The Flanged Coaxial Connector System: Enabling DC-220 GHz Connections

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[Summary] To cover the frequency range of broadband microwave and millimeter-wave test equipment, coaxial connectors are required to interface with coaxial probes or devices. Recently, a 70 kHz to 220 GHz broadband network analysis system was introduced[1) to 4)] having a flanged coaxial connector interface at its test port. This paper discusses the evolution of this flanged coaxial connector which supports frequencies to 220 GHz and addresses requirements of today's designs.

1 Introduction

Coaxial connectors are often found on broadband microwave and millimeter-wave test equipment. Selecting a coaxial connector size such that its first TE11 mode frequency is well above the maximum operating frequency of the instrument is a requirement to support a single mode signal propagation. A simple approximation[5)] for the cut-off frequency of a coaxial section is shown in equation 1. This equation approximates the frequency at which the first TE11 mode starts to propagate.

$$f_c = \frac{190.85}{(d+D)\sqrt{\varepsilon_r}} \text{ [GHz]} \quad (1)$$

where d and D are inner and outer diameters (in mm), ε_r is the effective dielectric constant of the section. Often, the mechanical features of an existing coaxial connector design are scaled in size to increase the TE11 mode above the highest frequency of operation. However, as frequencies reach beyond approxiamately 100 GHz, scaling the mechanical dimensions of an existing coaxial connector present manufacturing feasibility and customer usability issues.

A good example of a scaled connector interface is the 1-mm connector interface introduced in 1989 by Hewlett Packard. The 1-mm (W1) connector interface is an open standard[6)] and is very similar in design to the 1.85 mm connector interface but scaled down in size. The 0.8 mm connector interface is yet another example of a scaled connector interface. The connector interface as described in the IEEE-P287[6)] standard does not describe the complete design of a coaxial connector but only its interface and how it mates with another connector. Design features such as: slotted female contacts, center conductor bead supports and everything else behind the connector interface is impacted by scaling. This article discusses connector design problems due to scaling and some solutions to improve manufacturing feasibility and customer use. The article also discusses a new flanged coaxial connector system to enable DC-220 GHz measurements that addresses many coaxial scaling issues.

2 Design and use challenges of 1-mm and 0.8-mm connector and adapters

2.1 Female Slotted Contacts

Many of the design challenges of coaxial connectors operation above 100 GHz stem from piece-part machining limitations. Oldfield[7)] discussed the unavailability of slitting saws having thicknesses less than 2 mils. Slitting saws are machine tools used with screw machines to create the two and four slot slotted contacts on female coaxial center conductors. Most 0.8-mm, 1-mm (W1), 1.85-mm (V) connector sizes use a four slot female slotted contact. Figure 1 shows a 1.85 mm (V) four-slot female slotted contact.

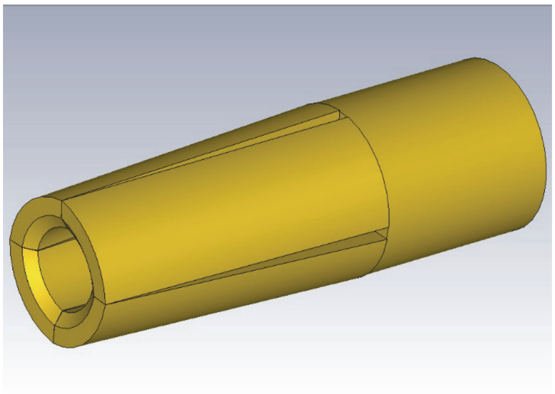

Figure 1 1.85 mm (V) four-slot slotted contact

For visual clarity, a strain analysis was performed on a single contact finger of a 1.85 mm (V) slotted contact to show the locations of the maximum strain with an outward force applied to the end of the finger in the direction of the

V-axis. This analysis was carried out using CST Studio Suite Structural Mechanics Solver[8]. The dark blue areas indicate compressive strain whereas the dark red areas indicate tensile strain. These are the locations where deformation occurs. If the yield strength of the material is exceeded then permanent deformation and failure will occur.

