THE GENERAL RADIO
EXPERIMENTER

# A RADICALLY NEW COAXIAL CONNECTOR FOR HIGH-PRECISION MEASUREMENTS

For many years the accuracy of coaxial VSWR measurements has been limited to a few percent by the deficiencies of coaxial connectors. With the introduction of the Type 900 line of coaxial measuring equipment, the limit is lowered by an order of magnitude, and VSWR measurements can be made to an accuracy of a few tenths of one percent. The principal factor in this substantial improvement is the Type 900 Precision Coaxial Connector, with excellent repeatability and VSWR below 1.004 to 3 Gc and 1.01 to 9 Gc. Without such a precision connector, highly accurate measuring equipment was not only impossible to design but also not worth designing, since any improvements would be obscured by the connector deficiencies. The development of the Type 900 Connector has overcome these problems and a line of precision coaxial instruments and components has been developed.

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# A RADICALLY NEW COAXIAL CONNECTOR

(Continued from page 1)

These instruments and components can also be used to advantage for measurements on systems fitted with other types of connectors through the use of adaptors. The errors introduced by these adaptors are small compared to the errors and uncertainties in the characteristics of most other connectors.

## Design Objectives

The design objectives of the TYPE 900 Connector program were:

(1) Each connector must mate with every other and be self-contained, with no male or female parts or loose parts, such as bullets.

(2) Characteristic impedance must be 50 ohms ± 0.1%.

(3) Connector VSWR must be better than 1.01 up to 9 Gc.

(4) Connector VSWR must be repeatable to within 0.1%.

(5) The connector must include an insulating bead support for the center conductor.

(6) All current-carrying surfaces must be of silver or a silver alloy for low loss and low contact resistance.

(7) The leakage of energy from the connector must be lower than that from any other available connector.

(8) The electrical length must be a convenient, integral number of millimeters.

(9) VSWR-guaranteed limits must be established and each connector checked against these limits up to the cut-off frequency of the air line.

The over-all objective, then, was to design a connector far better than any existing type and to manufacture it at reasonable cost. For example, the design tolerance on characteristic impedance was set at ±0.1%, and this dictated tolerances on the diameters of the inner and outer conductors of ±100 and ±200 microinches, respectively. Once this design objective was frozen, then extensive production engineering was required to find relatively economical methods of manufacture to such close tolerances.

## Description

The TYPE 900 Connector is intended for use on rigid air-dielectric, 9/16-inch, 50-ohm coaxial transmission line (principal dimensions: 0.5625 inch and 0.24425 inch). The connector (Figure 1) consists of (1) a solid silver-alloy inner conductor and spring contact, (2) a solid coin-silver outer conductor, stainless-steel centering gear ring, and locking nut, and (3) a solid Teflon bead support. The connector is attached to the air line by a coupling nut and retaining

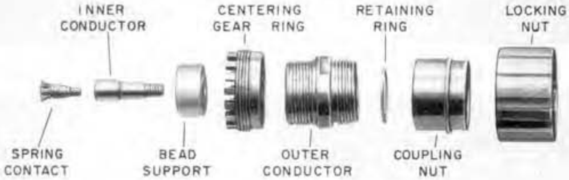


**Figure 1. Exploded view of the Type 900-BT Precision Coaxial Connector.**

ring on the outer conductor; the inner conductor is threaded into an 8-32 tapped hole in the center conductor of the air line. Silver is used extensively throughout the connector, and all silver parts are plated with a few microinches of gold to keep them from tarnishing.

## Mating Surfaces

When two of these connectors are mated, the centering gear rings interlock and overlap in order to center each of the connectors with respect to the other, and also to provide indexing in one of 16 possible positions. The outer conductors have solid coin-silver flange-type surfaces, which are butted tightly together by the pressure of the locking nut. Only one of the locking nuts is necessary for the connection; the unused one is backed off into a storage position. The over-all diameter of the mated pair is only 1-1/16 inches.

