

# The Importance of Coax Connector Design Above 110 GHz

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[Summary]

Connectors have become smaller and more compact, as they extend to higher frequencies. Anritsu has employed many new innovative design techniques to develop connectors that support frequencies above 110 GHz and address the requirements of today's designs.

## 1 Introduction

Historically, coaxial connectors have had two methods for center conductor mating, the hermaphroditic contact and the male pin /slotted female contact. The non-sexed connectors had many advantages, the main being that only one connector type was required. As frequencies went higher, connectors became smaller in order to remain single mode. The success of the SMA connector foretold the end of the non-sexed connectors. Mechanically it was difficult to make butt-type connectors. The pin depth tolerances were very critical and the small size made making the resilient contact difficult. These factors raised the cost of the connectors well above the simple male pin /slotted female contact.

This article discusses the advances in connector design in order to meet frequencies that extend above 110 GHz. It outlines the evolution of connectors in order to achieve this type of necessary performance, as well as how these connectors meet today's design challenges.

## 2 Slotted Connector Design

As connectors became smaller and reached higher frequencies, the male/female contact design became the standard. A slotless female design was introduced for metrology applications, but this became impractical above the 50 GHz 2.4 mm connector.

The slotted design, however, is not without problems. Starting with the two-slot female SMA contact, this design, while inexpensive, is very easy to damage. A half-round feature is not very flexible, and the SMA connector was rated for only 500 connections. A long male pin that allowed the center conductors to engage before the outer conductors aligned the connectors almost ensured that careless mating would damage the female contact.

A four-slotted contact is much more resilient. 3.5 mm

connectors, designed to mate with the SMA, incorporated a four-slot female contact and were an air interface design that was more precise. These types of connectors were required with the introduction of the calibrated VNA. The 3.5 mm connectors did have some problems. Since it had to be compatible with the SMA connector, the size of the male pin was set at 0.914 mm. The center conductor size of the 3.5 mm connector is 1.52 mm. This creates two problems. First, the wall thickness of the female fingers is 0.3 mm; quite thick for such a small diameter. After slotting, the fingers are closed and the part heat treated. If they are closed too little, the contact will be unreliable; if they are closed too far, even slightly, the insertion force required to mate the connectors will become quite high. This introduces excess wear and may ever distort the support beads holding the center conductors in place. The large wall thickness introduced more pin gap reflection. The impedance of the gap section is 80 ohms. Pin gap reflections are created by the higher impedance line section created by the exposed male pin.

## 3 Connectors for Higher Frequencies

The 40 GHz 2.92 mm K connector, introduced in 1985, reduced many of these problems. A short male pin ensured that, before the center conductors could engage, the outer conductor parts aligned the two connectors so the male pin could not damage the female by being inserted at an angle. The center conductor diameter of the K connector was 1.27 mm leading to a finger wall thickness of 0.18 mm. This meant that the fingers were more flexible and the insertion pressure was greatly reduced. As a result, K connectors are rated for 4,000 connections.

The 50 GHz 2.4 mm and the 65 GHz, 1.85 mm connector interfaces were introduced by HP/Agilent. The 2.4 mm connector was required for its 50 GHz VNA while the 1.85

mm V connector was introduced with the advent of the Anritsu/Wiltron 60 GHz VNA. Improvements of V connector bead design allowed the VNA frequency to extend higher, first to 65 GHz, then 67 GHz, and now 70 GHz.

The 110 GHz, 1 mm connector was introduced by Agilent. Anritsu introduced the 110 GHz W connector with the unveiling of its 110 GHz broadband VNA. Going beyond that, Anritsu has already demonstrated a 0.8 mm connector as part of a 70 kHz to 145 GHz VNA technology demonstration.

The slotted female contact performed well in the lower frequency connectors. As frequency increased and the center conductors became smaller, they came more fragile. In fact, the thinner wall designs of the K and V connectors translated to connectors 1 mm and smaller, making a female contact that was too fragile and creating a need for thicker walls. This made the pin gap impedance higher than desirable, but was a better choice than a fragile female contact with very thin walls. These connectors are quite expensive and a distorted contact is very undesirable.

