Connector and Termination Construction above 50 GHz

A summary of the design challenges presented by mm-wave interconnects

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This paper discusses the design and construction of connections operating above 50 GHz. Available connectors and their design principles will be discussed, as well as the pros and cons of various backside interfaces. Details of orthogonal connections that work to at least 90 GHz and terminations in coax, microstrip and CPW, operating to at least 110 GHz will be shown and their data presented. Broadband interconnects will also be examined to meet the demanding requirements of 40-gigabit optical systems.

Purpose of an ideal connector

The ideal connector is a lossless, reflectionless port into a circuit. The front side allows connection to another connector or a test instrument. The backside connects to the circuit. Backside design is the most critical feature of connector use and the one over which the user has the most control.

An important feature of connectors is that they must get smaller as frequency gets higher, i.e., if the frequency is doubled, the connector size must be cut in half. Mechanical tolerances must also decrease by half. Only the microwave portions of the connector must diminish with increasing frequency, the outside and connection parts can remain large.

Desired features of a practical connector:

- Low total cost.
- Sum of the material cost plus the assembly cost.
- Coverage of the desired frequency band
- In general, the higher the frequency, the smaller and more expensive the connector parts and assembly labor.
- Low loss, including structure loss and reflection loss. At high frequencies, reflection loss can be the greater value. A 10 dB return loss equals a 0.5 dB insertion loss.
- Meets environmental requirements.
- Hermiticity, thermal expansion, outgassing and voltage breakdown.
- Available standards. The SMA connector has no available standards. This is not problematic at low frequencies, but can cause problems at higher frequencies.

Table 1 lists the available connector types that work above 40 GHz and are supported by standards. Other types of connectors, such as GPO, are not supported by standards.

The upper frequency limit is defined as the frequency at which another propagation mode is possible in the coax case the TE_{11} mode. This usually occurs first in the support bead.

Front side interface [1]

The front side interface defines the connector. It is of little concern to the user except in regard to frequency range and compatibility of connection devices. The pin depth of the center conductor relative to the outer conductor is an

Connector type (outer conductor size)	Upper frequency limit	Center conductor size
2.4 mm	50 GHz	1.042 mm (0.041)
1.85 mm V connector	67 GHz	0.803 mm (0.0316)
1 mm W1 connector	110 GHz	0.434 mm (0.017)

▲ **Table 1. High frequency connector sizes.**

important parameter; a positive pin depth can destroy the connector. More details of connector interfaces can be found in the references.

Glass beads

Glass beads provide package hermaticity and mechanical isolation between the fragile backside connection and the exterior world. The center conductor pin is usually small enough to allow its overlap connection to a standard 10 mil alumina substrate. A typical glass bead assembly is shown in Figure 2.

Backside interface [2]

Backside interface is the most critical feature of connector use and the one over which the user has the most control. Most poor results and failures occur at the backside interface. The problem is how to connect to a very small (assuming high frequencies) microstrip or CPW transmission line in a way that will satisfy all of the RF and environmental requirements.

First we have to decide how to connect the coax pin to the substrate. Figure 3 shows the end view of two traditional methods and a side view of another possibility. The pin overlap design is the most traditional but has no flexibility in the joint and has a capacitive mismatch. It also requires a high skill solder joint. The wraparound is very inductive at higher frequencies.

The other method requires that gold ribbon be prebonded to the coax pin. However, the final connection is an easy gold ribbon bond which is very good from both an RF and an environmental position. It also allows connection to a very small substrate trace.

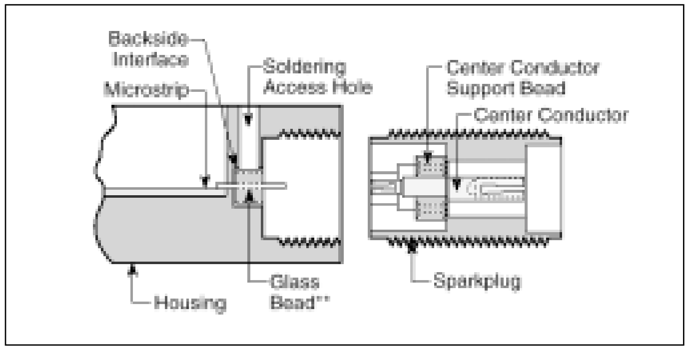
In all cases, this is the most critical and sensitive area in the connection system. Ground paths must be kept very short. This means that substrates on carriers must not be used if they allow a longer ground path.

