 kc to 50 Mc). Records were made directly in cycles-per-second deviation, since this is the most directly useful parameter for evaluating generator performance in narrow-band systems. Pertinent data are shown in Table 1. A typical production-run instrument was taken for these measurements and the results are to be viewed as typical, rather than guaranteed.

The results show that an observed unmodulated carrier-frequency stability of the order of one- or two-cycle deviation can be achieved over much of the carrier-frequency range of the generator. Moreover, the greatest contributing factor causing this degree of instability is related to the power-supply frequency. This is evident when the dominant power-frequency-generated component is filtered out. This suggests that for critical uses improvement can be obtained through the use of a dc heater supply. The generous cabinet size and low internal-temperature rise will permit the installation of an internal transistor-regulated heater supply. With such an arrangement, the residual fm noise should approach one-cycle deviation over most of the carrier-frequency range,

TABLE I

CARRIER FREQUENCY	RESIDUAL FM			INCIDENTAL FM With 400 ~ AM at 30% AM	INCIDENTAL FM With 400 ~ AM at 80% AM	MICROPHONICS Resulting from Mechanical Shock	
In Mc	± Δf Peak Deviation in cps	Major Component of Peak Deviation in cps	± Δf Peak Deviation — in cps with Major Component Removed	± Δf Peak Deviation in cps	± Δf Peak Deviation in cps	± Δf Peak Deviation in cps	Major Component of Deviation in cps
0.5	2	60	<1	75	260	500	290
1.6	1	240	<1	240	400	50	280
1.6	2	240	<1	60	260	1000	280
5	2	240	<1	360	1000	500	290
5	15	240	<1	50	200	1000	280
10	30	240	10	150	400	2000	290
16	6	30	4	290	800	500	280
16	26	240	10	425	1000	5000	280
20	35	240	13	300	700	3000	280
40	60	240	14	1500	3800	10,000	275
50	70	120	15	4200	10,000	5000	275

when the generator is operated in a normal laboratory environment.

Microphonic FM Noise

The TYPE 805-D Standard-Signal Generator has but one dominant mechanical resonance, and this is in the region of 275 to 290 cycles per second for most conditions. This was determined by mechanical and acoustical excitation of the generator over a wide-frequency range.

The data given in Table 1 illustrate what can happen to the carrier-frequency stability when the panel is struck a sharp blow (exceeding that likely to be encountered in normal use). A substantial frequency deviation can occur. The rate at which it will occur is largely determined by the frequency of the major mechanical resonance of the generator, while the magnitude of the deviation produced will be a function of the resonance Q and the nature of the impact.

The data shown are extreme; for normal laboratory conditions incidental fm resulting from microphonics are seldom significant.

Frequency Drift

A low-fm-noise signal generator will be of maximum utility only if its frequency-drift rate is also low. This should be low enough to enable the user to set a specific frequency and have it remain constant long enough to complete his measurement without reset annoyance. Here, again, the requirements are determined by the intended use of the generator. Since the minimum frequency drift will be obtained under constant operating conditions, it is always best to keep the generator in continuous operation to avoid the usual warm-up cycle. For those cases where this is not possible, the curves of typical frequency

