White Paper

Anritsu envision : ensure

Scaling the Test Equipment Size to Match Millimeter Wave Test Needs

Introduction

Millimeter wave frequencies were traditionally dedicated to military applications with some commercial use for point to point microwave links. Sub-octave bandwidth waveguide was the preferred transmission line as millimeter wave capable coax cable and connectors were not available.

All that has changed in the past decade with technology improvements in semiconductors, components, cable, and connectors. It is now possible to use millimeter wave frequencies for commercial / consumer electronics.

This white paper will discuss issues of transferring millimeter wave signals through coax cable within a test system and the benefits of improved measurement accuracy by reducing the size of the test equipment and using fewer interconnections.

Markets

There are a number of market segments preparing for enhanced use of millimeter wave frequencies, including:

- 5G
- Automotive radar
- 60 GHz WiFi (WiGig or 802.11ad)
- Point to point communications links
- Security and defense

5G

The demand for mobile data spectrum keeps growing with the increasing number of smart phone users and the fact users are finding new applications that require very high data rates. Recognizing this, in July 2016, the US FCC opened up nearly 11 GHz of spectrum in the millimeter wave frequency range, Specifically, 27.5 to 28.35 GHz, 37 to 38.6 GHz. 38.6 to 40 GHz, and 64 to 71 GHz. 5G is still evolving but it appears initial use will be for last mile residential service. Longer term, mobile devices and base stations will have beam formed antennas to compensate for the higher path losses at millimeter wave frequencies so millimeter wave applications will be more and more common.

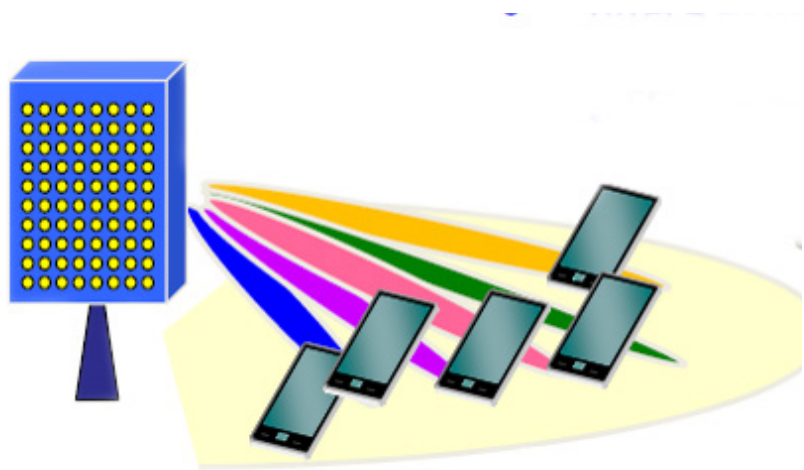


Figure 1. Millimeter wave beam forming

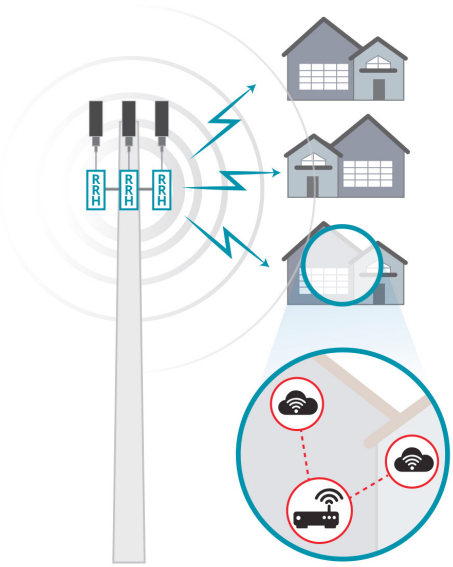


Figure 2. 28 GHz Fixed Wireless Service

Automotive Radar

A cornerstone in the ability to achieve self-driving vehicles is the ability to detect and avoid obstacles. Millimeter wave radar technology is advancing rapidly to support the array of sensors needed. Automotive Radar Frequency Bands are 24, 77, and 79 GHz.

