IMPROVING SMA TESTS WITH APC3.5 HARDWARE

Introduction

Some experts compare SMA connectors in the laboratory to fish out of water. But APC3.5 calibration devices, and a little specialized software, can net the needed improvements.

The SMA connector literally spawned an industry within an industry. The design, in all its incarnations,[1] extended the useful frequency range of coaxial devices to 18 GHz, encouraged the development of improved components, and enabled miniaturization and greater package densities.

Although the SMA stands as the most widely used microwave coaxial connector, controversy has dogged its use with network analyzers, and in other measurements. A basic fact remains: the SMA was designed as an economical, miniaturized, easy-to-use connector for system application — it was never intended to be a precision connector for the laboratory.

Critics of microwave measurements made with SMAs can describe the connector's shortcomings in detail (see *The Trouble With SMA Connectors* on page 5). But these well-founded concerns aren't likely to diminish the inevitability of SMA measurements. Manufacturers continue to apply SMAs extensively to their products, and the problem of SMA measurements will never be solved by eliminating it. Instead, improved techniques must overcome the difficulties, and enhance the accuracy of the measurements.

One such technique, the use of APC3.5 precision connectors on the instrument test port, and on any calibration devices, shows promise. Although this concept is still being developed, it can provide immediate improvements even in its present form.

SMA Interface Takes Many Configurations

Among the practical aspects that complicate measurements made with SMA connectors, a plethora of SMA interface configurations ranks high (and the same can be said of other coaxial connectors). Even in its most basic form, a single SMA female design is accompanied by *two* different male configurations, Figure 1.

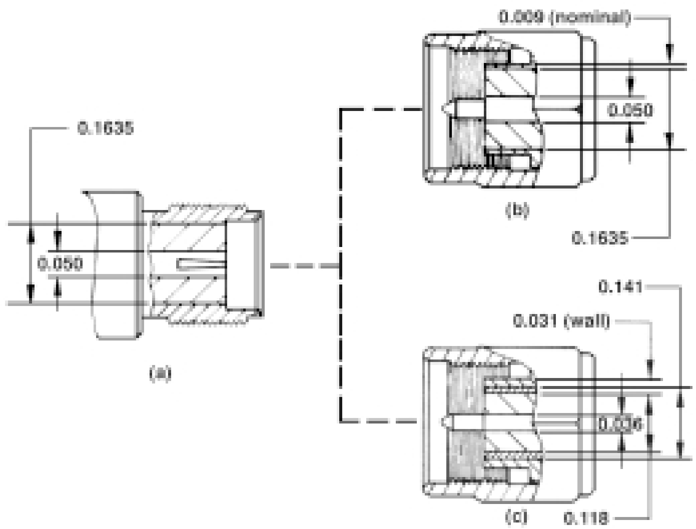

Figure 1: The single SMA female configuration (a) can mate with both the "conventional" male (b), and the "thru" male (c).

The "standard" SMA junction is composed of the female connector, **Figure 1(a)**, mated with the "conventional" male connector, **Figure 1(b)**. This junction can be labeled "standard" because it offers a uniform 0.050/0.1635 (inner conductor/outer conductor, both in inches) transmission line, without step discontinuities.

The coaxial line size limits the upper frequency of the SMA. For example, the 0.050/0.1635 line will theoretically mode at approximately 26 GHz. In practice, moding problems can occur in "conventional"

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male connectors at frequencies as low as 22 GHz, and caution is warranted at any frequency above 18 GHz.

The second male version, the "thru" male connector, **Figure 1(c)**, is the most widely used configuration. This connector, which is essentially the original SMA design, was conceived specifically to be compatible with 0.141-in. coaxitube. Consequently, the "thru" configuration uses the dielectric and the center conductor of the coaxitube as part of the connector itself. (The SMA female connector was actually developed to mate with this male.) Unlike the "conventional" male connector, the "thru" male has no step on its pin.

The numerous SMA interface dimensions and tolerances currently in use, **Table 1**, compound the measurement problem. Not only do the standards differ, but some (such as MIL-C-39012, which is item A in **Table 1**) allow considerable variations within the dimensions. Since connectors made under any one of these standards will mate with those manufactured according to any other, a broad range of possible electrical responses is created.

Direct physical measurements of the connectors offer some hope for quantifying their electrical performance. The interface may be defined in most instances by determining the critical axial dimensions of the interface (FP, FD, MP, and MD in **Figure 2**) with a connector gage, such as the Maury A027A.