The front surfaces of the inner conductors are recessed by 0.001 inch with respect to the surfaces of the outer conductors to insure that the outer conductors will always meet first. Inner conductor contact is made by a spring-contact assembly, which projects slightly beyond the surface of the outer conductors until the connector is mated (see Figure 2). The spring-contact assembly consists of six solid silver-alloy segments, independently sprung. Upon mating, these contacts are forced back and spread, making wiping contact both with one another and with the inside surface of the inner conductor. This method of mating inner conductors avoids the disadvantages of slots placed in the electric field, and it does not affect the diameter of the inner conductor. Only one spring contact is necessary for a good electrical connection; the spring

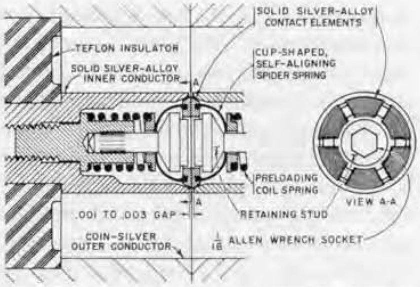


**Figure 2. Cross-section view of the connector showing contact surfaces of two mated inner conductors.**

contact will mate just as well with a flat surface.

When two connectors are mated, the conductors meet in the center of the connection, and this provides a very convenient electrical reference plane. (For instance, a reference short circuit consists of simply a disc, whose electrical position coincides exactly with the centerline of the mated pair.)

The outer conductors are held in alignment to within 0.001 inch by the centering gear rings and form a continuous tube through the centerline of the joint. In this respect, the connection is as precise as that formed by the junction of two waveguide flanges of the type used in precision waveguide standards. Unlike waveguides, however, the mating surfaces are protected from accidental damage by the teeth of the gear ring, which extend well beyond these surfaces. If the surface of the outer conductor is damaged or soiled, the gear ring and the spring contact can be removed without disassembling the connector, and the mating surface can be lightly lapped to restore it to its original condition.

## Bead Support

An essential part of any generally useful coaxial connector is the bead support, and this part usually is the most troublesome to design. A new approach has been used in the TYPE 900 Connector, in order to take advantage of the excellent electrical properties of Teflon without incurring the disadvantages associated with its difficult mechanical properties. The bead is made slightly larger than the inner diameter of the outer conductor, so that a press fit is necessary. Similarly, the bead thickness is slightly oversized, and the hole for the inner conductor undersized, so that the bead finally assumes the dimensions of the metal parts rather than its original dimensions. The faces of the bead are undercut to compensate for discontinuity capacitances at the interface. The depth of these undercuts is used to keep bead weight within close tolerance. Weight has been found to have a first-order effect on VSWR, while minor variations in dielectric constant or mechanical dimensions with weight held constant have only a second-order effect. As further advantages, the press-fit Teflon bead holds the inner and outer conductors together in a rigid assembly and keeps dirt and moisture from entering the line or component.

The electrical performance of the bead support determines the performance of the connector. The type of bead used in this connector was described by M. Ebisch[1], and it appears to give perfect results up to and above the cut-off frequency of the air line. The characteristic impedance inside the bead is exactly 50 ohms. Both the inner and outer conductors are stepped to accommodate the bead, for it has been found that the bead end capacitance is thus minimized. The effect of the remaining end capacitance is compensated by removal of some of the dielectric from both faces of the bead. As a result, the VSWR of a single bead support of this type can be held to less than 1.001 up to 9 Gc. The performance of the connector is theoretically equal to that of a beadless connector, and the only limitations are those imposed by manufacturing tolerances.