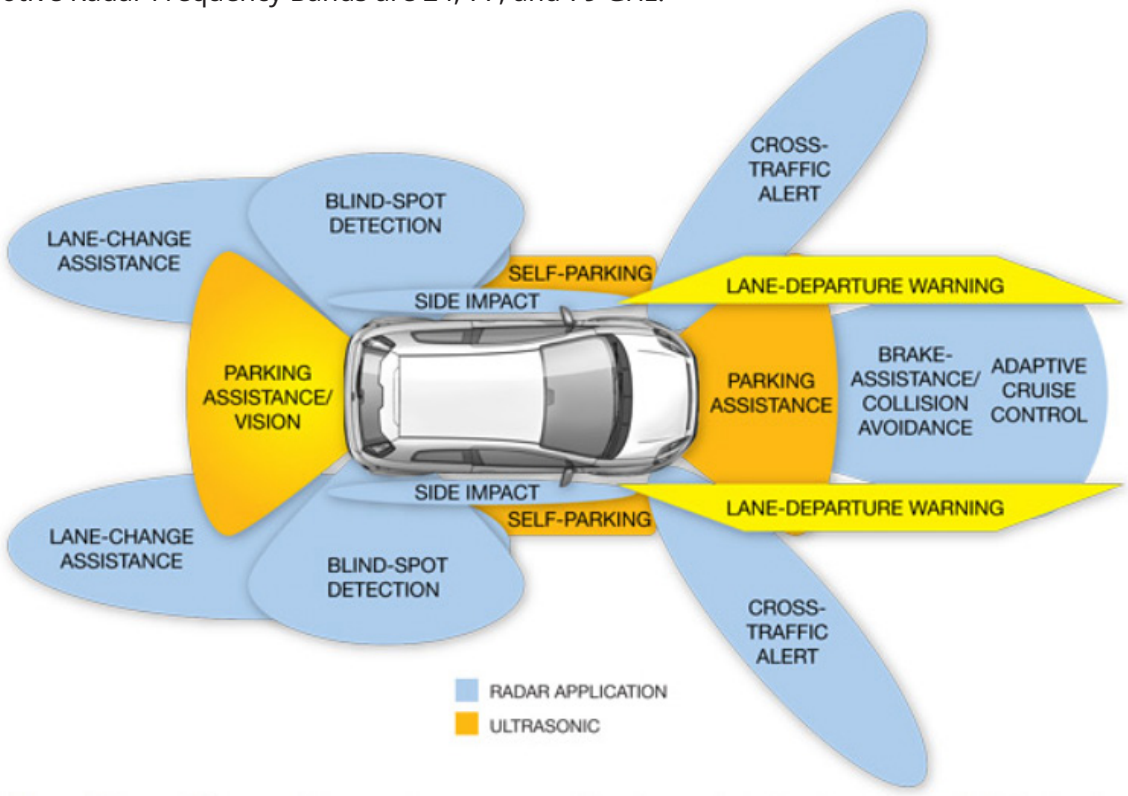


Figure 3. Millimeter radar is a cornerstone technology in achieving self-driving vehicles. Source EDN magazine

60 GHz WiFi (WiGig)

Consumer WiFi applications have expanded beyond what is available from 802.11ac devices. The designation 802.11ad is an extension of the IEEE's popular 802.11 family of wireless local-area network (LAN) standards. The 58 to 64 GHz spectrum has long been available for unlicensed services, and was recently expanded up to 71 GHz (FCC Part 15). Examples of applications are high-speed wireless multimedia services, including uncompressed high-definition TV (HDTV) and instantaneous music and image data transmissions.