Since the introduction of the SMA, connector designers have been seeking ways to improve it. Their efforts have resulted in connectors with the designations MPC4 (Maury Microwave Corporation, Ontario, CA), APC3.5 (Amphenol, Oak Brook, IL), WSMA (Wiltron Company, Mountain View, CA), among others (see *Improving the SMA* on page 7).

Although most of the "improved" connectors have air rather than dielectric interfaces, they mate *mechanically* to the SMA. Electrically, however, they present varying degrees of discontinuity at the interface.

In addition to the electrical properties of the connector interface, the mechanical nature of the SMA must also be considered. **Figure 1(b)** shows one of the weaker points of the SMA design; the thickness of the outer wall of the "conventional" male measures a mere 0.009 in. Extensive use (i.e., many connect/disconnect operations) and/or excessive torque can buckle this fragile component. And even though the "thru" connector possesses some immunity to mistreatment by virtue of its robust 0.031-in. wall, compensation is rarely provided for its junction discontinuity.

Table 1: Critical SMA Axial Interface Dimensions

Item	Specification	FP	FD	MP	MD	Comment
A	MIL-C-39012, class 2	0.000 +0.030 -0.000	-0.002 (maximum)	0.000 (minimum)	-0.002 (maximum)	Per MIL-C-39012/55 and /57
B	MIL-C-39012 (recommended)	0.000 +0.010 -0.000	0.000 ±0.002	0.000 +0.010 -0.000	0.000 ±0.002	Recommended tolerance for MIL-C-39012, class 2
C	MIL-C-39012 (standard test)	0.000 +0.003 -0.000	0.000 +0.002 -0.000	0.000 +0.003 -0.000	0.000 +0.002 -0.000	Per MIL-C-39012B, amendment 1
D	Maury Microwave (standard)	0.000 +0.005 -0.000	0.000 ±0.002	0.000 +0.005 -0.000	0.000 ±0.002	Used on most Maury components
E	Maury Microwave (precision)	0.000 +0.005 -0.000	0.000 +0.002 -0.000	0.000 +0.005 -0.000	0.000 +0.002 -0.000	Supplied on Maury precision components
F	Industry Standard	0.000 +0.010 -0.000	0.000 +0.005 -0.002	0.000 +0.010 -0.000	0.000 +0.005 -0.002	OSM 1979 catalog pg. 12

Note: Plus (+) tolerances indicate a recessed condition from the outer conductor mating plane. Minus (-) tolerances indicate a protruding condition.

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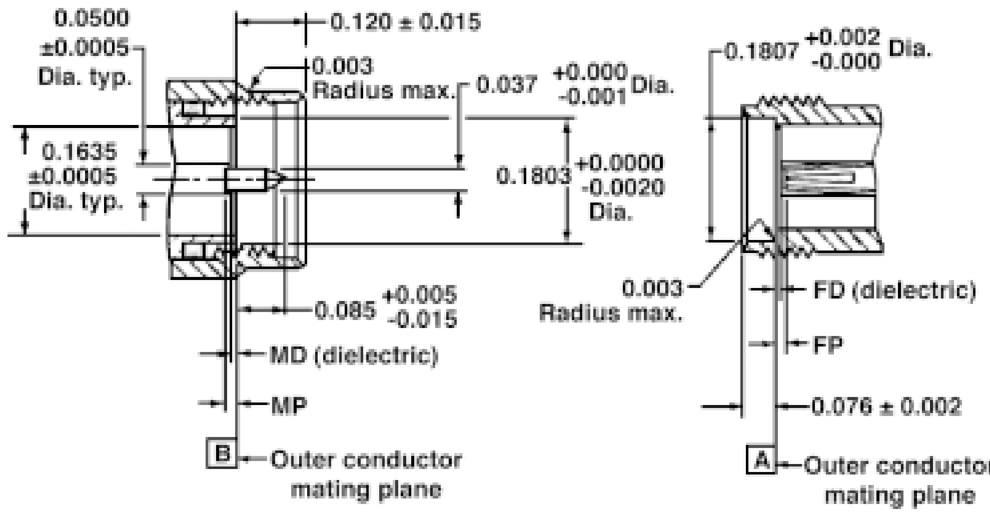

Figure 2: **Critical dimensions (FP, FD, MP, and MD) must be gauged to insure proper electrical performance.**

A quick review of **Figure 1** provides a summary of the mechanical misfortunes that can befall the SMA connector. The female contact, for example, is generally a two-slot type that is slightly deformed. This female contact can also cut into the male pin and cause necking with subsequent dielectric changes. In addition, the Teflon dielectrics tend to move and change the interface.