For 0.6-mm and 0.4-mm coaxial connector sizes, a 2-mil slitting saw and drilling operations remove a disproportionate amout of material away from the slotted contact producing thin and weak female slotted contacts. These fragile contacts have a good chance of permanently distorting when engaged with a male center conductor.

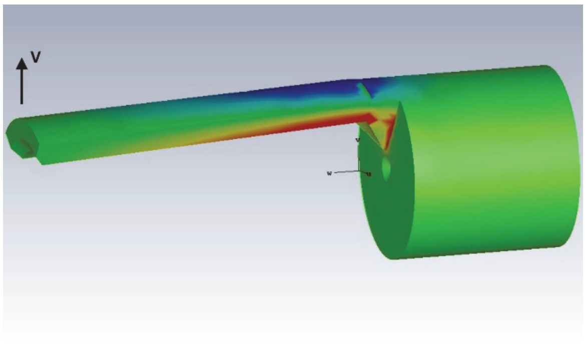

Figure 2 Strain analysis on a single finger of a 1.85 mm (V) four-slot slotted contact with outward force at end of finger in V-axis direction.

2.2 Precision Drilling

Another machining limitation is precision drilling of coaxial connector outer conductors. Coaxial connector outer conductors are usually drilled. For small diameters in the range of approximately 0.4 mm to 1 mm, the maximum achievable ratio of the drilled length to diameter is about 10. The bore length is limited by the drill's flute length. Generally, it is desired to keep bead-supported connector assemblies short to maintain concentricity and minimize the possibility of damaging female slotted contacts by mismated center conductors. Coaxial airlines typically have a diameter ratio greater than 10 to achieve broad calibration measurement bandwidths. A manufacturing technique[9] was developed to accomplish this.

Anritsu's 0.8 mm series of adapters (i.e., PNs: 33.8F.8F50, 33.8.8F50, 33.8.850) were designed as press-fit assemblies to minimize adapter length thus promoting good concentricity, improved manufacturability and better mechanical stability. On the other hand, a press-fit design requires tight tolerances along the press-fit surfaces. Further, the press fit design also requires both outer and center conductor part lengths to be of tight length tolerances so pin depths are within specification when the assembly is pressed together. Tighter piece part tolerances impacts manufacturing yield and cost. Figure 3 compares the size of an Anritsu 1-mm (W1) F-F adapter to a 0.8-mm F-F adapter.

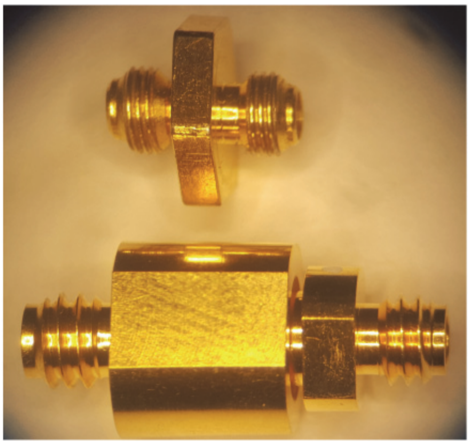

Figure 3 Length comparison between Anritsu 33.8F.8F50 0.8-mm F-F adapter (top) and Anritsu 33WFWF50 1-mm (W1) adapter (bottom)

2.3 Connector Interface Outer Conductor Mating Area

As connector assemblies get smaller in size they are more difficult for users to work with and handle. As standard threaded coupling nut coaxial connectors decrease in size, the mating plane surface area is reduced between the two outer conductors when connected. Table 1 shows a listing of the mating plane outer conductor surface area of several IEEE-P287 standard connectors. The connector sizes listed in table 1 are not mate-compatible and this forces coupling nuts (with geometries also defined in the IEEE-P287 standard) to have smaller size internal threads which indirectly sets the maximum allowed outer conductor mating surface area.