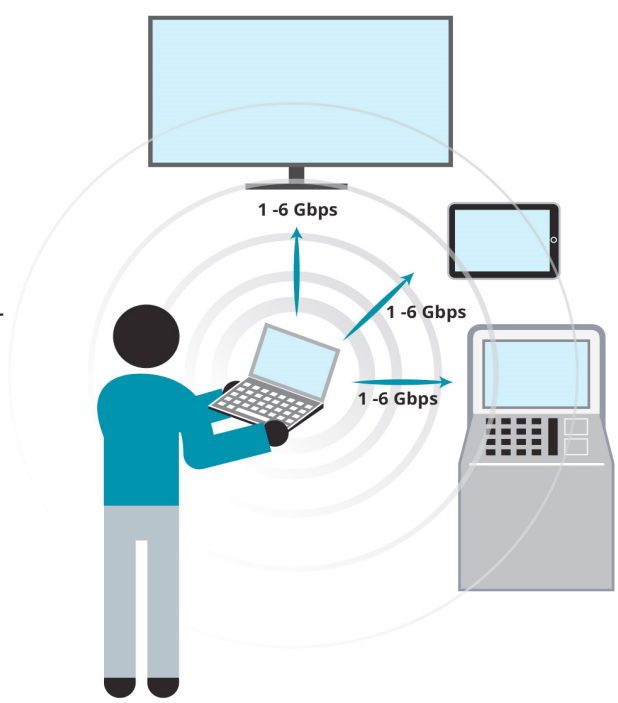


Figure 4. Millimeter Multi media applications

Point to point Links

Cellular base station sites are connected to the main switching office by backhaul. In telecommunications, both fiber and microwave backhaul are common. While fiber probably dominates the backhaul space because of its high-speed capacity, microwave and millimeter-wave backhaul are becoming more widespread.

Millimeter-wave backhaul is particularly attractive for the new smaller base stations (picocells, microcells, and metro cells). Millimeter-wave links were widespread in supporting LTE 4G cellular services in high-density areas.

The typical microwave backhaul bands are 6, 11, 18, 23, and 38 GHz. Unlicensed 60-GHz backhaul equipment is inexpensive but offers limited range due to its high oxygen absorption levels. Some 80-GHz backhaul units are also available. The most popular millimeter band has been E-band, which covers 71 to 76 GHz, 81 to 86 GHz, and 92 to 95 GHz.

Figure 5. BridgeWave Communications 60 GHz unlicensed point to point radios links to MMW radios.

Security and Defense Applications

Advanced imaging technology by using millimeter wave screens allows detection for both metallic and nonmetallic threats, including weapons and explosives, without any physical contact. Detection of these items is allowed even when they are concealed under the person's clothes. These are now common in US airports.

Radar and satellite communication are the main military applications for millimeter wave systems.

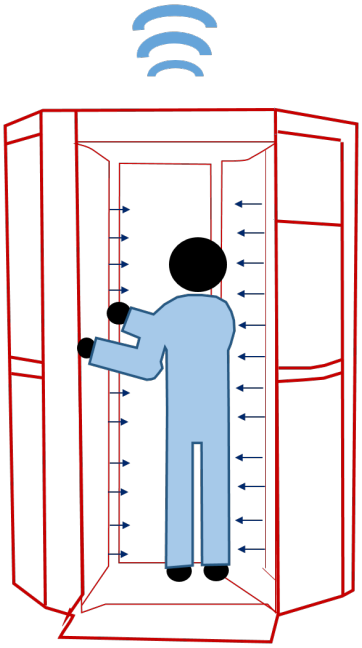


Figure 6. Millimeter wave airport scanner

Challenges of the Millimeter Wave Market

The advancement of millimeter wave technology is opening the door for numerous new applications, but higher frequency transmission comes with its own challenges, like higher propagation loss and issues with measurement repeatability.

Propagation loss

The loss of signals propagating at RF and microwave frequencies is proportional to the frequency and distance.

Loss (d) = $(4*pi*d*f /c)^2$.

Additionally, at millimeter wave frequencies, there is increased attenuation from components of the earth atmosphere. This effect is particularly pronounced at 60 GHz from oxygen absorbtion. Regulators have chosen the 60 GHz freqency range for unlicensed use in order to minimize co-channel interfernece, but due to the additional loss this presents a challenge to testing at these frequences as the test equipment needs higher power signals or improved sensitivity for measurements.