Gauging the connectors, which was mentioned earlier as a means of insuring consistent electrical performance, will also prevent mechanical damage from out of tolerance dimensions. Furthermore, measurement technicians should be trained and equipped to properly install the connectors. A connector torque wrench can be particularly valuable in reducing wear and damage. Applying the correct torque will also make the measurements more reliable and repeatable.

APC3.5 Connectors Improve SMA Measurements

A discussion of all the possible connector junctions would quickly grow far beyond the bounds of any reasonably sized article. An examination limited to the APC3.5 to SMA interface, however, can be useful, particularly since it leads to an improved SMA measurement technique.

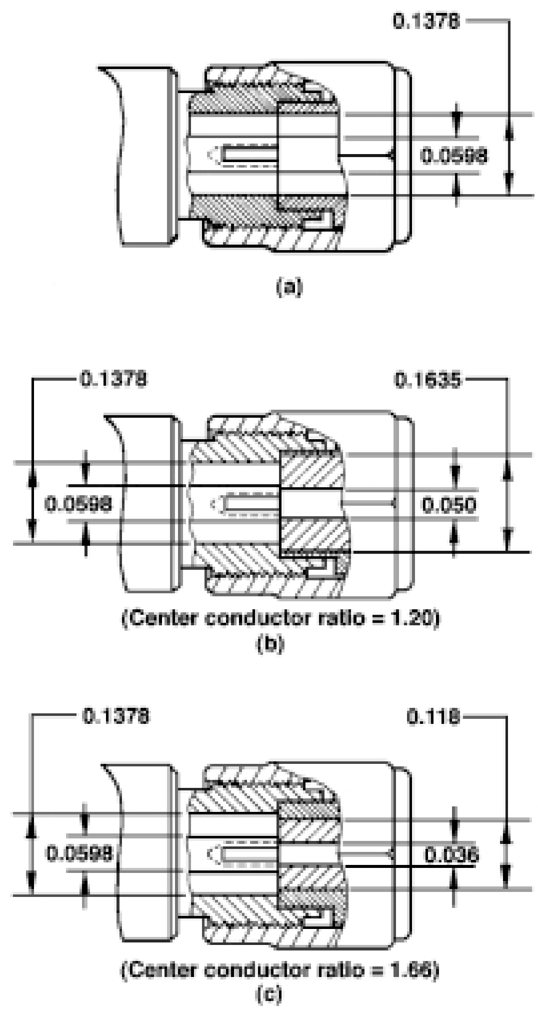

Figure 3: **An APC3.5 mated pair (a) provides a precision junction with no discontinuities. Line size discontinuitites are apparent when the APC3.5 mates to a "conventional" SMA connector (b), and are more of a problem with the SMA "thru" male (c).**

An APC3.5 mated pair, **Figure 3(a)**, provides a precision connection with no step discontinuities. However, line-size discontinuities become evident when an APC3.5 female is mated to a "conventional" SMA male connector, **Figure 3(b)**. The male APC3.5 to SMA female junction [not shown] is electrically equivalent to **Figure 3(b)**.

Figure 3(c) shows an APC3.5 female mated to an SMA "thru" male. The center conductor ratios in **Figures 3(b)** and **3(c)** indicate that the APC3.5 to SMA ("thru") junction will exhibit much greater discontinuity and reflection.

The performances of an SMA mated pair, an APC3.5 to SMA ("conventional") coupled junction, and an APC3.5 mated pair are compared in **Figure 4**. The VSWR plots indicate that of complimentary matching is achieved when an SMA mates to an APC3.5 connector. This matching allows the APC3.5 to SMA junction to actually surpass the performance of the SMA mated pair.

The proposed SMA measurement concept takes advantage of the precision, ruggedness, and dependability of the APC3.5 hardware (see *Why the APC3.5?*, on page 10), and of the embedded computer power of modern network analyzers (the method applies to both scalar and vector network analyzers). It calls for the calibration of the measurement system using APC3.5 connectors at the test port, and on all calibration devices (fixed shorts, open circuits, etc.). Software would then allow SMA measurements to be made by correcting any errors in the APC3.5 to SMA interface.