Table 1 Outer conductor mating area for standard sized connectors.

Coaxial connector size	Outer Conductor Mating Area [mm^2]*
1.85 mm (V)	14.9
1.00 mm (W1)	3.6
0.80 mm	2.3

* - no chamfers assumed

As mating surface area is reduced, heavy DUTs that are connected can introduce lateral torque and can flex the connector assembly arrangement. If the connector assembly is connected to the test port of a network analyzer and lateral torque is introduced then small variations in transmission and reflection parmeters can occur. Some metrology organizations have constructed free floating suspension systems to suspend their heavy millimeter-wave reflectomer heads so each 1-mm test port connector interface is perfectly in-line with one another minimizing any lateral mating connector torque[10].

3 The Flanged Coaxial Connector Interface

3.1 Slotted Male Contact

The "Lobster Claw" center conductor contact was introduced by Oldfield[7]. Instead of slotting the female center conductor, the slot is machined into the male pin. The hole remains in the female side of the center conductor and has no slots. On the female side, the hole diameter is increased such that the circular wall is very thin. A large hole allows the male slotted pin to be relatively close is diameter to the main center conductor size minimizing the impedance step discontinuity at the connection interface. As the male slotted pin is engaged into the hole on the female side, the slotted pin collapses inward slightly. This is in contrast to traditional female slotted contacts which spread outward when a male pin is engaged. Unlike the standard female slotted contact, the slotted male pin is more rigid since a only a single slot is introduced. Figure 4 shows a picture of a formed slotted male pin with center conductor diameter of 0.261 mm.

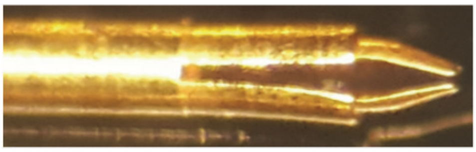

Figure 4 A formed 0.261 mm dia. slotted male contact pin

3.2 Flanged Outer Conductor

Standard coupling nut sizes force connectors to have minimum lengths due to minimum number of threads required and presence of a retaining ring to hold the coupling nut to the connector outer conductor. Introducing another way to hold the connector interfaces tightly together without small coupling nuts could allow a greater connector interface mating areas with increased rigidity and a shorter length connector assemblies.

A compatible UG-387/UM interface is used in place of the small threaded coupling nut to connect two interfaces together. Figure 5 shows the flange side of a prototype 1-mm (W1) to a 0.6-mm flange adapter. The waveguide interface allows significantly more outer conductor contact surface area translating to a more rigid connection when heavy DUTs are connected. The pinned waveguide flange provides precision alignment between the two flanged mating connectors and center conductors assuming good concentricity. Another benefit of the pinned flanged outer conductor interface has to do with measurement repeatability. The pinned flange allows only two rotational positions whereas traditional threaded coupling nut assemblies have an infinite number of rotational positions. Consistent rotational positioning maximizes connection repeatability from the pinned flange arrangement.

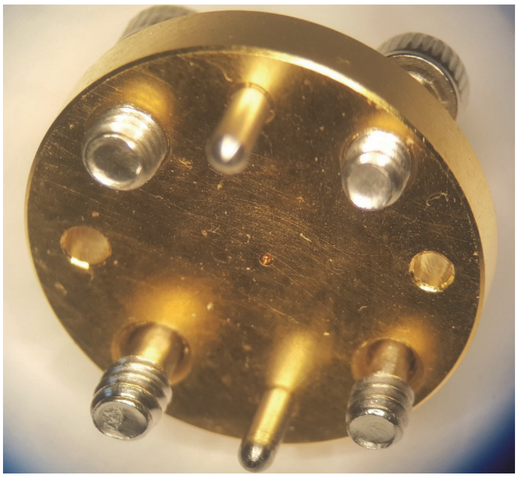

Figure 5 Flange side of an Anritsu 33WG50 prototype 1-mm (W1) Male to 0.6-mm Flange adapter