Range Switching Effect

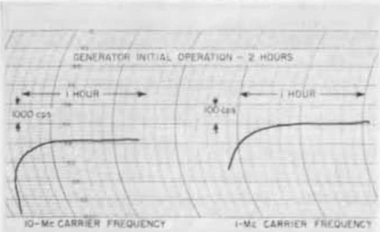
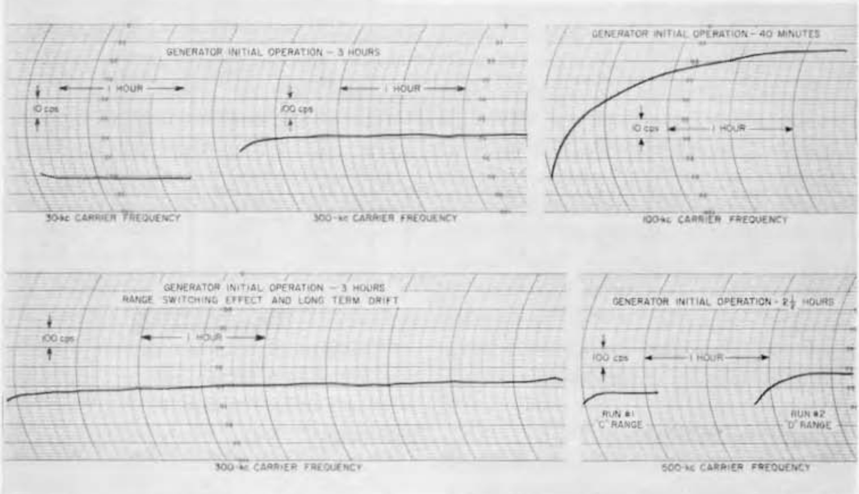
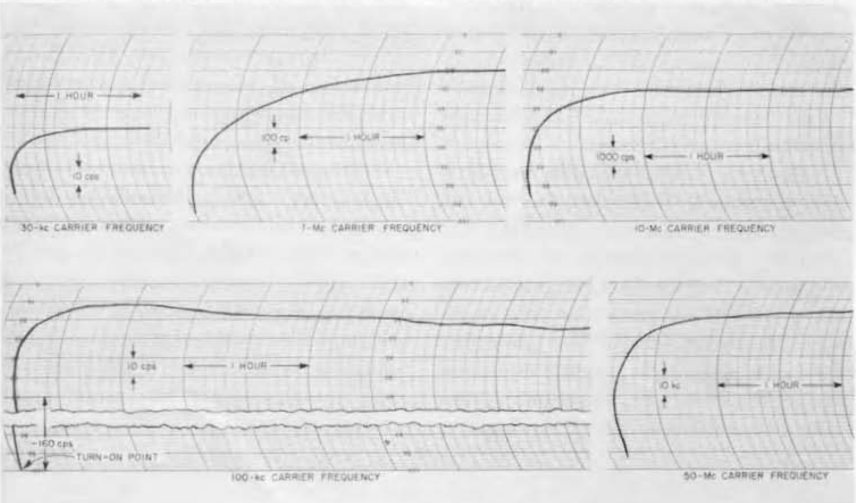


Figure 2. Graphic records of frequency drift. The upper set of curves shows the effects of range switching. The lower group shows drift at a constant switch setting. The records at the lower left in each group show typical long-term drift.



Generator Operation from Turn-On Point at Room Temperature — Cold Start



drift shown in Figure 2 will be helpful. These data represent the change in frequency beginning with the start of oscillations following turn-on of the power switch. Asymptotic stability will be reached within the first hour of operation.

Another source of frequency drift is sudden changes in oscillator-circuit conditions. Major contributors to this type of drift are band-switching and, to a lesser extent, changes in the frequency-dial setting. With the generator in normal operation (long enough to have passed through the initial warm-up cycle), a change from one frequency range to another will bring about a secondary frequency drift. Typical of the results to be expected are the curves shown in Figure 2. This characteristic appropriately defines the practical limit of frequency stability, rather than the final value reached under long-term, constant-operating conditions.

Incidental FM

In general, the incidental fm in a signal generator will be a function of carrier frequency, amplitude-modulation percentage, and modulating frequency. This last can be quite important at low carrier frequencies. The narrow bandwidths of the tuned circuits may result in substantial incidental fm being generated at high modulation frequencies. Figure 3 shows this condition for carrier frequencies in the 50- to 150-kc range. No great change in the level of incidental fm is found over this range of carrier frequency. Note, however, the rapid rise in incidental fm as the modulating frequency increases. This behavior suggests phase modulation arising from asymmetrical phases and amplitudes of the side-bands.