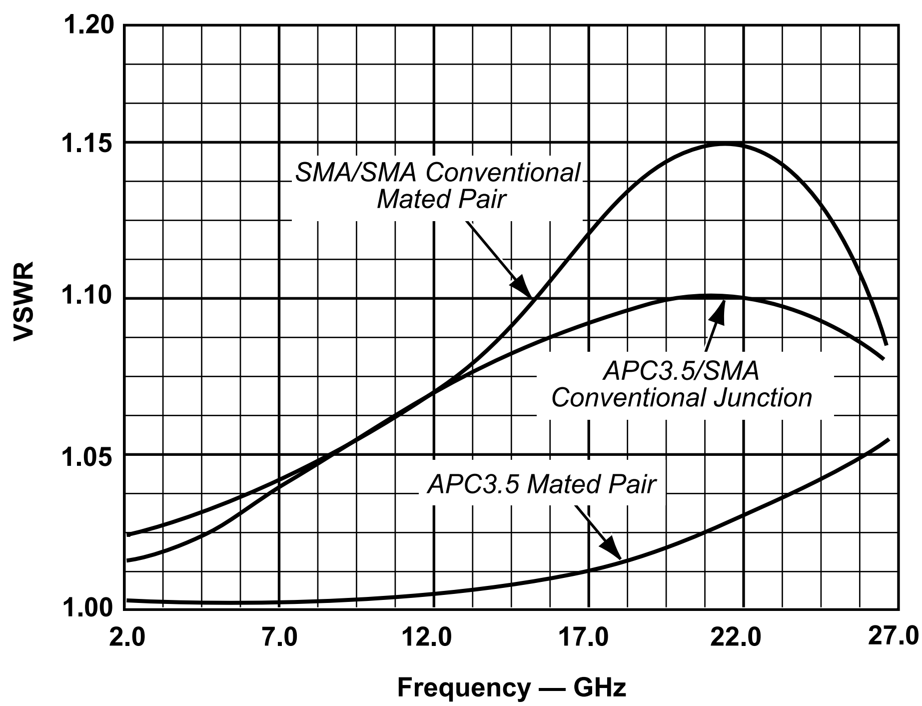

Figure 4: **Complementary matching occurs when an APC3.5 connector mates to a "conventional" male or female SMA. The matching allows the APC3.5 to SMA junction to surpass the performance of the SMA mated pair. These results indicate that the APC3.5 can be used to improve SMA measurements.**

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"Accuracy enhancement" in the software represents a more practical, economical, and reliable solution than an attempt to perfect the hardware. It can also account for the numerous interface possibilities, something that hardware could never accomplish.

Unfortunately, the development of the software presents a formidable and continuing task. Current efforts aim to increase accuracy, streamline procedures, and simplify entry of the interface parameters (such as using actual physical values of critical dimensions).

Although the development of the APC3.5 calibration hardware is also continuing, it has already been fruitful. Even without the error-correction software that will ultimately be available, the new hardware has considerably enhanced present techniques in making SMA measurements.

After the measurement software and its compatible APC3.5 hardware have been realized, they will represent a very practical solution to a very complex problem — without any changes to the SMA connector as it exists today.

The Trouble With SMA Connectors

Although the SMA connectors appear on so many coaxial devices, they present definite problems during microwave measurements. Here are some of the difficulties:

- A variety of interface configurations makes accurate data difficult to obtain. It isn't enough to have accurate equipment; the user must also understand the nature of the connector interface.
- The dielectrically loaded design makes accurate impedance and other standards difficult to establish.
- The SMA connector has some mechanically weak components such as a thin outer wall ("conventional" SMA male).
- Incompatible calibration standards can create serious measurement errors. Sliding loads and offset shorts must have the same connector interface and transmission line size.
- SMA connectors are prone to mistreatment by operators. Difficulties include cocked entry, dented Teflon dielectric, broken female contacts, and excessive torque.
- The SMA is not a "precision" connector and may be mechanically out of tolerance. Inaccuracies can be caused by excessive contact pin gap or protrusion, or dislocation of the dielectric.

Correcting an SMA Mismatch

The SMA connector is designed to achieve coplanar mating with the outer conductor, Figure 5(a). In other words, the center contact, dielectric, and outer conductor all lie in the same plane. This *reference*