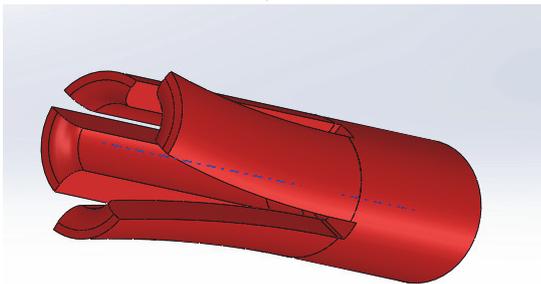


Figure 1 Damaged Female Contact

I have often said that all you have to do to make a higher frequency connector is divide by two. This has worked well for many years, (Does Moore's law apply to connectors?) but making connectors of smaller than 0.8 mm size begins to have problems.

#### 4 Tools and Tolerances

If you are going to divide the part size by two, it is only reasonable to divide the tolerances by two. Also, the thickness of plating starts to take up a larger percentage of the total size of the part. Tools begin to get very tiny. Fortunately, there are very tiny drills available, down to 0.05 mm. Drills are required to make the holes in the support beads. You also need a saw to cut the slots in the female center conductor, and it has to cut deep enough to make long enough slots.

Figure 1 provides a good example of the problem. A 0.025 mm saw would do the job nicely, but unfortunately only 0.05 mm saw blades are available. However, even if a 0.025 mm saw was available, the slotted female contact would be very fragile. If a thin walled design was used, the insertion force would be very slight, but so also would be the contact pressure. If a thick walled design were used, the contact pressure would be greater but the finger flexibility would be slight.

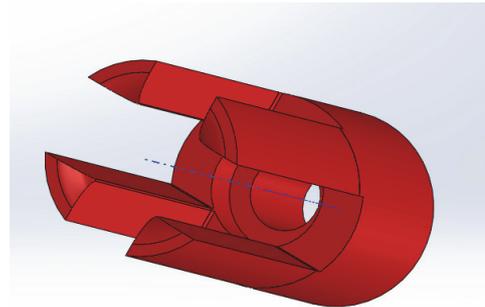


Figure 2 0.4 mm center conductor with 0.05 mm slots.  
The center conductor size is 0.17 mm

A slotted female contact seemed out of the question. An out-of-the-box comment supplied the answer. "Don't slot the female, slot the male pin." What would that look like? We could make the female wall very thin, it has no slots. Therefore, the male pin could be large, closer to the main center conductor size.

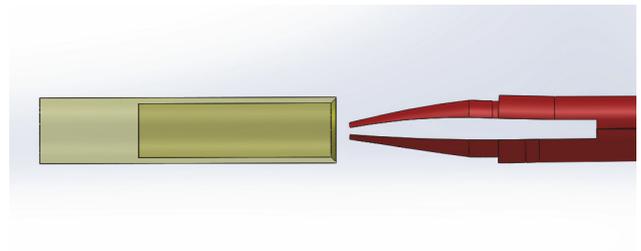


Figure 3 THE LOBSTER CLAW

This pin could be made with a 0.05 mm slot, as shown in figure 3. Also, since the slotted portion is contained inside the unslotted hole, it would be quite robust with no tendency to spread out like the standard slotted female contact.

The impedance of the pin gap is 65 ohms, much lower than the lower frequency designs. This makes the connector less sensitive to pin depth reflections, evident by figure 4.

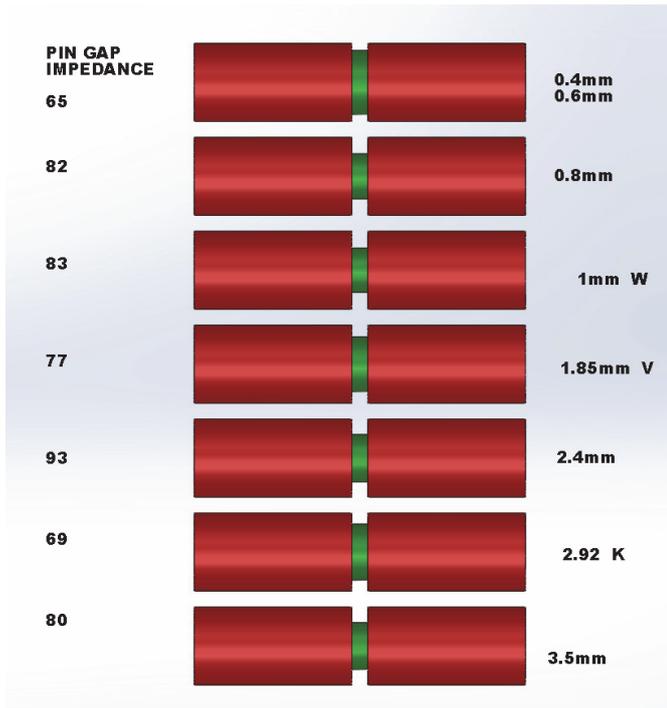


Figure 4 Pin Gap Impedance

The chart below gives information on existing connectors and those in design. The current plan is to use the new slotted male design “The lobster claw” in the 0.6 mm and 0.4 mm connector designs.