Here are guidelines for dealing with high frequency interconnects:

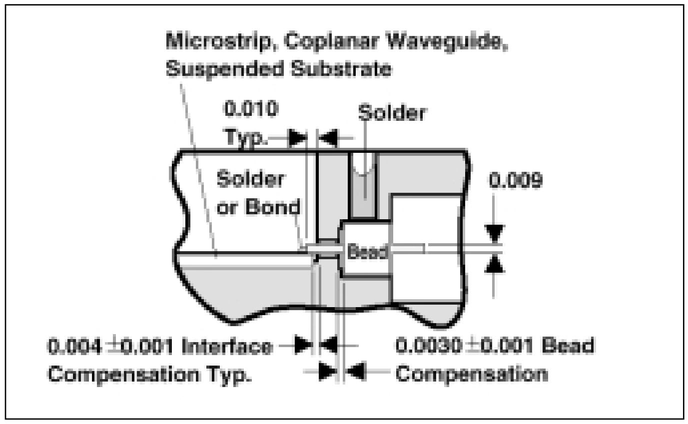
- Keep the coax entry size as small as possible and have an air dielectric.
- Compensate every change in transmission line size.
- Aside from compensation steps, all transmission lines should be 50 ohms.
- Keep bond connections very short. A 10 mil bond wire gives 10 dB return loss at 90 GHz.
- Provide for stress relief at the coax-substrate interface.
- Keep ground paths short. Beware of carriers. The ideal ground path length is zero.
- Keep everything as simple as possible.

Here are guidelines for dealing with substrates:

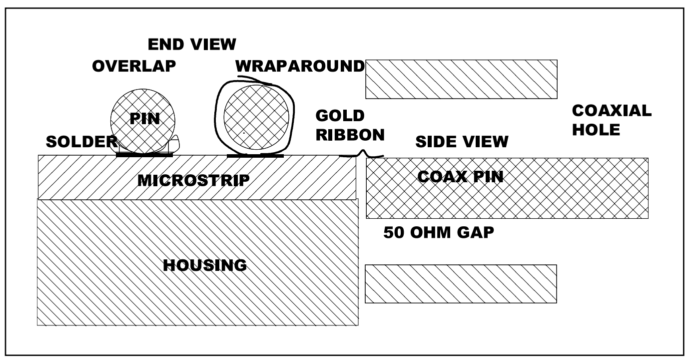
- 10 mil microstrip will work above 70 GHz, but using 7.5 mil will cause fewer problems.
- 5 mil Teflon works very well up to 110 GHz.
- 5 mil Quartz is very low loss to 110 GHz and has a nice wide trace.
- CPW must be very small to work well. Thin substrates are best.