## Performance

### *VSWR*

The most important characteristic of a precision connector is, of course, its VSWR; that is, the extent to which it introduces reflections into an otherwise matched transmission line. Figure 3 shows the VSWR test specifications that each connector pair must meet ($1.001 + 0.001\ f_{Gc}$), as well as an average characteristic. Connector VSWR is measured at six frequencies up to 9 Gc. Since it is impossible to say how much each connector contributes to the VSWR of the pair, the test limits for the pair are used as the catalog specification for a single connector. Since the VSWR of these connectors is well below 1.01 over the entire frequency range, several new techniques and new instruments had to be developed to measure such low values of VSWR. For example, a substitution method of measuring the VSWR of pre-

[1] M. Ebisch, "Coaxial Measurement-Line Inserts of High Precision for the Frequency Range 1–13 Gc," *Frequenz*, February 1959, Vol 13, No 2, pp 52–56.

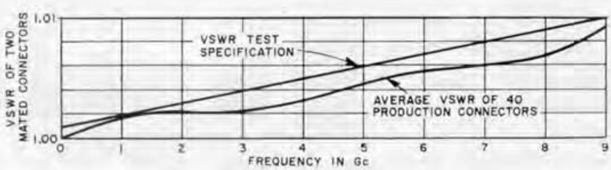


**Figure 3. Type 900 Connector VSWR vs frequency. All connectors must meet the test specification shown.**

cision connectors[2,3] was devised to distinguish the VSWR of the connectors from the residual VSWR's in the slotted line and termination. In this method the basic standard is a short length of rigid air line whose characteristic impedance can be accurately calculated. A slotted-line recording system was developed, which made possible the measurement of VSWR's as small as 1.0005 by a substitution method. The chart record of such a measurement is shown in Figure 4; the full-scale value of VSWR can be adjusted continuously from 1.20 to 1.008.

## Repeatability

Another very important characteristic of a precision connector is repeatability, that is, the consistency of measured value as the connection is broken and remade in different orientations. The repeatability of the butt joint of the outer conductors is virtually perfect as long as the faces are kept reasonably clean and free from nicks or scratches. The connection of the inner conductors repeats to within $\pm 0.03\%$ up to 9 Gc, owing mainly to the action of the spring contacts, which maintain a good connection even when there is some misalignment, without transmitting torque or bending moments across the joint. This is important because the two inner conductors are rarely perfectly centered with respect to the outer conductors, so that, as two connectors are mated in different orientations, the alignment of the two inner conductors changes. The misalignment itself is not so important as the stresses and strains introduced when "bullets" are used to force the center conductors into alignment. A chart record of a repeatability run is shown in Figure 5; between each line the joint was broken, rotated 45 degrees, and remade. The total spread is less than $\pm 0.02\%$.

## Leakage

The leakage of energy from a coaxial connector can be of great importance in measurements at low levels, or when large amounts of attenuation are present in the system. For example, energy could be lost at the input connector of an

[2] A. E. Sanderson, "A New High-Precision Method for the Measurement of the VSWR of Coaxial Connectors," *IRE Transactions on Microwave Theory and Techniques*, November 1961, Vol MTT-9, No 6, pp 524–528.

[3] A. E. Sanderson, "An Accurate Substitution Method of Measuring the VSWR of Coaxial Connectors," *The Microwave Journal*, January 1962, Vol 5, No 1, pp 69–73.

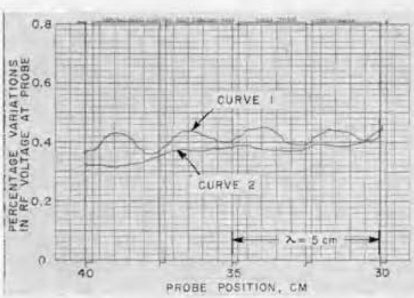


**Figure 4. Chart record of the measurement of the minimum detectable VSWR. Curve 1 shows a peak-to-valley voltage variation of 0.05%, corresponding to a VSWR of 1.0005. Curve 2 shows for comparison a "flat" line, VSWR = 1.0000. The frequency is 6 Gc.**