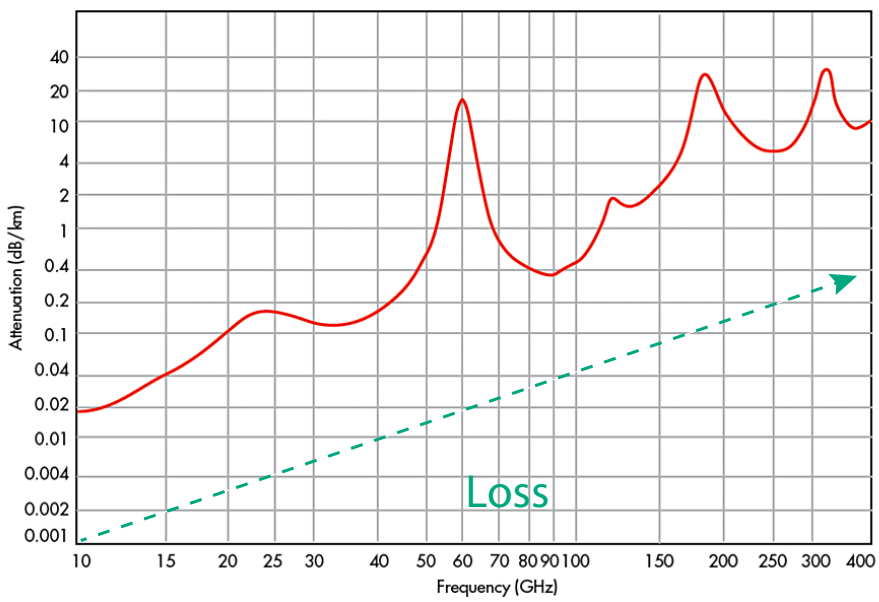


Figure 7. Propagation loss versus frequency

Connection repeatability

At 70 GHz the diameter of the coax center connector is just 1/2 mm (20 thousandths of an inch). A center pin diameter is also just 20 thousandths of an inch. Scratches and dust particles on the connector interface are more damaging to the impedance match at millimeter wave frequencies, and connector dimensions are approaching the limits of machine shops. As a result, millimeter wave connections require significantly more care. Connector interfaces should be inspected with a microscope and cleaned before each use. Connectors should be tightened with a torque wrench to the proper specification. (8 in-lbs max).

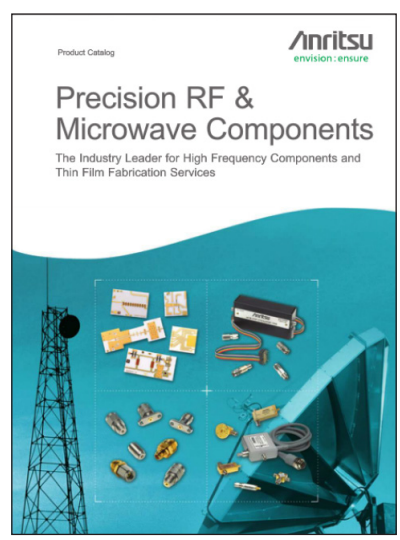


Figure 8. Anritsu Microwave Components catalog available at:

https://dl.cdn-anritsu.com/en-us/test-measurement/ohs/Components-Catalog-2015/index.html

Field Testing Issues

Spectrum analyzer measurements are often used to measure path loss of a proposed wireless link. A test source with antenna and spectrum analyzer with antenna are placed at realistic locations. The antenna locations are often elevated, see Figure 9.

At millimeter wave frequencies long cable runs can result in in significant loss. At lower frequencies, a bench instrument on a cart with the antenna elevated on a pole fed with coax cable would be used. But at 70 GHz a 3 meter cable would have over 20 dB loss, significantly reducing the measurement range and accuracy. Also, the loss and phase characteristics of cables vary with temperature adding to the uncertainty. A portable spectrum analyzer, like the new Anritsu MS2760A, can be directly connected to the antenna and elevated away from the control PC with a USB extender cable.

