DEVELOPMENT OF BROADBAND COAXIAL COMPONENTS
FOR A 0.01 TO 40 GHz MEASUREMENT SYSTEM

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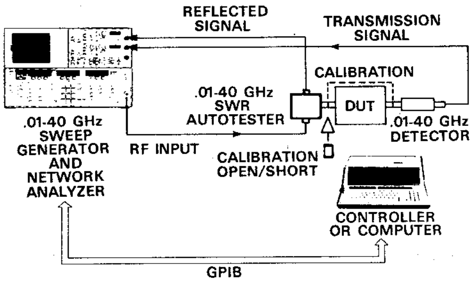
ABSTRACT

Broadband millimeter coaxial components, including a new connector are used to configure an accurate automated scalar network analyzer system with continuous coverage from 10 MHz to 40 GHz.

INTRODUCTION

This paper discusses the development of the first coaxial measurement system capable of measuring transmission and return loss over the full 10 MHz to 40 GHz range (Figure 1). New components which had to be developed for the system include reflection bridges (SWR Autotesters), reference air lines, open/shorts, adapters, detectors, directional detectors, and a PIN multiplexing switch. To complete these designs, a new connector had to be developed since 3.5 mm connectors mode near 34 GHz.



1. .01 to 40 GHz Measurement System

Requirements established by the EW and communication industries for broadband systems have created considerable interest in 40 GHz coaxial components. Even though there have been no formal specifications written for a 40 GHz connector, there is general agreement among microwave engineers that a 2.92 mm connector design holds the greatest promise, that it must have an air dielectric, and that it must be compatible mechanically and electrically with SMA and GPC-3.5 connectors.

Designated a type K connector, the new WILTRON design is 2.92 mm, is compatible with SMA, GPC-3.5, and WSMA connectors, and enables the new components to operate as high as 45 GHz. The connector will be commercially available.

THE CONNECTOR

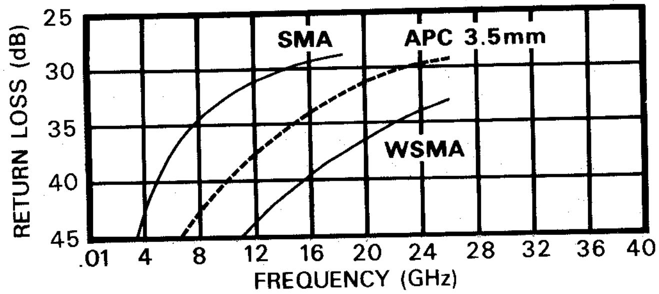
The GPC-3.5 and WSMA connectors that made 26.5 GHz coaxial components possible have 3.5 mm geometry and a TE11 mode at approximately 34 GHz. A 40 GHz connector had to be smaller. Unfortunately, smaller connectors like the 1.9 mm design are lossy, fragile, dielectric loaded, and hence, not precision components. The new 2.92 mm design avoids these shortcomings and is compatible with SMA connectors. It is called type K because K band historically has been identified as millimeter microwave.

A connector has three main parts, each requiring careful design: the connector interface, the center conductor support, and the back-side interface.

The design criteria for the connector were

1. That the connector would have optimum performance when mated with another K connector and that performance when mated with an SMA, GPC-3.5 or WSMA connector would be acceptable for system applications.
2. That the parts would be field replaceable.
3. That the parts would be protected against damage caused by mismating.

The extent to which the first criterion was met is shown in Figure 2, where return loss frequency curves are drawn for various connectors. The data were taken using a two-air-line measurement technique[1].

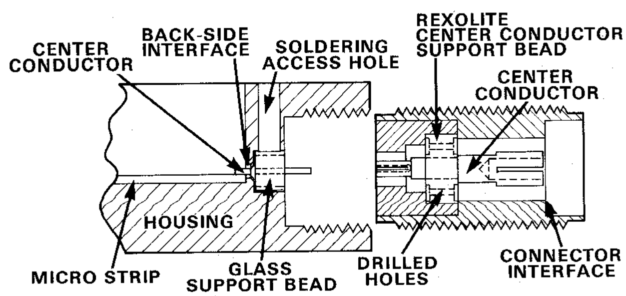


2. Return Loss of K Connector when Mated with SMA, GPC-3.5 and WSMA

A failure analysis showed that the female pin could be damaged by the male pin during mating whenever the two were not in close axial alignment. Fortunately, the problem was easily corrected. The length of the male pin was shortened so that as the male and female come together the outer conductors align before contact is made with the center conductor. This design improvement could also be applied to SMA and GPC-3.5 connectors. WILTRON is now contacting connector manufacturers and appropriate government agencies to recommend that specifications be changed to incorporate this idea.