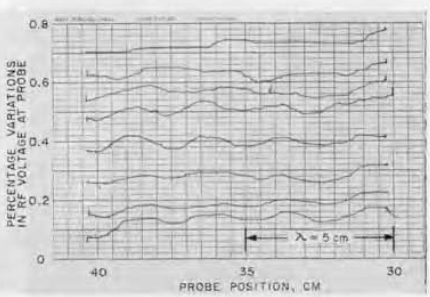


**Figure 5. Repeatability of the Type 900 Connector at 6 Gc. Between each pair of lines on the chart, the connection was broken, rotated 45°, and remade. The spread in measured VSWR's is less than ±0.02%.**

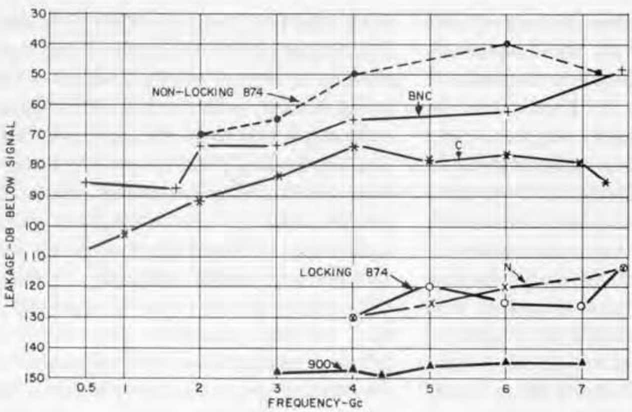


**Figure 6. Leakage of coaxial connectors as a function of frequency.**

attenuator and recovered at the output connector, causing an erroneous indication of attenuation. The leakage of the TYPE 900 Connector is compared with that of other types of connectors in Figure 6, and is lower than that of any other commonly used coaxial connector.[4] This is due to the triple shielding action of (1) the butt contact of the outer conductors, (2) the interlocking and overlapping of the centering gear rings, and (3) the outer locking nut.

### *Insertion Loss, Electrical Length, and DC Resistance*

The insertion loss or attenuation of the TYPE 900 Connector is minimized by the use of Teflon for the bead and solid silver alloys for both the inner and outer conductors (silver-plated surfaces are relatively poor conductors in contrast to these alloys). The insertion loss of a mated pair depends on frequency, according to the following approximate formula:

$$\text{Loss} = \sqrt{f_{Gc}} \times 0.002 \text{ db.}$$

[4] J. Zorzy and R. F. Muehlberger, "RF Leakage Characteristics of Popular Coaxial Cables and Connectors, 500 Mc to 7.5 Gc," *The Microwave Journal*, November, 1961, pp 80-86.

This is virtually the same as the loss in an equivalent length of silver, air-dielectric transmission line.

The electrical length of a pair of TYPE 900 Connectors is 3.50 cm and is virtually independent of frequency. The dc resistance of a mated pair is typically 0.4 milliohm for the inner conductors, and 0.04 milliohm for the outer conductors.

### Conclusion

The TYPE 900 line of coaxial equipment includes many instruments and components either now available or in development. Among those soon to be announced are a precision slotted line, a slotted-line recording system, and various terminations, air-line sections, and adaptors.

During the past three years, prototypes of the TYPE 900 Connector have been used at General Radio and at other research laboratories. This extensive field testing has proved that the theoretical excellence of this connector design has been realized in a stable, practical connector.

—A. E. SANDERSON

## SPECIFICATIONS

**Frequency Range:** DC to 9 Gc.

**VSWR:** Less than 1.001 + 0.001 $\times f_{Gc}$ per connector. (Connectors are tested by pairs, and this figure is used as the test limit for a *pair* of connectors.)