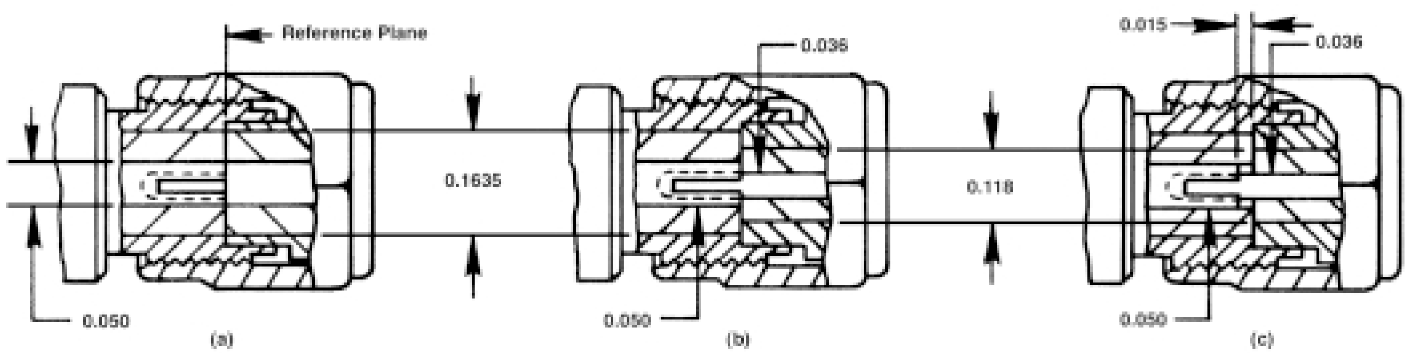

Figure 5: The "conventional" SMA connector achieves coplanar mating with the SMA female (a), but the "thru" male produces a capacitive discontinuity (b). Offsetting the female contact (c) can compensate for the mismatch.

plane, to which all electrical and mechanical measurements are referred, is established by the outer conductor.

The dissimilar coaxial line sizes of the SMA female and the "thru" male connectors produce a capacitive discontinuity at the reference plane, **Figure 5(b)**. An inductive compensation for this capacitance can be provided by offsetting the female contact, **Figure 5(c)**.

In the original female SMA design, the contact was offset by 0.015 in. Unfortunately, this offset conflicts with the "standard" SMA coupled junction shown in **Figure 5(a)**. (If the female contact in **Figure 5(a)** were offset by 0.015 in., the resulting inductive discontinuity would create a mismatch in the "standard" junction.)

In deference to the "standard" SMA configuration, the mismatched interface of **Figure 5(b)** is currently the predominant "thru" connector junction. However, two solutions can be applied to compensate for its mismatch.

One solution requires a portion of the Teflon dielectric to be removed to create a small section of inductive air line which cancels the capacitance. The same electrical compensation can be accomplished by adding a small ring or washer at the interface to create the inductance.

The typical VSWR performances of various SMA coupled junctions are compared in **Figure 6**. Although the "conventional" junction offers the best performance, the compensated "thru" male connector provides better VSWR than an uncompensated version.

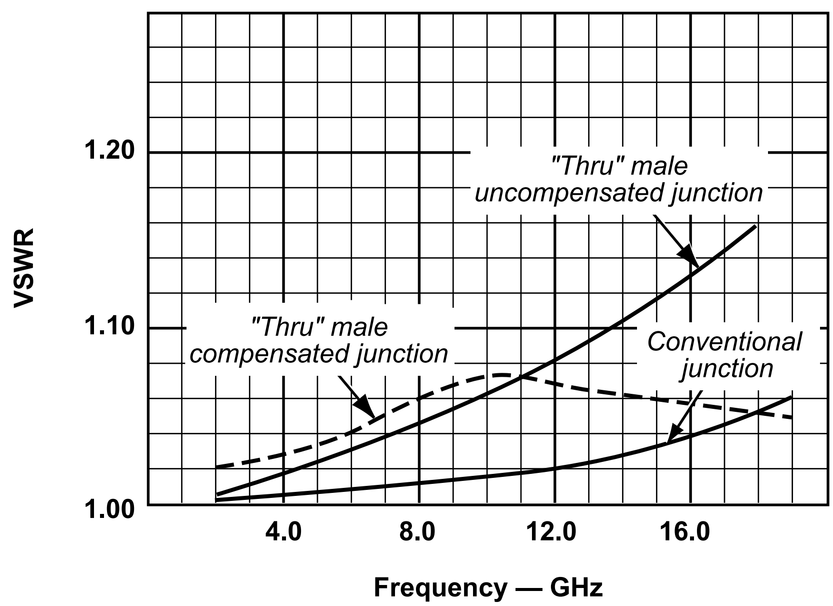

Figure 6: **Typical VSWR data shows the improved performance of the compensated "thru" male connector.**

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Improving the SMA

Air-interface connectors have been developed in an effort to make improvements over the SMA for certain applications. They will not, however, replace the SMA in any practical sense, nor can they be called SMA.

The MPC4 connector, **Figure 7(a)** was produced by removing the dielectric in an SMA connector, and increasing the center conductor to achieve a 50 ohm impedance. It is a 0.071/0.1635 air line connector with a diameter of approximately 4mm and a rated upper frequency of 26.5 GHz. The MPC4 is currently being supplied on offset shorts and open circuits as part of standard SMA calibration kits, as well as on other calibration devices.