▲ **Figure 1. Typical connector system.**



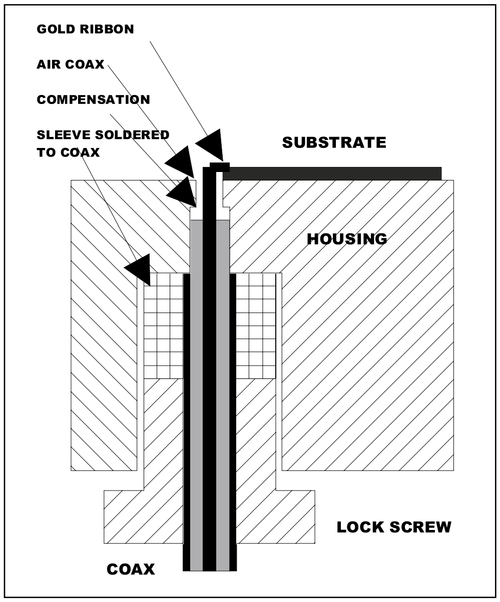
▲ **Figure 2. Glass beads.**



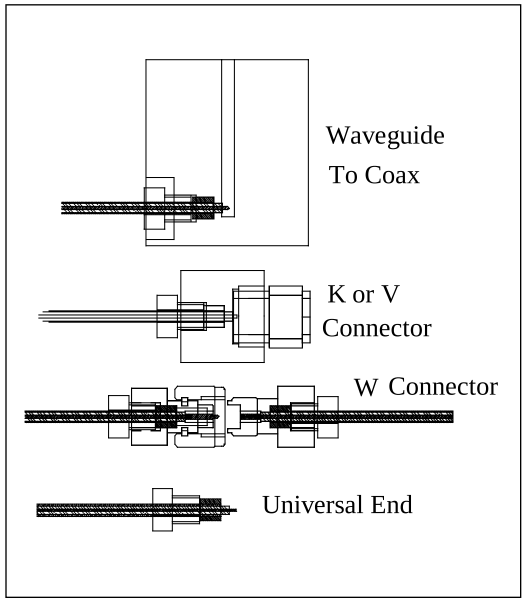
▲ **Figure 3. Coax pin to microstrip connections.**

Orthogonal connections

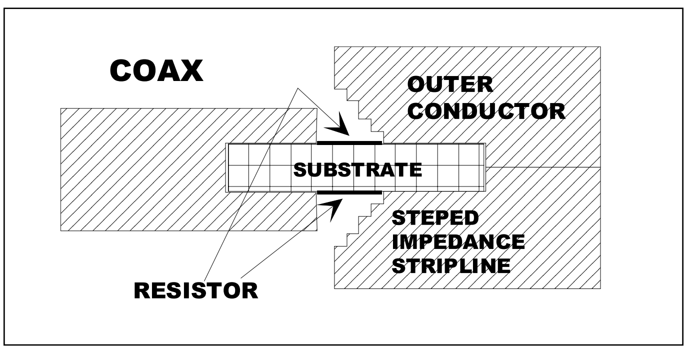
Orthogonal connections are particularly useful when using MMICs in high frequency subsystems, allowing connections to be made anywhere in the assembly as opposed to only the perimeter when using standard connections. The examples shown use UT47 coax cable, which can support frequencies up to 110 GHz.



▲ **Figure 4. Orthogonal connection.**



▲ **Figure 5. Universal connection system.**



▲ **Figure 6. Planar resistor coaxial termination.**

The assembly shown in Figure 4 can give return losses in the order of 20 dB to 60 GHz and 16 dB to 90 GHz. The design can be modified for an orthogonal feed through and can also be used as a standard axial connection. The other end of the coax can be adapted to waveguide, a 1 mm connector or other type of coax connector.

An alternative connection system

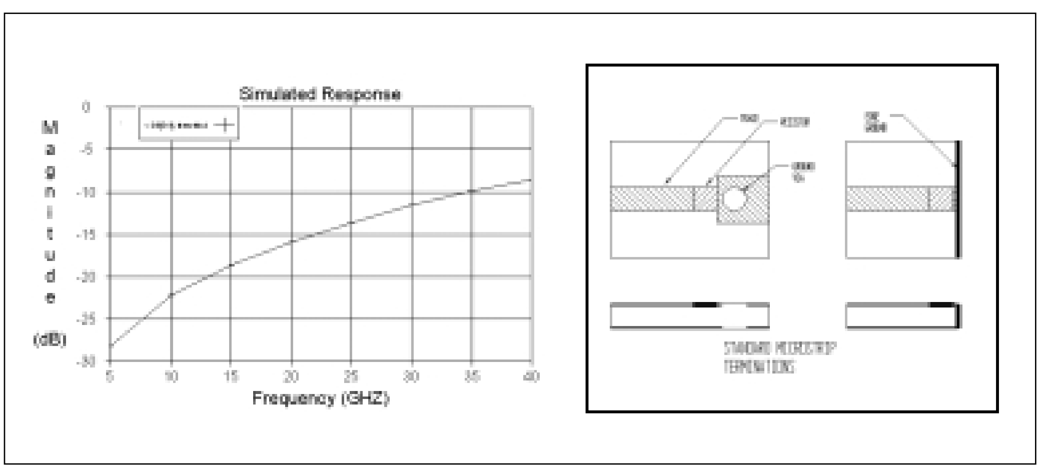
One of the problems with building components at higher frequencies is that the connectors on the component do not always match the available test equipment. This is the case, for instance, if the test equipment is waveguide and the component is coax. One way to solve this problem is to use coax cable as the bridge. UT47 coax with a "universal end" is the ideal size: it is thin with a small center conductor and can support frequencies up to 110 GHz. The universal end is the same as the one shown in the orthogonal connection. Waveguide to coax transitions using this system can have a return loss of greater than 20 dB over a full waveguide band.