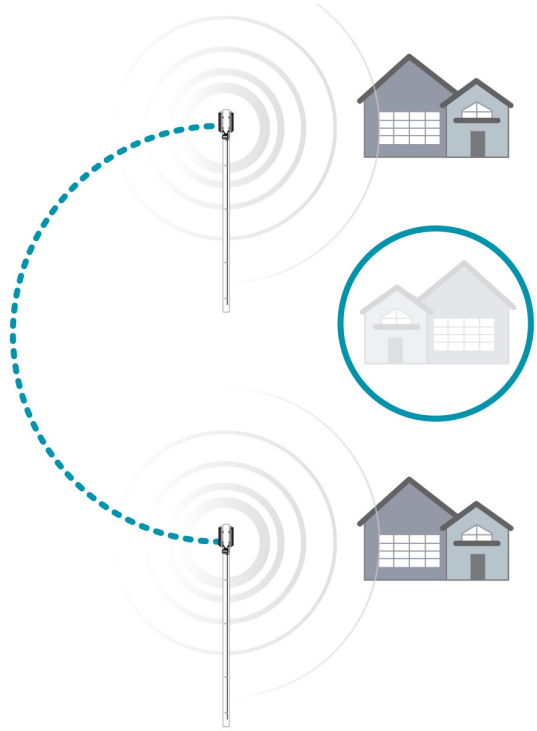
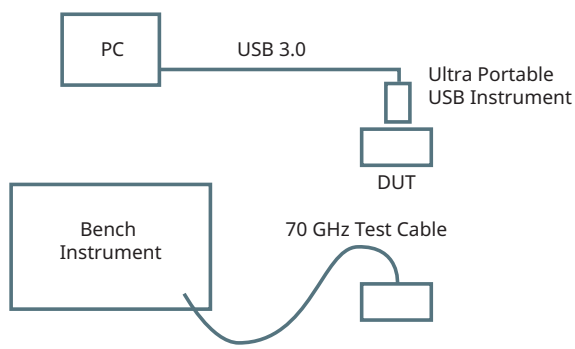
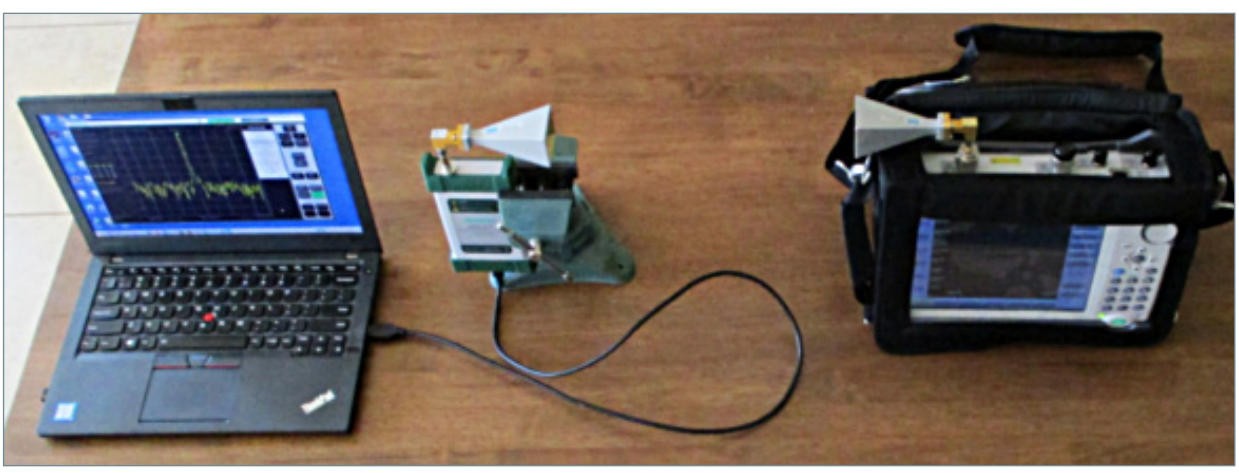


Figure 9. Example millimeter wave last mile testing.