**Repeatability:** Within 0.05%.

**Leakage:** Better than 130 db below signal level.

**Insertion Loss:** Less than 0.003 $\sqrt{f_{Gc}}$ db per pair.

**Electrical Length:** 3.500 ±0.005 cm per pair.

**DC Contact Resistance:** Inner conductor, less than 0.5 milliohm; outer conductor, less than 0.07 milliohm.

**Dimensions:** Length of one connector, 1-3/16 inches (31 mm); maximum diameter, 1-1/16 inches (27 mm).

**Net Weight:** 2 ounces (60 grams).

| *Type* | | *Code Number* | *Price* |
|---|---|---|---|
| **900-BT** | **Precision Coaxial Connector** .................. | 0900-9405 | **$35.00** |

# MEASUREMENT OF DIELECTRIC PROPERTIES OF PLASTIC TENSILE SPECIMENS

By LAWRENCE C. LYNNWORTH*

Avco Research and Advanced Development Division
Wilmington, Massachusetts

## Introduction

New research and production-line applications for instruments of calibration-laboratory caliber are being motivated by reliability requirements for aerospace materials. These requirements, and the corresponding need for electrical measurements, may be explained as follows:

The tensile properties of metals, ceramics, and plastics exhibit considerable variability. Plastics, in particular, show variations attributable to composition nonuniformity, porosity, degree of cure, anisotropy, cracks or foreign inclusions, and absorbed moisture. In view of this observed variability, a nondestructive means of predicting the tensile properties of plastics is desirable. Prediction of properties becomes especially important in aerospace applications where safety factors are minimum.

One approach to the problem of predicting the tensile properties of variable plastics lies in the correlation of dielectric properties to the above-mentioned factors that influence mechanical properties. These correlations have been reported in the literature and occasionally

Figure 1. Standard tensile bar in dielectric sample holder. Pin in jig acts as stop for shorter specimen.

*Now with Parametrics, Inc., Waltham, Mass.

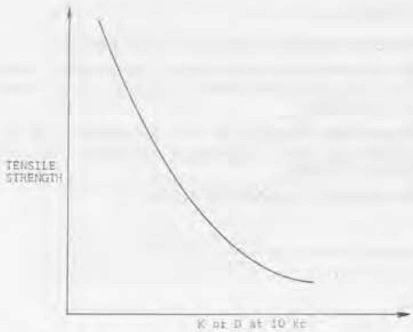


**Figure 2. Hypothetical inverse relation when water absorption reduces tensile strength of a hygroscopic plastic.**

provide the basis for quality-control procedures.[1–8] For example, absorbed water weakens plastic, while increasing its dielectric constant $K$ and dissipation factor $D$. Therefore, measurement of $K$ or $D$ indicates water content, from which reduction in strength may be predicted.

In this note a fast and simple means of determining the degree of correlation between dielectric and tensile properties is described.

## Discussion

In Figure 1, a tensile bar is centered in a General Radio Dielectric Sample Holder, Type 1690-A. The tensile bar conforms to the dimensions recommended in ASTM D638-61T; i.e., the gage length is two inches. This is fortunate, because the sample holder (see ASTM D150-59T) accordingly samples only the gage length.

The unorthodox removal of the side doors has not yet caused measurement difficulty, as was verified by tests on the Teflon specimens in the foreground. In an electrically noisy environment, however, shielding would be required.

Since the specimen is one-quarter inch thick, but the gage area is only about one square inch, $C = \epsilon_r\epsilon_0 A/d$ is usually between one and ten pf. Therefore, a shunt capacitor is required, such as Variable Air Capacitor, Type 874-VC, to bring the capacity up to the range of the Capacitance-Measuring Assembly, Type 1610.

## Procedure

In practice, to determine whether a useful correlation exists between dielectric and tensile properties, a tensile bar, after suitable environmental conditioning, is wiped dry, centered in the sample holder, and $C_x$ and $D_x$ are determined at 10 kc, for example. The bar is removed and is ready for tensile testing, with less than one minute added to the interval between pretest environment and tensile test.