Figure 4 shows the incidental fm produced at the high carrier frequencies. The presence of a substantially higher level of incidental fm is clearly apparent.

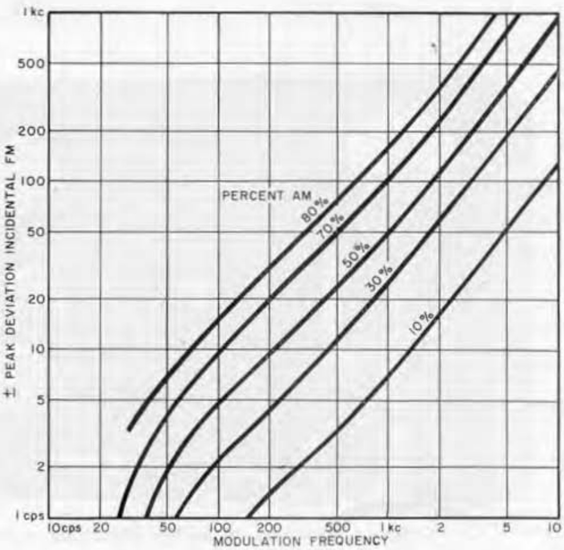


Figure 3. Incidental fm as a function of percentage modulation at carrier frequencies between 50 and 150 kc.

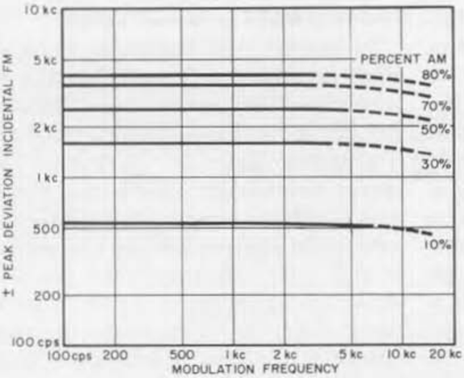


Figure 4. Incidental fm as a function of percentage modulation at high carrier frequencies.

but note the absence of a change with modulation frequency. This behavior suggests pure frequency modulation resulting from reaction on the oscillator.

Table 1 shows typical performance at two specific amplitude-modulation levels for various carrier frequencies throughout the range of the signal generator. As might be expected, the magnitude of incidental fm will increase on any given carrier-frequency range as the carrier frequency increases.

Carrier Distortion

Another characteristic of general interest to signal generator users is carrier-frequency distortion, which is important in wide-band testing. In tests on video amplifiers, for instance, carrier distortion should be held at a minimum.

Some compromise between carrier distortion and envelope (amplitude-modulation) distortion is usually necessary in an instrument covering a wide frequency range. This results from over-

Figure 5. Panel view of the Type 805-D Standard-Signal Generator.

TABLE 2

CARRIER FREQUENCY IN Mc	CARRIER HARMONIC DISTORTION
1.6	2.3%
5	5.5%
5	1.0%
16	3.1%
16	1.2%
50	3.1%

lapping requirements in the frequency ranges, as for example, the maximum modulation frequency at the minimum carrier frequency. In the TYPE 805-D Standard-Signal Generator, these frequencies are identical but would not be used simultaneously. This imposes a practical limitation on the isolation of audio-modulation stages from the low-frequency carrier stages. Some distortion exists at low carrier frequencies from this cause. At the higher carrier frequencies, less carrier distortion is found. This results from the increasing selectivity at higher carrier frequencies. Table 2 shows results typical of the TYPE 805-D Standard-Signal Generator.

— C. A. CADY

The TYPE 805-D Standard-Signal Generator supersedes the TYPE 805-C. Older types of tubes, meters, and other components have been replaced with current types, and there have been some mechanical changes. Performance specifications and price remain unchanged and are listed in our current catalog.