The main weaknesses of the MPC4 are its thin, 0.009-in. wall section, and the discontinuity it creates at the center conductor when it is mated to an SMA (1.40 center conductor ratio).

The APC3.5, **Figure 7(b)** was originally developed by Hewlett-Packard to extend the upper frequency of their devices to 26.5 GHz. It has a 0.0598/0.1378 air line which makes it a 3.5mm connector that's rated to 34 GHz.

The APC3.5 provides low VSWR as a mated pair, and reasonably low VSWR when mated to an SMA. In the case of the male versions, its 0.021-in. wall makes it more rugged than the "conventional" SMA.

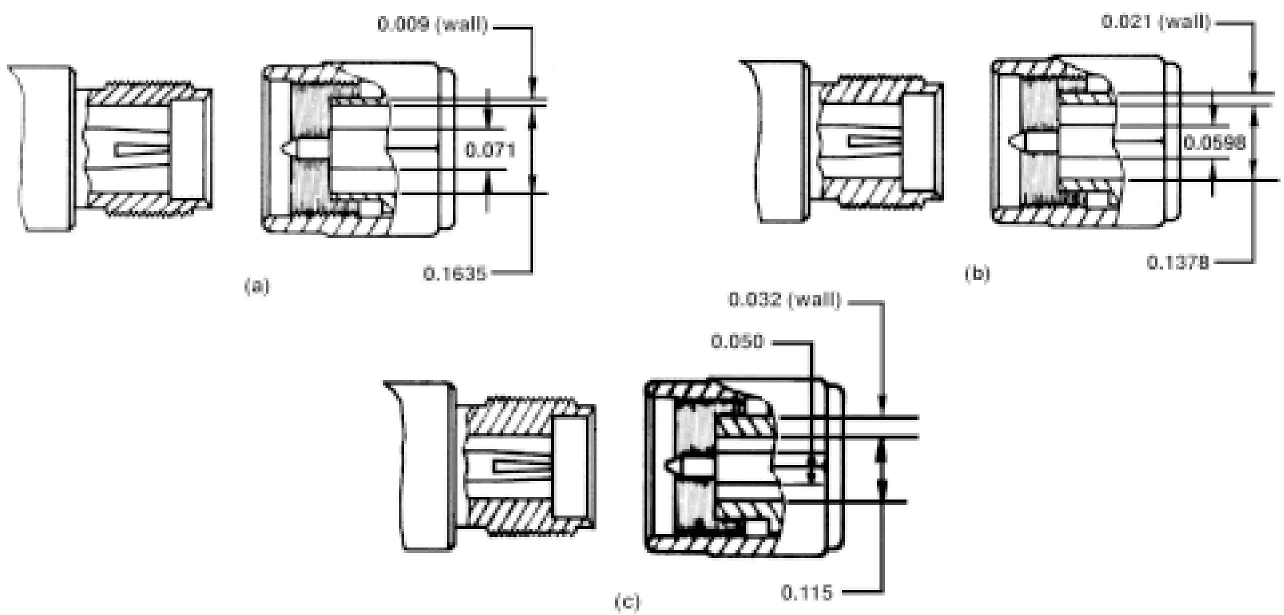

Figure 7: **"Improved" SMA connectors include the MPC4 (a), the APC3.5 (b), and the MPC3 (c).**

The MPC3, **Figure 7(c)** connector answered the need for a mode-free design for ECM/EW applications to 40 GHz. This connector was essentially derived by removing the dielectric from the SMA conductor, and then reducing the outer conductor to achieve 50 ohms.

The MPC3, with its 0.050/0.115 air line, is approximately a 3mm connector and is primarily intended for high frequency operations. Since mode free performance requires the use of a fragile bead support, it should not be used below 18 GHz unless its bandwidth is required.

The mated pair VSWR performance of these three air-interface connectors is compared to the conventional SMA in **Figure 8**.