Terminations

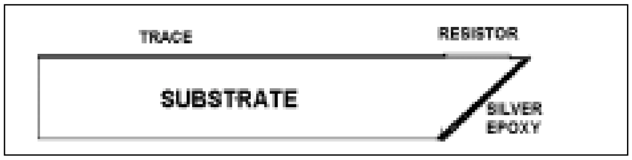
The ideal termination is a reflectionless transition from the transmission line impedance to ground. This is usually is realized as a resistor in the value of the transmission line impedance and surrounded by the proper topology. The most commonly used terminations are the coax variety used to terminate external ports. Terminations used internally in subsystems are usually in microstrip or CPW topologies. High frequency CPW terminations are easy to make. Microstrip terminations usually become increasingly reflective above 20 GHz.

Coaxial terminations

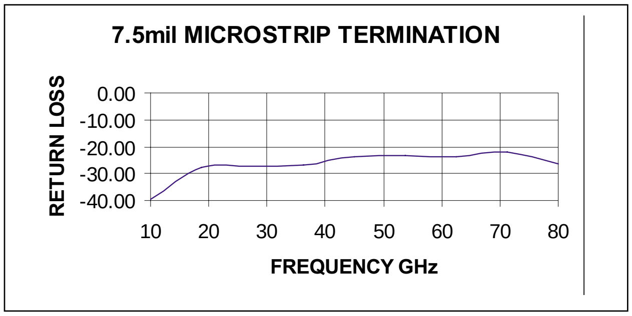
Traditional coax terminations use rod resistors that are about the same size as the coax center conductor of the connector associated with them. At higher frequencies, as the center conductors become smaller, rod resistors become difficult to fabricate and are fragile. An alternative design uses planar substrates and a semi-stripline, semi-coax topology. The



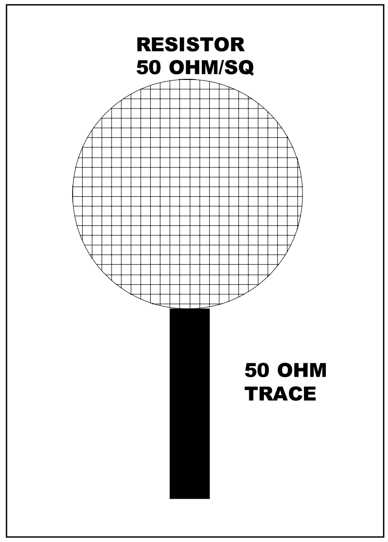
▲ **Figure 7. Microstrip terminations.**



▲ **Figure 8. Improved microstrip termination.**



▲ **Figure 9. Improved microstrip termination performance.**



▲ **Figure 10. Improved microstrip termination performance.**

alumina substrate is easy to fabricate and also serves as a support for the center conductor, eliminating the support bead and its associated mismatch. Terminations using this design can have return losses of greater that 40 dB to 40 GHz and 35 dB to 60 GHz. The design has been used to 110 GHz.

Microstrip terminations

Standard microstrip terminations give poor results at higher frequencies, as shown in Figure 7. Designs using open circuit stubs work well for narrow bands even at higher frequencies

A design that works well at high frequencies is shown in Figure 8. The tapered ground plane provides the correct topology for a broad band termination.

With the proper shaping of the substrate, the return loss of this termination is greater than 25 dB to 40 GHz and 20 dB to 80 GHz. The best substrate thickness for use above 70 GHz is 7.5 mil alumina or 5 mil Teflon.

CPW terminations

CPW terminations can work well to high frequencies and are easy to fabricate. CPW substrates are not easy to design at high frequencies as they tend to mode jump. The best performance is achieved using thin alumina substrates with another dielectric and some lossy material attached to the bottom side of the alumina.