4 Transitioning from Coax to Waveguide

Thin, in-line transition shims were developed to facilitate coaxial-to-Waveguide mode conversion and allow connection of waveguide devices. These shims are sandwiched between flange coaxial connector interface and a standard waveguide thru line. The shims have an internal stepped detail similar to Levy's design[11] and either an integrated pin or hole to mate with the Flanged Coaxial connector interface (See Figures 6 to 8). Depending on the transition shim used, the flanged coaxial connector interface that mates to the transition shim can either have a slotted pin contact center conductor or a center conductor with a hole.

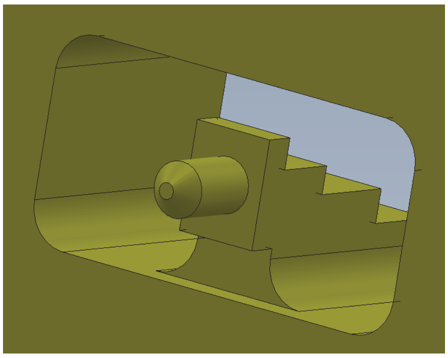

Figure 6 Integrated pin 0.6-mm Flange to WR5 in-line shim transition

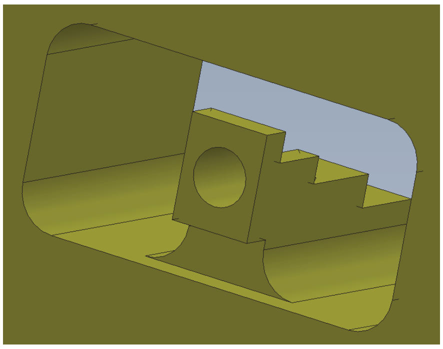

Figure 7 Integrated hole 0.6-mm Flange to WR5 in-line shim transition

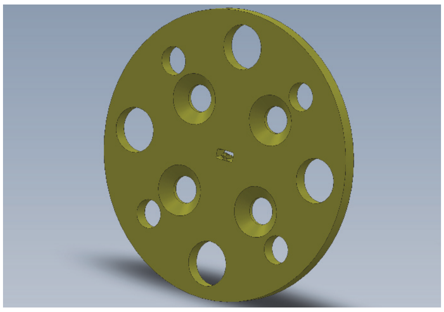

Figure 8 Zoomed-out view of 0.6-mm Flange to WR5 in-line shim transition

The transition shims are limited in thickness to 0.9 mm due to the available length end mill tool used to produce the internal features. The integrated pin is solid and not slotted. It is not feasible or necessary to make the integrated pin slotted since waveguide is a high pass structure and passing DC is not necessary. A slip-fit connection of the integrated pin to the flanged center conductor provides enough capacitive coupling for the signal transmission over the full waveguide band. A Full 3D Electromagnetic model was constructed using CST Microwave Studio[8] and a parametric sweep of the integrated pin diameter to the flanged coaxial center conductor including the waveguide transition shows little adverse effects on the transmission and reflection parameters. (See Figures 9 to 11). As the pin diameter is decreased and capacitive coupling reduced, |S11| degrades at 140 GHz in the WR5 frequency band.

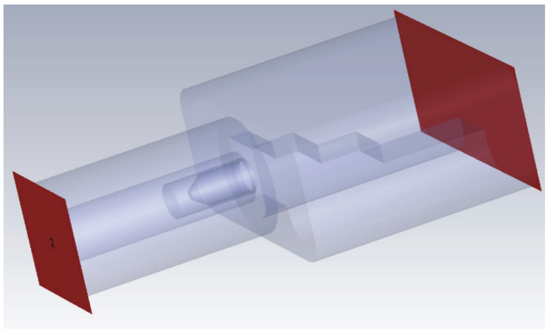

Figure 9 3D EM model of 0.6-mm coax-to-WR5 Waveguide transition with integrated pin