When more than one factor is suspected of influencing tensile properties (for example, moisture absorption *and* resin-hardener ratio), it may be necessary to use two or more test frequencies.

## Results

For a hypothetical case, wherein moisture absorption reduces tensile strength and is the only variable present, correlation is illustrated in Figure 2.

**Figure 3. Closeup of probe and slabs.**

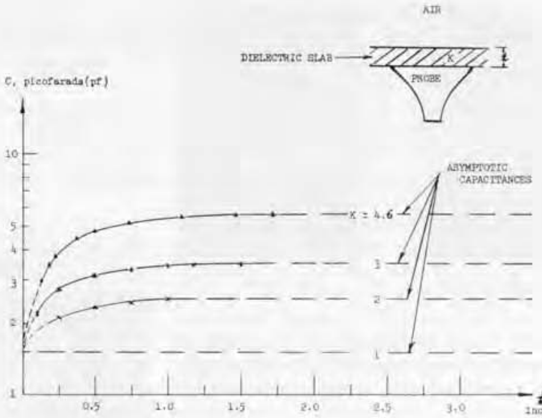


**Figure 4. Capacitance vs thickness of air-baked dielectric slab.**

## Quality Control on Production Line

Once a correlation has been established, tensile properties may be predicted on the actual production part by using an electrode arrangement designed or calibrated to yield *K* and *D*. One useful configuration consists of concentric electrodes (Figure 3). Other shapes, such as contoured or elongated probes, are of course possible.

It may be mentioned that even if probe geometry is not amenable to mathematical analysis, measurement of *K* and *D* is still simple, since probe calibration by slabs of standard dielectric materials is straightforward (Figure 4).

## Conclusions

As capacitance and dissipation-factor measurements become increasingly sensitive over a range of frequencies, correlation of dielectric and physical properties may provide the basis for quality-control procedures and for new and interesting applications for instruments that may have been occasionally confined to the calibration laboratory. The TYPE 1690-A Dielectric Sample Holder has been used satisfactorily with ASTM D638 tensile bars, and may also be suitable for testing tensile samples of thin plastic sheeting (ASTM D882-61T) or nonrigid plastics (ASTM D412-61T).

## References


[1] A. R. Von Hippel (ed.), *Dielectric Materials and Applications*, 311, Technology Press of M.I.T., Cambridge, Mass., and Wiley, New York (1954).

[2] J. Vitins, "Dielectric Properties and Moisture Content Determination in Paper," *Tappi 43*, 4, 318 (April 1960).

[3] H. W. Gebele, "Moisture Measurements in Industry," *IRE Trans. Industrial Electronics, IE-9* 1, 7 (May 1962).

[4] J. A. Wickett, Jr., "Moisture Measurement and Control—an Increasingly Exact Technique," *Chemical Processing 25*, 15, 20 (September 10, 1962).

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[6] R. F. Wall, "Analysis and Control by Dielectric Constant," *Ind. Eng. Chem. 50*, 69A (June 1958).

[7] R. J. Ward and E. G. Bobalek, "Some Correlations Between Thermal, Electrical, and Mechanical Properties of Alkyd-Epoxy Copolymer Adhesives," *American Chemical Society, Div. of Organic Coatings and Plastics Chemistry, Papers Presented at the Atlantic City Meeting, 22*, 2, 236 (September 1962).

[8] L. C. Lynnworth, "Inspection of Material Uniformity and Thickness Using Dielectric Measurements," to be presented at Fourth International Conference on Nondestructive Testing, London, September 1963.

## RANGE EXTENSION OF THE TYPE 1615-A CAPACITANCE BRIDGE


In the Type 1615-A Capacitance Bridge the largest standard capacitor is 1000 pf, and the largest ratio in the transformer ratio arms is 1000:1. The bridge can, therefore, measure unknown capacitors up to 1.11110 μf. The range of the bridge can be extended upward continuously through another decade to 11.11110 μf by the use of an external standard capacitor of 10,000 pf.