The support for the center conductor (Figure 3) is a Rexolite bead with holes drilled through it to reduce the effective dielectric constant to 2.0. The bead provides lateral, axial, and rotational stability for the center conductor without introducing a large reflection or an unwanted mode.

The design of the back-side interface (Figure 3) was critical because it connects with very fragile devices, such as the 10 mil (0.01 in.) wide center conductor on 10 mil alumina microstrip. Designing such interfaces always involves a trade-off between RF performance and mechanical strength. One of the best compromise solutions is the use of a glass hermetic bead as the support element. The bead is made of Corning 7070 glass, which has a dielectric constant of 4, and has a 12 mil diameter center conductor.



3. Anatomy of K Connector

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THE AIR LINE REFERENCE STANDARD

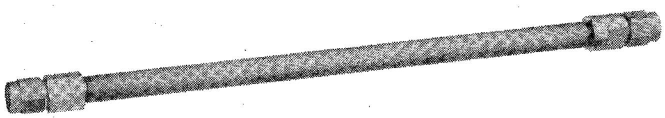
Basic microwave measurements require detectors and directional devices. The calibration and measurement of these devices require reference standards. Therefore, the design of a measurement standard was necessary before serious work could be done on the 40 GHz components.

Air lines are an excellent in-place impedance standard which can be used to separate the desired phasor (the device-under-test reflection) from system error phasors. The use of air lines in measurement systems is covered extensively in the references.

The new coax air lines are made of specially drawn tubing. The outer conductor is brass and has an outer diameter (OD) of 0.260 in. and an inner diameter (ID) of 0.115 in. (2.92 mm). Before the tube is machined, the ID of the outer conductor is plated with gold and ball-sized to give it a uniform ID and a smoother-than-drawn surface finish. Machining with a high coolant flow rate and with light cuts eliminates changes in the critical ID uniformity. The tubes are then gold-flashed on the ID and gold-plated on the OD. Brass was chosen as the tube material so that the outer conductor ID uniformity can be held to ±0.0001 in.

The center conductor is made from beryllium-copper tubing with a 0.050 in. (1.27 mm) OD and a 0.036 in. ID. The measurements of the outer conductor are used to establish the exact diameter to which the center conductor is plated to achieve an impedance of 50 ± 0.15 ohms. This impedance tolerance requires a dimensional tolerance of ±50 millionths of an inch, and the equivalent variance return loss limit due to impedance is 56 dB.

The input end of the air line shown in Figure 4 has a support bead, allowing precise control of the test port pin depth; the test port is beadless.



4. K Connector Reference Air Line

THE COMPONENTS

SWR Autotester

The SWR Autotester (reflection bridge) consists of a microwave bridge and a detector. Its output is a dc voltage which varies in proportion to the square of the reflection coefficient being measured.

The bridge circuit consists of thin-film suspended substrate and a specially developed zero-bias Schottky diode as the detector. The built-in reference termination is coaxial and uses the same resistor as that used in the new 40 GHz terminations. The bridge circuit is supported by glass beads, allowing all RF connectors to be easily removed and replaced.

The SWR Autotester is connected to the parent network analyzer via a low microphonic, low thermocouple cable. As an integral part of the network analyzer system, the SWR Autotester makes possible the accurate measurement of return loss over the 10 MHz to 40 GHz range.

Specifications are:

Directivity:.01-18.5 GHz, 35dB; 18.5-26.5 GHz, 32dB; 26.5-40 GHz, 30dB.

Test Port Match:.01-26.5 GHz, 19dB; 26.5-40 GHz, 17dB.