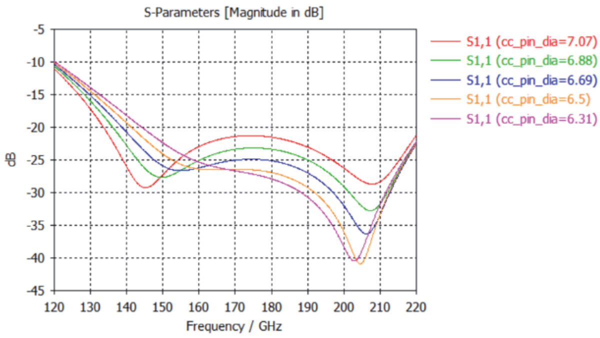

Figure 10 Parametric sweep of |S11| vs. Frequency, by varying diameter of solid pin inside a 7.1 mil dia. hole

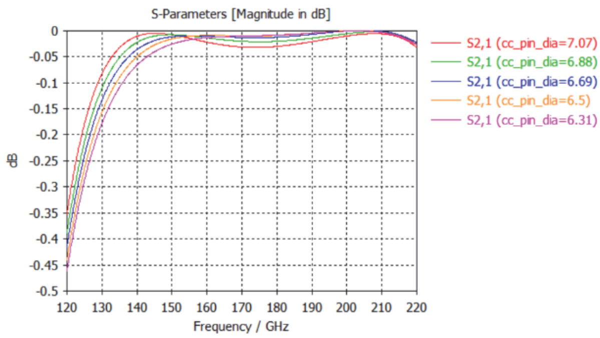

Figure 11 Parametric sweep of |S21| vs. Frequency, by varying diameter of solid pin inside a 7.1 mil dia. hole

A WR5 waveguide thru having a standard UG-387/UM interface is connected to the waveguide side of the transition shim to: 1) extend the reference plane away from the shim transition steps, 2) allow the end of the thru section to be torqued against transition shim and flanged coaxial interface and allow waveguide devices to be attached to the opposite end of the thru 3) provide a more precise rectangular waveguide interface extending beyond the shims 0.127 mm corner radii and transition steps. Figure 12 shows the complete assembly and Figure 13 shows a plot of the measured reflection and transmission response. The electrical measurement was made using a 1-port UFX (Universal Fixture Extraction) advanced de-embedding feature[12] of the Anritsu Vectorstar VNA.

Figure 12 Assembly of Anritsu's 35WR5G adapter showing 0.6-mm coax-to-WR5 transition shim and waveguide housing

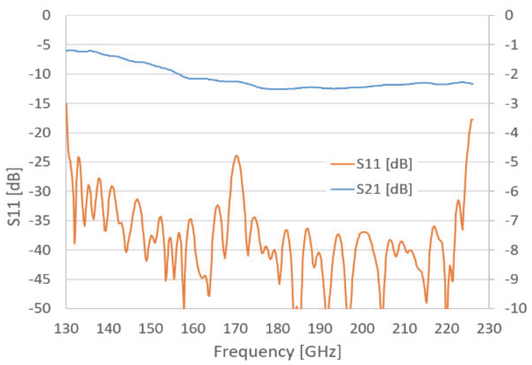

Figure 13 Reflection and Transmission response of Anritsu's 35WR5G 0.6-mm coax-to-WR5 adapter

5 Flanged Coax to 1-mm (W) and 0.8-mm adapters

Both 1-mm (W1) and 0.8-mm coaxial-to-flanged adapters were developed to facilitate connection of standard coaxial connector types. These adapters are constructed as two thin shims (e.g. outer conductors) bolted together with four flat-heat screws recessed into the surface on the flanged side. The opposite side incorporates a male threaded coupling nut. One of the two shim acts as the center conductor bead support holder. Both shims need to be relatively thin to keep the overall assembly length to a minimum and bore lengths-to-diameter ratios less than 10. Designing these adapters as bolt together assemblies instead of press-fit assemblies allows precise adjustment of pin depth and concentricity as well as improved manufacturing yields. Figure 14 shows a two-piece 1 mm (W1) to 0.6 mm coaxial flange assembly.