A CONNECTOR IS KNOWN BY THE CONNECTIONS IT MAKES

The hermaphrodite coaxial connector (General Radio TYPE 874*) was initially greeted, upon its introduction in 1948, with reactions ranging from "Oh, no! Not another connector!" to "Good! It's about time!" Since then, this connector has seen increasing use each year and recently has been selected by several well-known manufacturers for use on new and advanced instruments. Examples of some of these large-scale uses are shown in the accompanying photographs. These manufacturers certainly have not based their selection on whim or novelty, but on sound engineering judgment and common sense. Here is a brief report about why the General Radio connector has been chosen by some of its large-scale users.

*U.S. Patent No. 2,548,457

Most people feel that there are already too many different types of coaxial connectors. This feeling poses a formidable hurdle that must be surmounted before any connector can become widely accepted. A new connector must prove that any possible complication it may bring is greatly outweighed by its advantages. For the GR connector, the major advantages are:

1. Hermaphrodite design — the resulting elimination of plugs and jacks greatly simplifies interconnections and drastically reduces stocks of adaptors and patch cords needed.

2. Reflections considerably lower than those of other coaxial connectors, and recently improved even further.

3. Convenience of quick-connect/disconnect connections — now enhanced by

Tektronix, Inc., uses the GR Connector on several new oscilloscopes, including the Model 519 DC to 1 Gigacycle Oscilloscope (125-ohm version—see paragraph at end of article), the Pulse Sampling Systems, and the recently announced Model 567 Digital Readout Oscilloscope. The versatility of these instrument systems is reflected in the various ways they can be connected, and the convenience of the quick-connect/disconnect hermaphrodite connector is very important. The ability to handle extremely fast pulses with negligible reflections was also an essential factor in the selection of the GR Connector by Tektronix.

provision of a locking arrangement,[1] effective at the user's option and compatible with non-locking versions.

4. Availability of low-VSWR adaptors to all commonly used connector systems, with fewer adaptor types needed.

HERMAPHRODITE CONNECTORS VERSUS PLUGS AND JACKS

It was not easy to introduce the hermaphrodite connector into a well-established world of male and female connectors. It certainly was easier, though, than if the situation had been reversed, and plugs and jacks were trying to gain acceptance against the established convenience of hermaphrodite connectors. The plug-and-jack system for *power* connections has an essential, practical advantage in terms of safety, but the carry-over of the plug-and-jack

[1] "New and Improved Coaxial Connectors," *General Radio Experimenter*, 35, 10, October, 1961.

Computer-Measurements Company selected the GR Recessed Locking Connector for use on their Model 708B 100 Mc Frequency-Period Counter for several reasons. The fact that a low-VSWR adaptor to any common connector type can be locked in place on the instrument allows CMC to meet differing customer requirements very easily — and the hermaphrodite characteristic greatly reduces the number of adaptor types required. Finally, excellent shielding and low VSWR are mandatory. CMC sees this locking connector as an excellent solution to an old problem and expects it to find increasing use on modern electronic test instruments in the future.

Eldorado Electronics has selected the GR Connector for use on their Model 1-109 2-Nanosecond Time-Interval Meter. The high-frequency pulses handled by this new instrument impose severe frequency-response conditions on the connector, which must have constant-impedance characteristcs at gigacycle frequencies and excellent pu'se response. The electrical performance of the GR Connector, its convenience, and the wide variety of available accessories make it ideally suited to this application.

concept into low-power, high-frequency *communications* and *measurement* equipment rarely has any basic advantage and results instead in a basic nuisance. A major reason for the adoption of the Type 874 Connector by its large-scale users has been the elimination of this nuisance — there is only one basic type, and any connector connects directly with any other. For example, the comprehensive General Radio line of vhf-uhf instruments and coaxial elements, many of which are two or more port devices, would have been much less practical and flexible without the hermaphrodite connector.