CONNECTOR	AIR FRE- QUENCY	MAX RATED	PIN GAP	SIZE OF CENTER	SIZE OF
# * compatible connectors	CUTOFF GHz $F_{co}$	FREQUENCY GHz	IMPEDANCE	CONDUCTOR mm	BEAD mm
TYPE N	19.4	18	-	3.04	-
SMA #	NA	18	NA	1.27	NA
3.5 mm #	38.8	33	80	1.52	3.6
2.92 mm K #	46	40	69	1.27	3.05
2.4 mm *	56	50	93	1.042	2.1
1.85 mm V *	73	70	77	0.803	1.5
1 mm W	133	110	83	0.434	1.15
0.8 mm	166	TBD***	82	0.347	0.559
0.6 mm	222	TBD***	65	0.26	0.406
0.4 mm	332	TBD***	63	0.174	0.28

Notice that the center conductor of the 0.4 mm connector is about 1/20 the size of the N connector center conductor.

\*\*\*These designs are under development. The theoretical number is the same as the  $F_{co}$ , but has not been tested.

## 5 Connector Sizes and Identification

Traditionally, connectors moving up in frequency became smaller but how small is too small? We decided to keep the

outer parts of these connectors the same size as the 1 mm connector. If it was smaller, the connectors would be difficult to get fingers around. They are designed so that they cannot be destructively connected. In other words, a male connector of a larger size cannot be mated with a female connector of a smaller size.

The connectors are identified by a Laser engraved number that shows the connector size, as shown in Figure 5. The number is also etched on the coupling nuts.

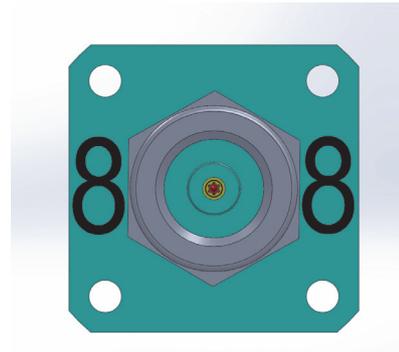


Figure 5 Connector Identification by Number

The connectors above the 1 mm connector have a maximum rated frequency that is the same as the  $F_{co}$ , the air dielectric cutoff frequency. The lower frequency connectors have support beads that are larger than the air outer conductor size. This means that they have an  $F_{co}$  that is substantially lower than the air  $F_{co}$ . The cutoff frequency is inversely proportional to the square root of the dielectric constant of the material between the center conductor and the outer conductor. The new designs have support beads that are substantially smaller than the size of the air outer conductor. They are designed to have an  $F_{co}$  that is the same frequency as the air  $F_{co}$ . They have also become very small, as shown in Figure 6.

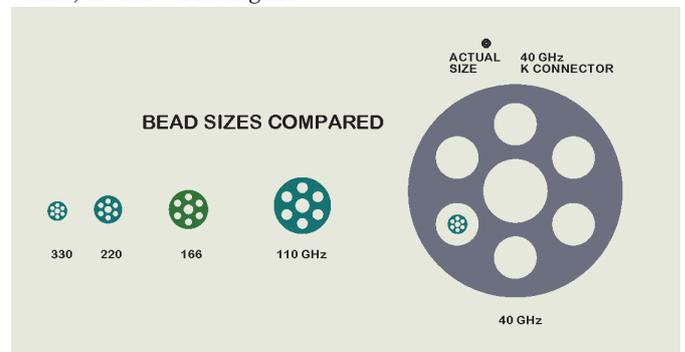


Figure 6 The progression of sizes of the beads since the K connector

## 6 Captivating Small Beads

A major problem with making the bead size smaller than the air dielectric outer conductor size is how to captivate the bead. Just making a hole in the outer conductor that contains the bead presents two problems. First, boring such a small hole deep down in the outer conductor is difficult, and the bead is only held mechanically in one direction. The old designs in which the bead is larger than the air outer conductor allowed a mechanical capture in both directions. The solution was a sleeve (figure 7) that contained the bead and had an outer diameter about the same size as the air outer conductor. The sleeves have very thin lips on both ends and are swaged to hold the bead in place. The assembly can then be soldered in place, thanks to available high-temperature plastics.