Open/Short

An open/short was also developed. It is used during return loss calibration procedure to eliminate errors due to test port mismatch. The open/short provides full reflection from either end, one end displacing the reflected signal from the other by 180°.

Adapter

During the transmission measurement calibration procedure, the detector is connected to the SWR Autotester test port. Since the bridge and the detector typically have male connectors (test devices normally have female connectors), a 40 GHz female/female adapter is necessary to make the connection.

A second adapter was needed for installation between the output connector of the sweeper and the RF input port of the SWR Autotester. The adapter outer conductor has spring fingers, ensuring excellent electrical connection. Mechanical strength is provided by large diameter coupling nuts which are about the size of a type N connector. The connector is called "ruggedized K."

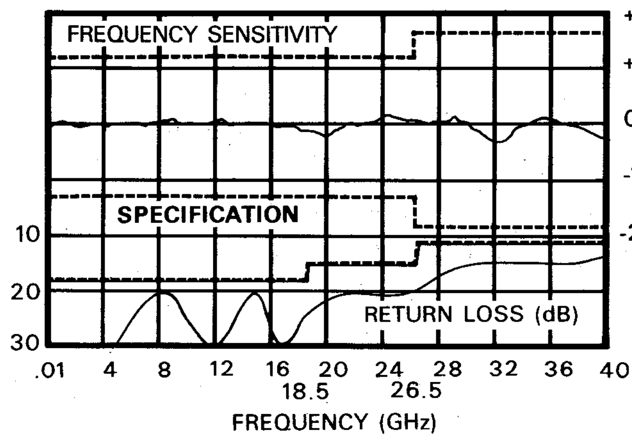
Termination

The new precision termination is used in most reflection measurements when the device-under-test has low thru-loss. Its specifications exceed those of sliding loads, and the terminations are much easier to use.

Detector

Detectors can be used in two major applications: as a power indicator and as an amplitude comparator. In either application, poor return loss can create serious measurement errors. To avoid this problem, the new 40 GHz detector uses a specially developed zero-bias Schottky diode. The diode parasitics are incorporated in the 50-ohm load structure and optimized for match and frequency sensitivity. A dc blocking capacitor is included in the RF input.

The detector is connected to the network analyzer with the same type cable used on the SWR Autotester. Consistent with one of the design objectives, the detector module is replaceable. Performance data are given in Figure 5.



5. .01 to 40 GHz Detector Peformance

Multiplexing/Modulating PIN Switch

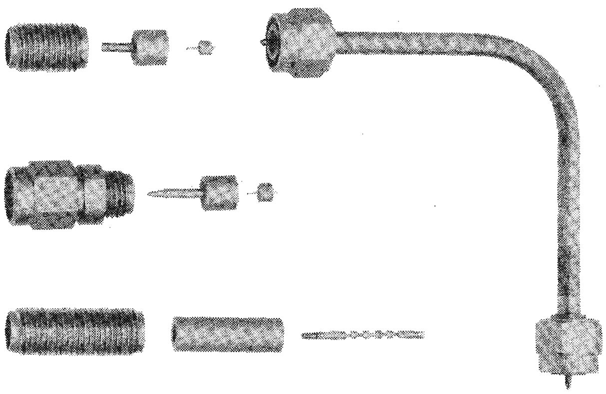
Multiplexing standard-band oscillators with a PIN switch is a common method for achieving broadband coverage in microwave sweep generators. A sweeper covering the 10 MHz to 40 GHz range requires a coaxial PIN switch capable of operation over the full range. The new switch includes a very small eleven-section, 40 GHz, low-pass, coaxial filter which reduces harmonics in the highest frequency band.

During the early stages of the PIN switch design, a computer analysis indicated that available pin-chip and beam-lead diodes would do the job. They did. The connector design shown in Figure 3 was used. Very thin Duroid microstrip conductors were set in narrow channels to minimize stray radiation. Designing a bias arrangement which would operate over the 10 MHz to 40 GHz range was a major problem. Once this problem was solved, the design was completed without complications. The isolation of the switch is 80dB to 18 GHz, 70db to 26.5 GHz. The 26 to 40 GHz band does not require a modulator and has 30dB isolation. The insertion loss of the 26 to 40 GHz band is 5dB maximum (4.5dB typically), including the low pass filter.