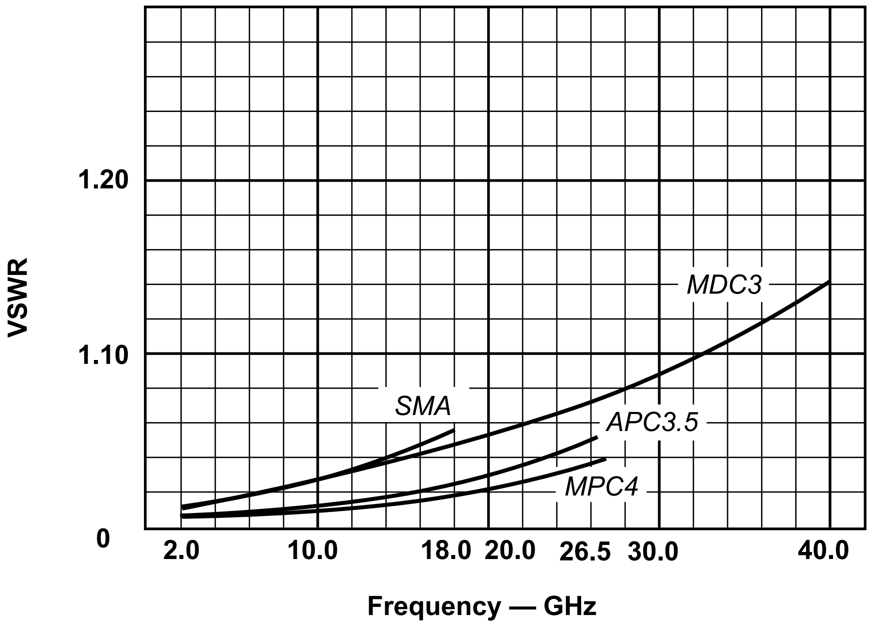

Figure 8: The typical VSWR performances of the "improved" versions are compared to the "conventional" SMA.

A New Reference Plane Short

Part of the effort in developing a new SMA measurement procedure has gone into improving APC3.5 calibration hardware. The work has produced APC7 to APC3.5 adapters, fixed terminations, offset shorts, and open circuits. An improved female reference plane short (Maury Microwave Corporation's model 360D) exemplifies the progress that has been made. [2]

The improved fixed short eliminates all of the problems that are present in the more familiar "buried contact" devices. It incorporates a large contact that defines the complete shorting plane, **Figure 9**. When mated with a male connector, the improved short makes a firm contact with the outer conductor. As the male connector is tightened into position, the female contact is compressed so that it grabs the male pin to make an almost perfect short circuit. Cross section A-A in **Figure 9(a)** shows the radial slots in the face of the contact which provide "grabbing" action. (The beryllium copper contact is heat treated and gold plated.)

The reference plane fixed short is compared to the older "buried contact" versions in **Figure 10**. As frequency increases, the return loss and the phase error of the older devices degrades, with a definite roll-off and increased error at 18 GHz.

Although tests of a number of "buried contact" devices showed great inconsistencies from piece to piece, a phase comparison of six improved fixed shorts, **Figure 11**, indicates excellent reproducibility.

(This data was collected with an HP8409B automatic network analyzer using Maury model 8050B APC3.5 calibration kit.)

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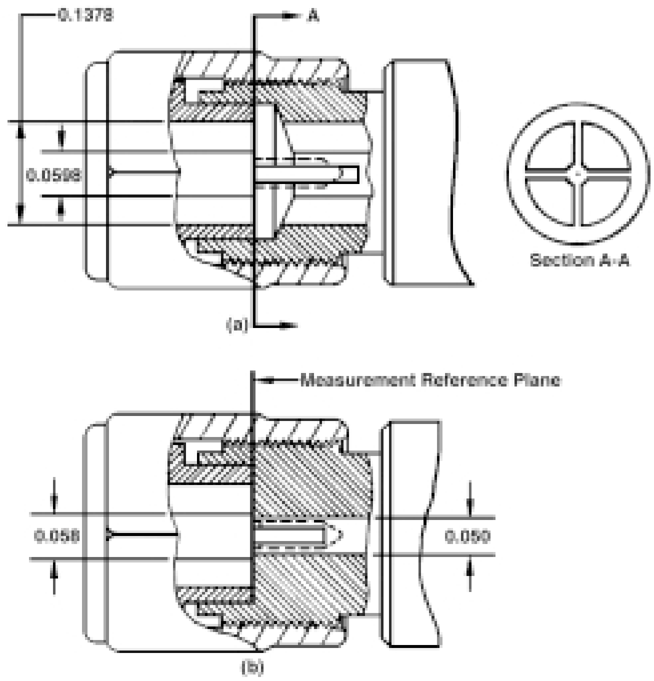

Figure 9: **The design of the new reference plane female fixed short (a) is shown with an older "OSM" device (b). Section A-A depicts the radial slots in the face of the female contact which allow it to grab the male pin and make an almost perfect short circuit. The contact is made of beryllium copper, which is heat treated and gold plated.**