REFLECTIONS AND VSWR

Another, and important, reason for General Radio's development of the Type 874 Connector was the lack of any other connector with low enough VSWR to allow its use in a flexible system of coaxial elements for measurement pur-

At Sage Laboratories, Inc., GR Connectors are widely used in their production and laboratory test work to save time. Many of the measurements made on Sage microwave components, such as their TEMLINE Hybrid 3 db Couplers, involve many connect/disconnect operations to determine coupling, directivity, and VSWR for each unit over its frequency range. These components are temporarily fitted with GR adaptors to make the operator's work easier and to avoid wear on the equipment under test.

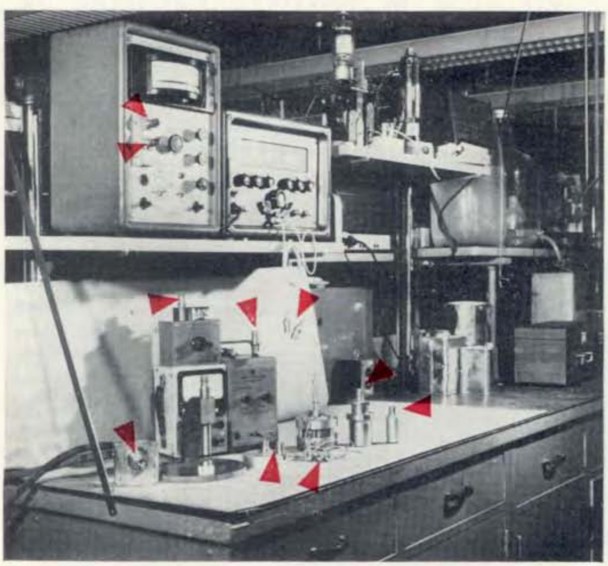
Edgerton, Germeshausen & Grier, Inc., uses the GR Connector on their Model 751 Pulse Generator. The major factors that influenced their selection are ease of use ("no plugs or jacks to worry about"), excellent electrical characteristics, and ruggedness ("a good, rugged connector").

poses. Since the GR connector's introduction, other connector types have been substantially improved (and many *new* types created — e.g., C, HC, SC, TNC, etc.), but the GR connector, which itself has been improved by many refinements, *still* has the lowest reflections of any general-purpose coaxial connector in its frequency range (dc to 7 Gc).

Some of the reasons for this performance are:

1. Larger internal diameters (about twice the dimensions of Type N) reduce

The General Electric Company's Chemical and Materials Engineering Laboratory in Schenectady has largely eliminated connector problems in the wide variety of measurements they make between DC and 50 Mc by selecting the GR Connector for use on their equipment. This equipment includes screened rooms, controlled-temperature chambers, dielectric-specimen holders, and measuring instruments of various makes, which are modified on arrival to use the GR Connector. This laboratory uses Teflon beads (available on special order) in the GR Connectors in order to permit use in high-temperature tests and to reduce difficulties from dirt and moisture in measuring systems involving extremely high impedance levels.



Ballantine Laboratories, Inc., needed a well-shielded connector that would mate without any kind of twisting action for their Model 393 High-Frequency Transfer Voltmeter. In this highly accurate instrument the interchangeable measuring probes are plugged straight into a deep panel recess, with the connector joint inaccessible, for DC standardization after first being connected to an unknown rf voltage to be measured.

errors due to any specified absolute tolerance in dimensions. However, the *outside* diameter of the GR connector is *not* greater in proportion to its larger internal diameters, because its design is simpler and more efficient in this respect.

2. Tighter *absolute* tolerances of internal dimensions of *mated* connectors resulting from more favorable connector geometry and through use of special control methods in fabrication processes (to be described in a future article).

3. Hardened beryllium-copper inner-conductor spring contacts give stability and permanence to the initial low VSWR of the GR connector.