Coaxial Cable

Because no suitable coaxial cable was available, a new semi-rigid cable was custom designed. The center conductor is made of very soft copper with a 0.032 in. diameter, allowing a bend radius of 0.25 in. without displacing the center conductor from the center of the coax. The outer conductor is solid copper. The dielectric is microporous teflon, a choice which achieved a theoretical TE11 mode of 46 GHz, well above the cable's 40 GHz rating.

The cable connectors (Figure 6) were designed to achieve the lowest loss, the best reflection characteristics, and the least amount of heating during assembly. Design goals of 1.35 SWR and 1.0 dB loss per foot at 40 GHz were met.



6. K Connector Coax Cable, Spark Plug Connector, and 40 GHz Low Pass Filter

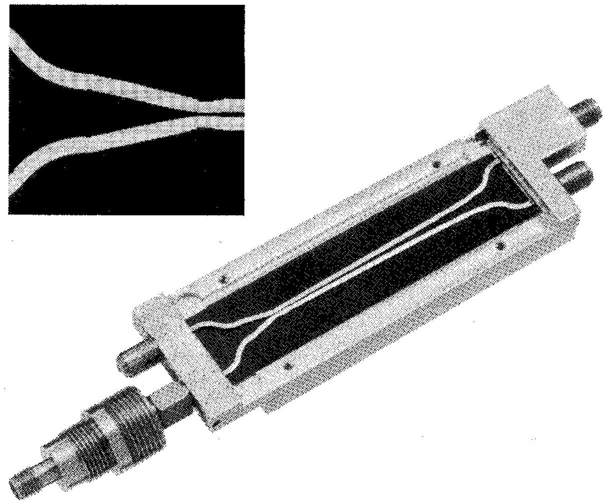
Directional Detector (2 to 40 GHz)

The design of the directional detector (coupler with built-in detector) was the most challenging project. A directional detector is needed in the sweeper to control output impedance (source match) and to level the output power across the frequency range.

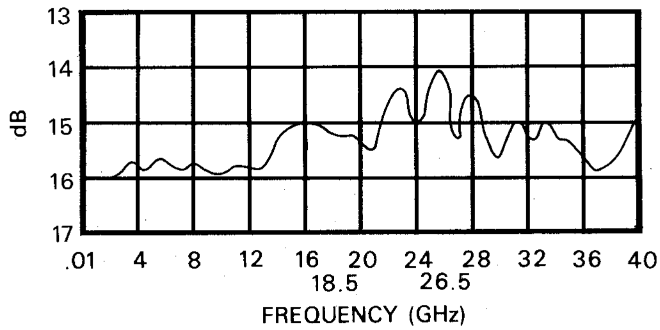
The design of the directional detector was divided into semi-independent efforts: connector, detector, termination, theoretical coupler design, and form factor. The connector, detector, and termination were designed by modifying the components discussed earlier. The theoretical coupler design effort was largely a major computer analysis. The determination of an optimum form factor was the most crucial task. The task was complicated by the knowledge that the traditional techniques involving photo-etched dielectric plastic created serious problems at higher frequencies. For example, just the problems of uneven velocities in the odd and even modes caused by minor air gaps and the extreme thinness of the material called for new ideas.

It was clear that an air dielectric design would give the best microwave performance. But the problem of machining 160 very small steps seemed impossible--until laser machining was considered. After several methods were tried, a feasible technique was developed, a technique so novel that WILTRON is applying for a patent.

The directional coupler and its performance characteristics are shown in Figures 7 and 8 respectively. Future modifications of the design will incorporate the termination and detector on an alumina substrate.



7. 2 to 40 GHz Coaxial Coupler



8. 26 to 40 GHz Coupler, Frequency Sensitivity of Coupled Arm

SUMMARY

The development of components covering the 10 MHz to 40 GHz range makes it possible to measure transmission and return loss in a single setup. Accurate measurements are made without interruption to adjust the setup or to install components. The availability of a measurement system, a 40 GHz connector, and cable will encourage the development of coax systems operating to 40 GHz and beyond.

REFERENCES

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