Figure 11 shows an example setup at 28 GHz with an Anritsu S820 battery powered portable source giving 0 dBm directly to an antenna. The MS2760A is also directly connected to its antenna.



10. Direct connection to a device under test versus a cable connection.

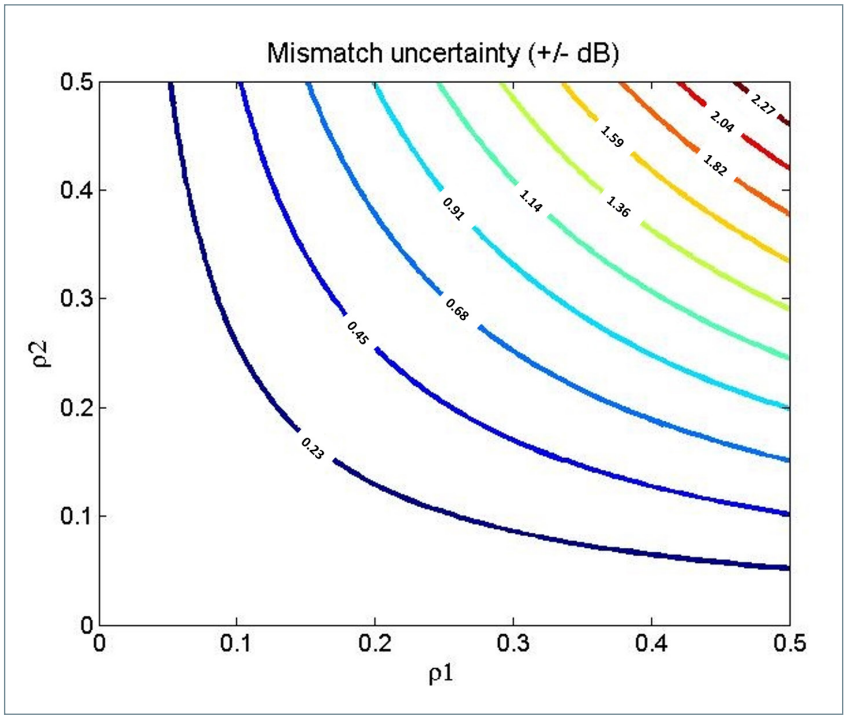


11. 28 GHz propagation loss testing using a battery powered Anritsu S820E 40 GHz handheld cable and antenna analyzer for the test signal and an Anritsu MS2760A spectrum analyzer as the receiver.

Overcoming millimeter wave challenges

Reducing the number of connections

Reducing the number of connections in a test system reduces the number of points of failure (measurement error) due to dust / dirt damaging the return loss of a connection. It also minimizes the chance for imperfections to cause test system impedance variation from 50 ohms. Each connection in the system (male to female connector pair) will add uncertainty. Millimeter wave connectors and cables must be handled carefully to insure accurate measurements. Appendix A shows some of the precautions needed to make reliable measurements. Power meter and spectrum analyzer measurements are "scalar", meaning the phase of the signal is not known. Mismatch at the sensor / analyzer end will cause a portion of the signal to be reflected back towards the source. Mismatch at the source end will cause this reflection to return towards the sensor / analyzer. As the tested frequency changes, the mismatch voltages will sequentially sum together and then cancel causing amplitude ripple on the measurement results. The resulting measured values can be either above or below the value that would be achieved with ideal 50 ohm components (in a 50 ohm system). ρ (or rho), the voltage reflection coefficient, is commonly used to characterize impedances at microwave and millimeter wave frequencies.