Dot terminations

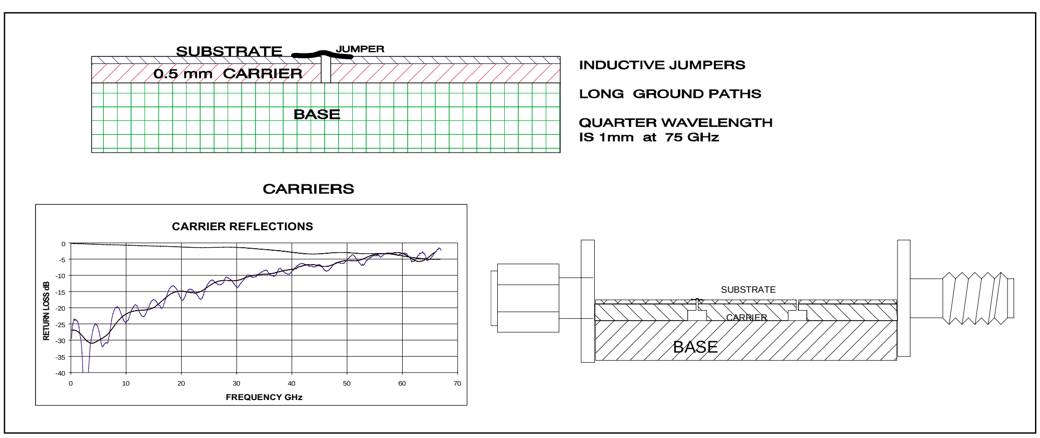
Dot terminations are high frequency, high return loss microstrip terminations that do not require a ground but have a low frequency limit. They consist of an input trace and a circle of resistance material. The resistance is 50 ohms per square.

The size of the dot determines the low frequency limit of the termination. Dot diameters up to 15 times the trace width will perform to the upper limit of the microstrip. Minimum diameters of the dot should be at least three times the trace width. A dot termination can give 25 dB return loss from 8 to 110 GHz.

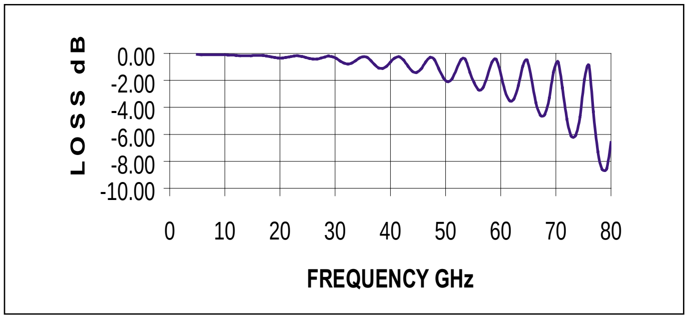
Broadband interconnects

The 40 gigabit optical modulator will dramatically increase the need for broadband high frequency interconnects. DC to 80 GHz connectors and interconnects with low loss and low reflections will be in great demand. Substrates mounted on carriers of standard design will not meet these requirements. This section discusses designs that will meet these interconnect requirements.

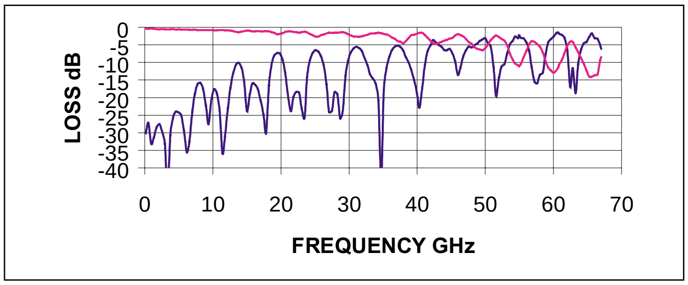
Carriers are a very convenient method of mounting multiple devices. They can be processed outside of the housing and can be replaced without destroying the entire subsystem contained within the housing. Carriers can be made of material that matches the expansion coefficient of the substrates, thus allowing the housing to be made of a more common material. They also provide flat surfaces, which allow easy bonding compared to the