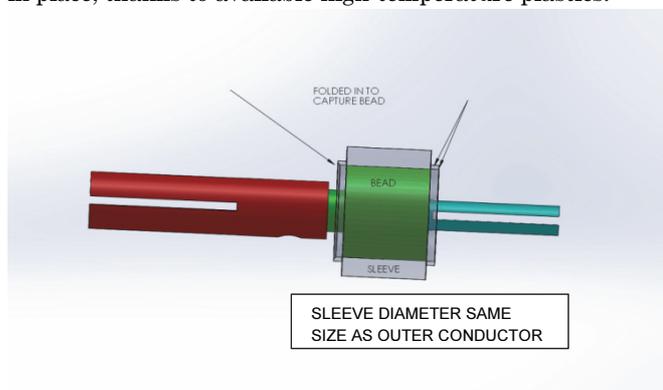


Figure 7 Swaged Bead Sleeve

## 7 Assembly Details

Figure 8 shows the assembly of these higher frequency connectors. The figure is a 0.8 mm connector and does not have the lobster claw design. The backside of the connector is a CPW design similar to a wafer probe. The center conductor is common, but the outer conductor end cap can be configured to accommodate different CPW designs. The figure also shows how the bead sleeve is soldered into the outer conductor.

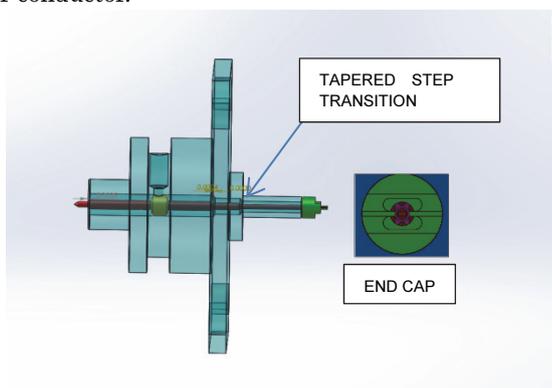


Figure 8 Connector Details

Boring of the outer conductor hole presented a problem: it was impossible for a small boring bar to go as deep as required. We used a drill and left the transition between outer conductor sizes as a taper. Modeling on HFSS showed that this design was less sensitive to tolerance than the flat bottom created by a boring bar. Then we tapered the center conductor and found it even less sensitive to tolerance. It is not often that a design simplification gives better RF results.

## 8 Connector Backside Design

The backside interface is where the connector mates with the circuit inside of the component. It is a critical interface and gets more critical and much smaller as frequencies increase. Substrate traces as small as 0.1 mm or smaller must be connected reliably and with precision for good performance. CPW is the preferred substrate format at the higher frequencies. In fact, most of the testing done by high-frequency VNAs is done with wafer probes on CPW substrates. When these substrates are put into a component or system, connectors become involved. The backside of these connectors is a wafer probe built into the connector.

A feature of the design is the ability to adjust the position of the back side CPW interface. Correct positioning of the connector to the substrate is critical to performance. Figure 9 shows the method. Holes are located at the edges of the flange, centered on the flange edge. A tapered pin allows the flange to be moved up and down, and left and right. When the connector is properly connected to the CPW substrate, the flange screws are tightened. Figure 10 is a view of the connector back side. A support bead holds the CPW center conductor in place.

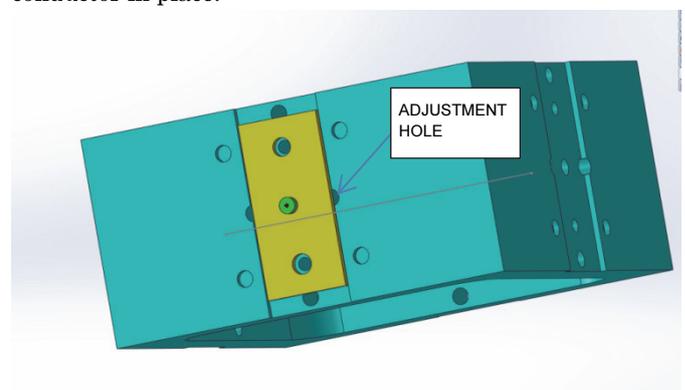


Figure 9 Adjustable Backside Design Showing Adjustment Holes

## 9 Selectable Connector Design

Figure 11 shows a design that permits different front-end connectors to be connected to the housing, allowing wafer probes with different connectors to be attached to a common broadband VNA module. This would include 1 mm, 0.8 mm, both male and female, or a special wafer probe. The adjustment concept applies to single design connectors, as well.