12. A profile of mismatch uncertainty (dB) values resulting from two reflection coefficients.

For each value ρ, the + and – uncertainty in dB can be as large as

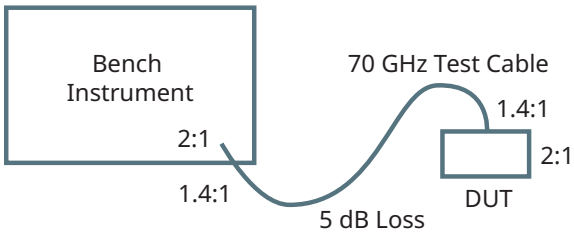
$20\log_{10}(1/(1-\rho 1*\rho 2))$

ρ can be measured with a vector network analyzer such as the Anritsu MS4640B Series. Models with coaxial connections are available to 145 GHz.

The results of these equations are shown graphically in Figure 12.

For example, if a 70 GHz signal generator with 2:1 SWR is connected to a power sensor or spectrum analyzer also with 2:1 SWR, a 0 dBm power measurement could have worse case measurement uncertainty of +0.92 – 1.02 dB. Errors compound as the number of connections in the system increases.

Measure as close to the DUT as possible



13. Mismatch analysis for a bench analyzer connected to a3device under test using a 2 ft test cable.

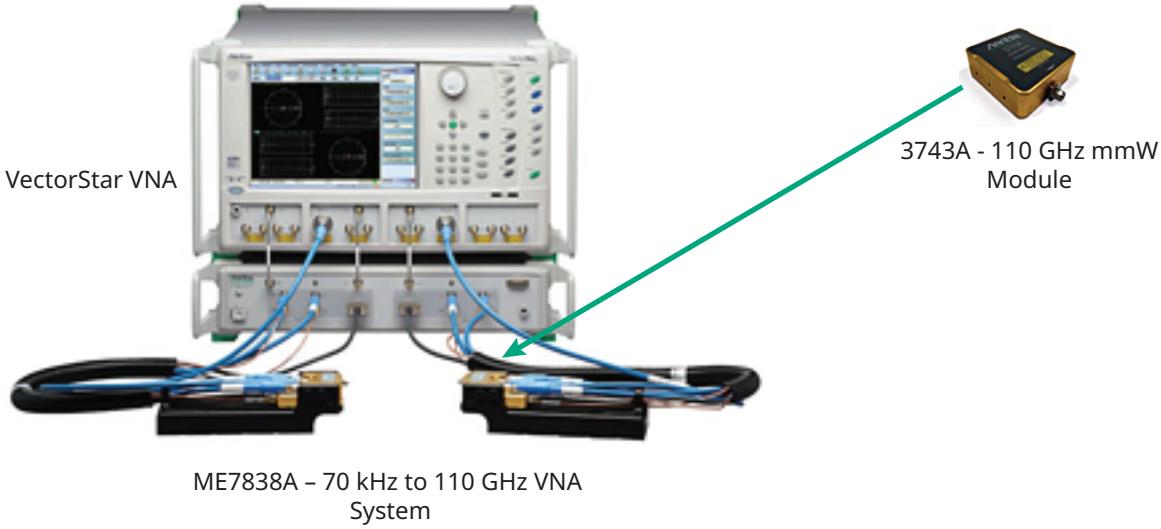
Precision, low-loss cables can be used to improve system performance. A 2 foot long precision test cable will typically cost more than a thousand of dollars and will still add uncertainty from mismatch and insertion lost. The issue of cable loss gets more complicated if multiple cables are used in a system and one tries to use a fixed set of values to correct all measurements for loss. For example; if one cable has 5 dB of insertion loss at 30 GHz and 8 dB at 70 GHz and the second cable, from the same manufacturer, has 5 dB of insertion loss at 30 GHz but 10 dB at 70 GHz it will be difficult to know what the net loss is. In order to properly characterize and remove the impact of the cables, a network analyzer can be used to characterize each cable to know the net cable loss at each measurement frequency. This, however, can be complicated, time consuming, and costly. The only way to simply and completely remove the impact of cables is to remove the cables altogether and take measurements directly at the DUT. In this case, direct connecting the spectrum analyzer to the DUT would improve the sensitivity by 5 dB and reduce measurement uncertainty by approximately +-0.4 dB.