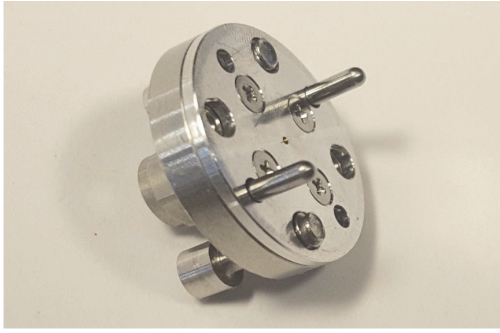

Figure 14 Anritsu's 33WG50 0.6-mm flange-to-1 mm (W1) coax two-piece adapter. Image shows 0.6-mm flange side.

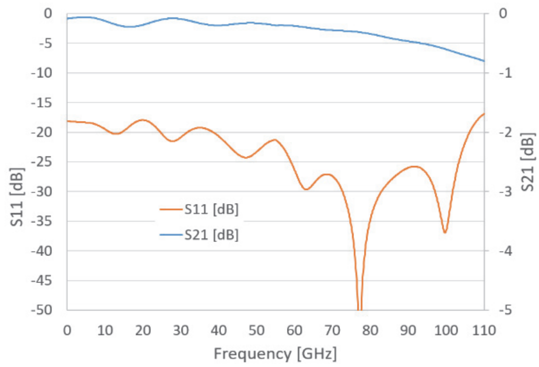

Figure 15 Reflection and Transmission response of Anritsu's 33WG50 1-mm (W1) coax-to-0.6 mm Flange adapter

6 Flanged Coaxial Probes

Flanged Coaxial Wafer probes were developed in partnership with MPI (www.mpi-corporation.com) to facilitate 70 kHz to 226 GHz continuous swept frequency on-wafer testing using Anritsu's ME7838G vector network analyzer system. The probe incorporates a continous coaxial structure from the flange interface down to the ground-signal-ground (GSG) probe tips. This continuous coaxial structure allows the probes to be short, with minimal thru-loss. The probes flange interface allows it to be directly connected to the Anritsu MA25400A reflectometer module flange interface without any adapters or cables (see Figure 16).

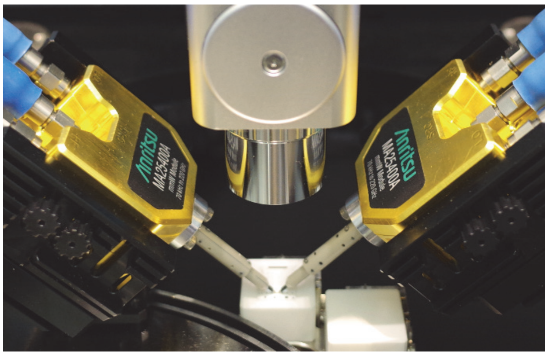

Figure 16 Two-port wafer probe measurement using MPI flanged coaxial wafer probes direct connected to Anritsu's MA25400A reflectometer modules.

7 Conclusions

Scaling standard threaded coupling nut coaxial connectors is not practical for connectors with outer conductor inside diameters below 0.8 mm. Machining limitations of center conductors and outer conductors requires other approaches to the design of the connector interface, connector and adapter assemblies. The prevalence of relatively heavy waveguide components (used above 110 GHz) requires a sturdy coaxial connection interface having an outer conductor that does not flex under perpendicular load with respect to the connectors axis. The mechanically sturdy flanged coaxial interface has the additional benefit of being mate compatible with a standard UG-387/UM waveguide interface using an in-line coaxial-to-waveguide transition shim.

8 Acknolegement

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