The Type 1615-P1 Range-Extension Capacitor is a 10,000-pf mica capacitor, designed for easy connection and adjustment to extend the range of the bridge to 11 μf.

The bridge has EXT STANDARD terminals to which this capacitor can be connected and an eleven-position rotary switch, which connects the capacitor to the transformer taps to provide the same steps of adjustment in the external decade which the levers provide for internal standards.

This capacitor is not a calibrated standard. It is to be adjusted in terms of the standards in the bridge, by means of its variable trimmer capacitor, for either two- or three-terminal operation.

**Dimensions:** Diameter 3-1/16 by length 4⅞ inches (78 by 125 mm).

**Net Weight:** 1 pound (0.5 kg).

| *Type* | | *Code Number* | *Price* |
|---|---|---|---|
| **1615-P1** | **Range-Extension Capacitor** . . . . . . . . . . . . . . . . . . . | 1615-9601 | **$35.00** |

## TYPE 1633-P1 RANGE-EXTENSION UNIT

The Type 1633-P1 Range-Extension Unit can be used with the Type 1633-A Incremental-Inductance Bridge to extend the current ratings to 50 amperes. It connects a 250-watt, 0.1-ohm resistor in parallel with one of the bridge arms.

High-current terminals capable of accommodating leads up to 1/4 inch in diameter are provided on the range-extension unit for the generator and unknown. A cable is furnished for connection to the bridge.

When the range-extension unit is connected, the operation of the bridge is unchanged, but only the *a*, *b*, and *c* ranges can be used. Bridge readings must be multiplied by 0.1. The upper limit of measurement is 100 mh up to 120 cps and 10 mh up to 1 kc.


The use of the Type 1633-P1 Range-Extension Unit at frequencies up to 400 cps can cause up to 1% additional error in the bridge readings. Correction can be made for the larger error occurring at higher frequencies. The temperature coefficient of the resistor is less than 20 ppm per degree Centigrade.

Any current up to 30 amperes continuous, or 50 amperes intermittent, ac or dc, can be used. Continuous operation at 50 amperes without forced-air cooling is not recommended.

**Dimensions:** Width 10½, height 4¼, depth 5 inches (270 by 110 by 130 mm).

**Net Weight:** 5¼ pounds (2.4 kg).

| *Type* | | *Code Number* | *Price* |
|---|---|---|---|
| **1633-P1** | **Range-Extension Unit** . . . . . . . . . . . . . . . . . . . . . . | 1633-9601 | **$125.00** |

## PERSONNEL CHANGES at our Sales Engineering Offices

Richard G. Rogers, now at our New England Office, will be devoting full time to calling upon our customers in the Boston and southern New England areas.

Gerald L. Lett was assigned to our Washington Office, in November 1962.

Gerald Lett

Richard Rogers

Crawford Law

Richard Eskeland

Richard K. Eskeland has recently joined the staff of our Metropolitan New York Office. He will be calling on our customers in the northern New Jersey area.

Crawford E. Law has been at our Syracuse Office since October 1962. He will be visiting customers in New York State west of Syracuse.

## INSTRUMENTATION IN ISRAEL

The First International Electronics, Nucleonics, Control and Scientific Instrumentation Exhibit in Israel was held at Tel Aviv, November 7 through 16, 1962. Some 5000 representatives of science, engineering, and industry in Israel came to see the latest equipment displayed by 16 manufacturers, including General Radio, whose booth is shown in the photographs below.

**(*Left*) Mr. R. Danziger of Eastronics, Ltd., General Radio representatives in Israel, demonstrates GR instruments to Mr. I. Ben Menachem, Postmaster General of Israel. (*Right*) Colonel M. Kashty, Deputy Director General, Israel Ministry of Defense, watches a demonstration of the Strobotac® electronic stroboscope by Peter Macalka of General Radio Company (Overseas).**

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