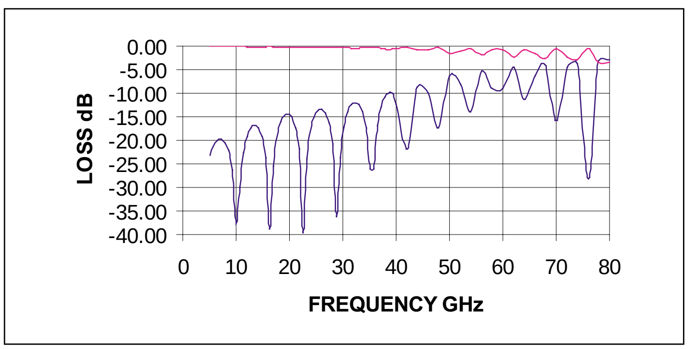
▲ **Figure 11. Standard carriers.**



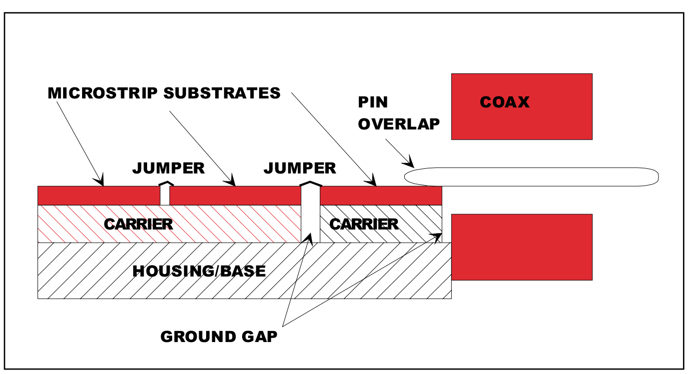
▲ **Graph 1. Insertion loss of a microstrip through line mounted on a 0.5 mm carrier. A long ground path formed by the carrier causes the problem. The results are similar whether connecting to another substrate or to a coax connector.**



▲ **Graph 2. Measured efffects of the carrier gap.**



▲ **Graph 3. Simulated effects of the carrier gap.**



▲ **Figure 12. Ground gaps.**

housing cavity when devices are mounted directly into housing. However, the carrier introduces a long ground path, which seriously degrades high frequency performance.

Figure 11 shows the details of a standard carrier assembly and the performance of a single gap. The two reflection traces are standard frequency domain and frequency gated by time. Notice the good agreement. Time domain is a very useful tool for measuring this type of mismatch.

The carrier gap can be located internally in the housing or at a connector port. Both gaps cause equivalent problems. Graphs 2 and 3 show both simulated and measured effects of a carrier. In general, the measured data seem to be worse than the simulated data.

Figure 12 also shows both type of gaps in addition to the gap formed by two substrates mounted on the carrier. This gap (Graph 4) also gives a significant mismatch at higher frequencies. The standard pin overlap causes a sizable mismatch at higher frequencies. All of these design features must be refined in order to obtain good high frequency performance.

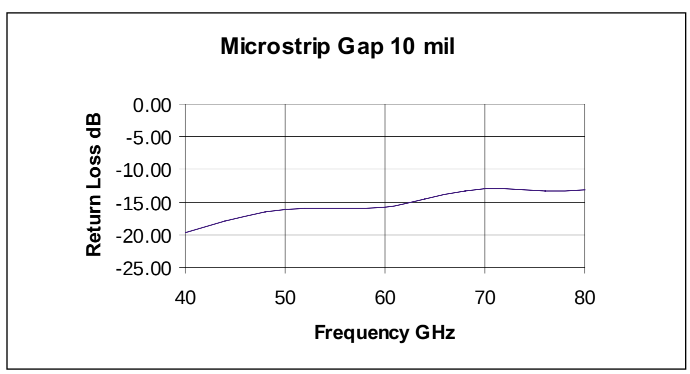
Solutions

Narrowband designs can vary the ground path solution so that the mismatches occur outside of the narrow frequency band. Broad band solutions, however, require that long ground paths be eliminated.