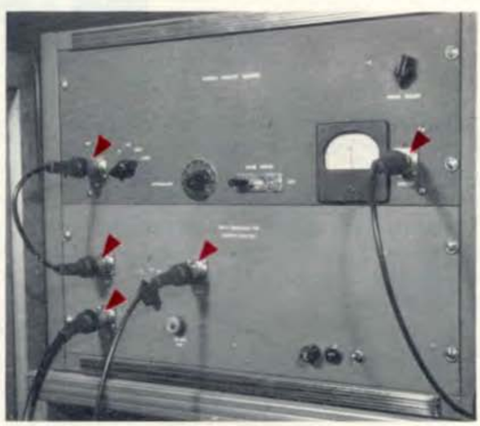
4. Optimum insulator design, in terms of diameter compensation, spacing-to-thickness ratio, etc.

The advent of fast-pulse counting circuits and oscilloscopes covering a spectrum to hundreds or thousands of megacycles has further accelerated the demand for low-VSWR connectors.

CONNECTION CONVENIENCE

Other connectors are of two basic styles — bayonet-lock types (such as Types C and BNC) for use where connect/disconnect speed is most important, and screw-on types (such as Types N, SC, and TNC) for use where the mechanical weakness and electrical leakage of bayonet-lock types are intolerable. A choice must be made — convenience versus strength and shielding.

No such choice is necessary with the



The Physics-of-Insulation Section of the Westinghouse Research Laboratories uses the GR Connector widely on measuring equipment operating at frequencies from DC to microwaves. Ten to fifteen years ago, before adopting this connector, they used three or four different connector types, each with male and female versions, and found them to be a continual source of inconvenience. Now the single GR hermaphrodite type is used wherever possible on such instruments as standard oscilloscopes, special fast-pulse corona test apparatus, amplifiers, special capacitance bridges, and interconnecting cables. As a result, more time can be spent on the measurement and less on the setup.

new TYPE 874 Locking Connector. A locking sleeve is provided and is always ready, but its use is optional. Therefore, *in one connector*, *speed* and *convenience* have been *combined with* high mechanical *strength* and *low* electrical *leakage*.

HIGH-IMPEDANCE CONNECTORS

Several organizations have satisfactorily adapted the GR connector to 100-ohm and 125-ohm impedance levels. The 9/16-inch electrical diameter of the outer conductor allows inner-conductor dimensions large enough to be practical, and the basic connector design makes it relatively simple to use high-impedance bead and inner-conductor designs while still retaining the desirable hermaphrodite characteristic. These high-impedance designs are used on equipment associated with ion or radiation detectors in order to obtain maximum output from the detectors, which are constant-current devices. Large-scale users of these high-impedance versions of the GR connector are Tektronix, Inc., and Edgerton, Germeshausen & Grier, Inc. In every instance so far, General Radio has supplied the outer conductor parts only, with the user furnishing the high-impedance beads and inner conductors to obtain the desired impedance level of either 100 ohms or 125 ohms.

— W. R. THURSTON

THE NEW ENGLAND OFFICE

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The New England Manager is Robert B. Richmond. He is assisted by Ralph K. Peterson and Stuart P. Roberts. Mr. Peterson has recently transferred from the general sales engineering group and will devote his full time to our Connecticut and Massachusetts customers. Mr. Roberts joined the General Radio Company two years ago and will be responsible for much of the sales coverage in Eastern Massachusetts and Rhode Island.

A telephone call to these engineers at EMerson 9-4400 or MIssion 6-7400 will bring prompt information about General Radio products.

GENERAL RADIO IN FLORIDA

The accompanying photograph shows the entrance to our new Florida office, announced in the October issue of the EXPERIMENTER. Located at 113 East Colonial Drive, Orlando, the office is managed by John C. Held of our Sales Engineering Staff. Telephone is GArden 5-4671.

General Radio Company

extends to all *Experimenter* readers its best wishes

for a Happy and Prosperous 1962.

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