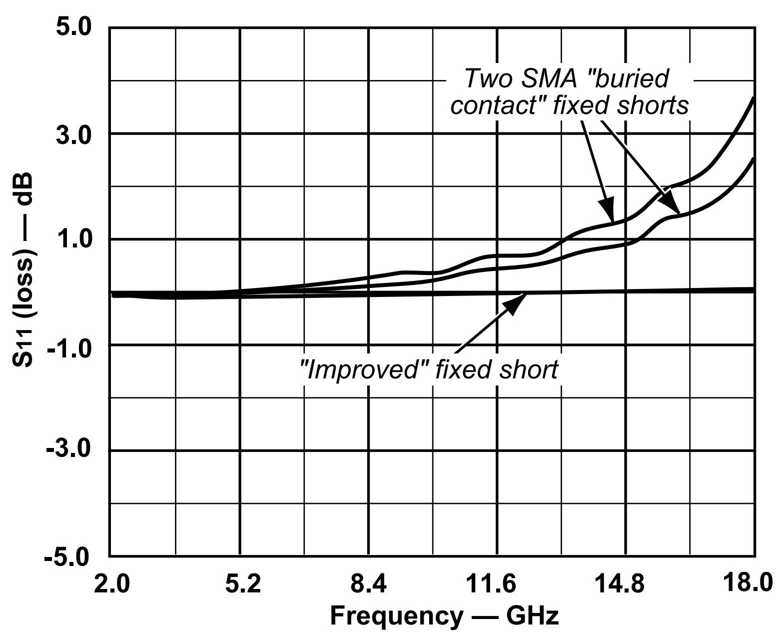

Figure 10: **The new device offers better performance than the "buried contact" designs as frequency increases.**

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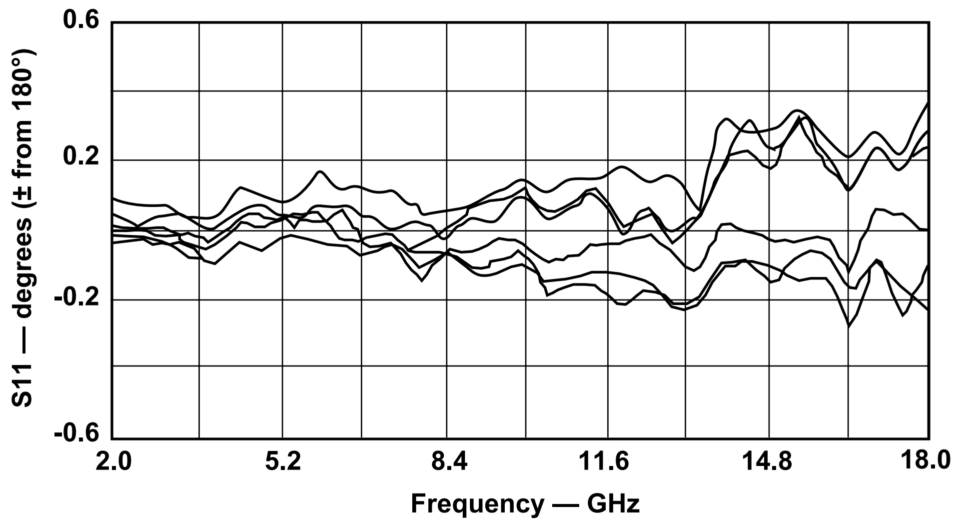

Figure 11: A phase comparison of six improved fixed shorts proves that the design is reproducible.

Why the APC3.5?

The APC3.5 is a good choice for measurement applications for several reasons.

- It is a precision connector that is SMA mateable (in fact, when mated to an SMA, it provides lower VSWR than an SMA mated pair).
- Since the APC3.5 has no dielectric interface, it produces measurements that are consistent and repeatable. Its air interface provides a well-defined measurement plane.
- Both the female and male versions of the APC3.5 have more rugged construction, with heavier walls, than the SMA.
- Accurate APC3.5 air line calibration standards (sliding loads, shorts, etc.) can be produced without fundamental discontinuities.
- The APC3.5 allows accurate network analyzer calibration and the subsequent introduction of interface error correction in software.
- The APC3.5 should satisfy National Institute of Standards and Technology requirements, and enable the establishment of measurement hardware that can be traced to NIST standards.
- The APC3.5 has been adopted as a standard by one of the major instrument manufacturers (Hewlett-Packard).

Notes

1 The SMA connector first appeared around 1958 as the "BRM" developed by the Bendix Scintilla Division. In the early 60's, it became popular as the "OSM" from Omni-Spectra. In 1968, it obtained its current "SMA" designation. Since SMA connectors have *dielectrically* loaded interface, an air-interface connector cannot be designated SMA.

2 The original design developed by R. Stewart at Hewlett-Packard (Santa Rosa, CA).

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Reprinted With Corrections From
Microwaves
September 1981