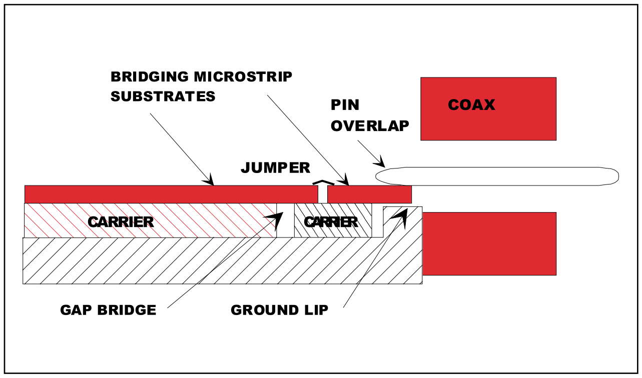
Carrier to housing

The easiest solution is to bridge the gap with a microstrip line, as shown in Figure 13. The line can be preattached to the carrier and connected to the housing or the next carrier by various methods including screws, conductive epoxy, solder or conductive rubber. Conductive rubber can cause problems at high frequencies. The bridge line can also be assembled into the system after the carriers are mounted.

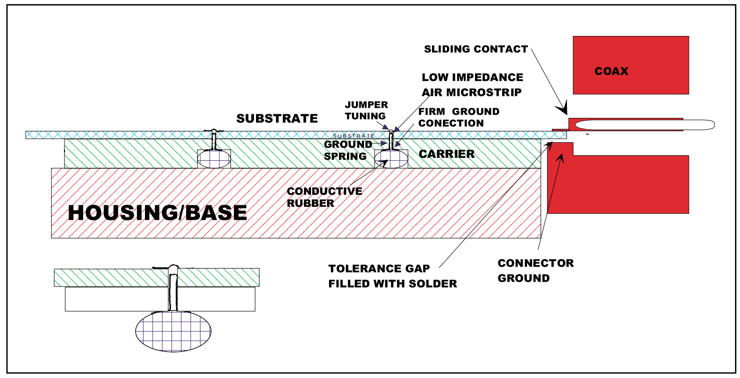
Another method, which is patented, is shown in Figure 14. A flexible ribbon spring, held in place by conductive rubber, fills the gap between carriers and with the trace jumper ribbon, forms a 50-ohm transmission line. This system is flexible, requires no ground solder-



▲ **Graph 4. Carrier gap as shown in Figure 12.**



▲ **Figure 13. Bridging substrates.**



▲ **Figure 14. Alternative designs.**

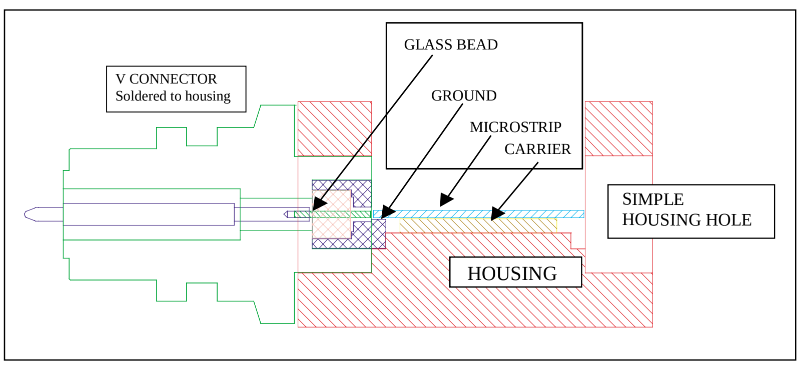
ing and gives very good performance up to 90 GHz.

Carrier to connector

The best solution to this connection is to have a ground lip at the coax interface and a microstrip substrate cantilevered from the carrier and connected to the ground lip. This is shown in Figures 13 and 14. The ground lip can be part of the housing or incorporates into the connector as a newly developed connector. The connector also contains a glass support bead and the required compensation steps. The connector therefore solves the problems of the hermetic seal and ground. The connector is shown in Figure 15. The connector eliminates the hassle of soldering a glass bead into the housing. A sliding contact is used to connect the coax center conductor to the microstrip trace. This allows a flexible connection and eliminates the capacitive mismatch of the pin overlap design. The sliding contact is bonded to the microstrip trace.

Conclusion

Carriers can be used at high frequencies, but care must be taken to eliminate long ground paths. Ground gaps can be bridged using cantilivered substrates. Gaps between substrates cause a significant mismatch above 40 GHz. ■



▲ **Figure 15. Connector for substrates on carriers.**

References

1. "The Connector Interface," *Microwave Journal*, March 1996.
2. "Backside Interface," *Microwave Journal*, March 1997.

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