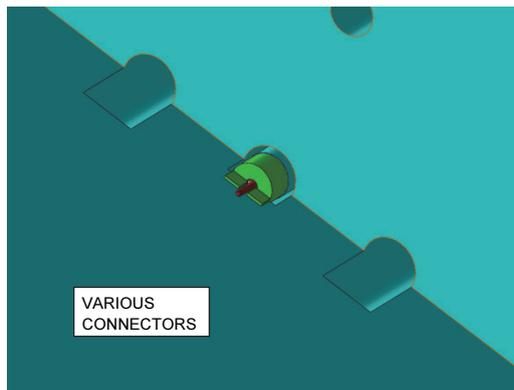


Figure 10 Adjustable CPW Backside Connection

The green cap is designed for the specific CPW substrate to be used. The other connector parts are common.

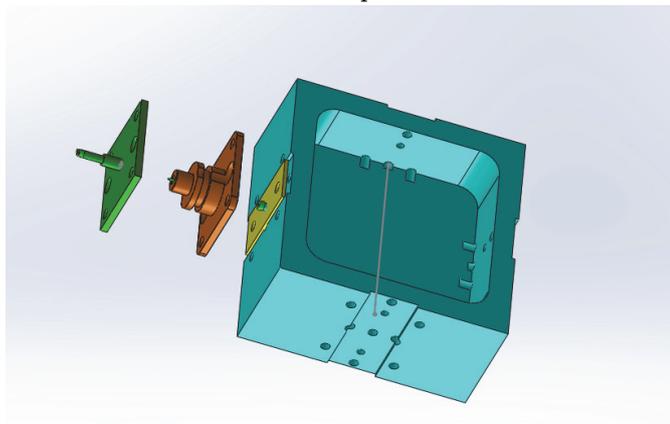


Figure 11 Different front-end connectors attached to a housing

## 10 Importance of These Connections

It is not likely that these connectors will be used in the traditional manner. That is, a series of components will be designed and connected together with these connectors to make a system. It is not even likely that they will be used as test ports of a VNA to measure components with those type connectors. It is most likely they will be used to connect a high-frequency VNA module to a wafer probe, which in turn will be used to measure CPW substrates over a very large

band width. The current Anritsu VectorStar™ VNA covers 70 kHz to 125 GHz in one sweep. Anritsu has also shown a technology demonstration of a 70 kHz to 145 GHz VectorStar system featuring 0.8 mm connectors. Waveguide modules extend that coverage up to 1.1 THz. These “lobster-claw” connectors are intended to extend the broadband coverage from 70 kHz to 332 GHz. Figure 12 shows the broadband Anritsu VectorStar, directly connected to wafer probes measuring a broadband substrate.

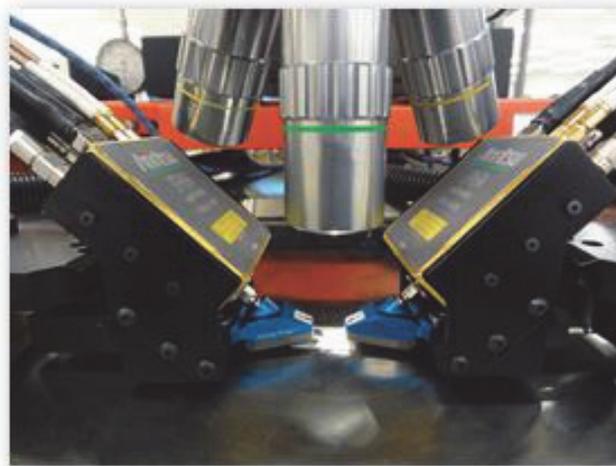


Figure 12 70 kHz to 125 GHz VectorStar Broadband System

## 11 Conclusion

Will the 0.4 mm connector be the last of a long string of higher and higher frequency connectors?

In 1983, a 40 GHz coax connector was considered unlikely. Today, we are designing a connector that reaches almost 10 times higher in frequency. The circuit designers seem to be able to create devices that operate at ever higher frequencies, and some kind of connection is always needed to make these devices useful. Let's not limit our imagination.

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