Anritsu is a leader in millimeter wave testing

Anritsu has been a pioneer in millimeter wave testing with development of the 40 GHz K connector in 1983, 70 GHz V connector in 1989 and 110 GHz W connector in 1997. A detailed description of the "V" connector is given in Appendix B.

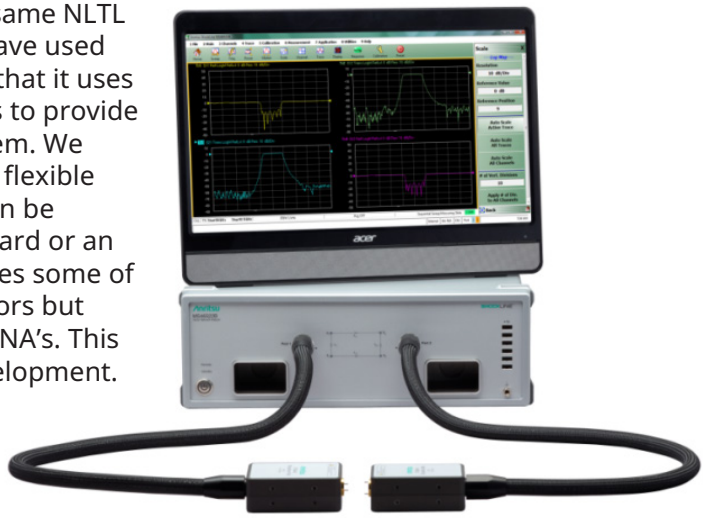
Anritsu is also a leader in millimeter wave vector network analysis with the MS4640B Series VectorStar & MS46522B-082 ShockLine Network Analyzers.

VectorStar VNA's offer a variety of models covering the 70 kHz to 20, 40, 70, 110, 125 and 145 GHz frequency ranges in either full broadband or banded systems. The VectorStar based ME7838A broadband systems are an excellent choice to do full frequency coverage for on-wafer measurement systems due to their unique, highly integrated, very small millimeter wave frequency extension modules. These modules make use of Anritsu's exclusive non-linear transmission line (NLTL) technology which allows the probes tips to be mounted directly to the modules. This greatly enhances measurement and calibration stability.



14. Anritsu's VectorStar vector network analyzers

Anritsu's MS46522B-082 ShockLine VNAs use the same NLTL technology in an E-Band VNA configuration. We have used the same philosophy in designing this system in that it uses small remote millimeter wave extension modules to provide a banded 60-90 GHz high performance VNA system. We have also designed this system to be a small and flexible platform by making it a "headless" design that can be controlled via external display, mouse and keyboard or an external touch screen display. This design removes some of the costs associated with front panels and monitors but retains the high performance of our VectorStar VNA's. This system is perfect for component or antenna development.



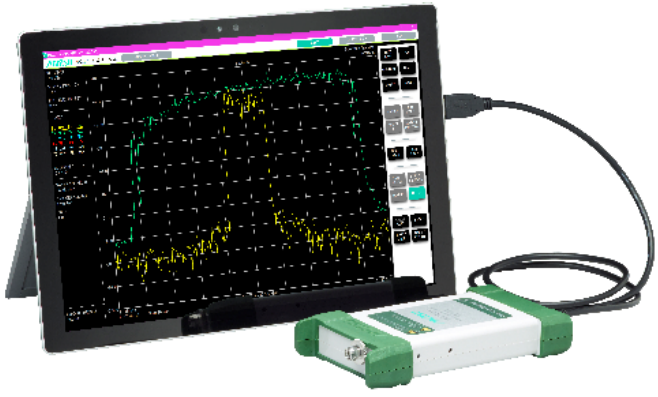
15. MS46522B-082 E-Band ShockLine VNA

MS2760A Spectrum Master Ultraportable Spectrum Analyzer

Anritsu is also continuing its leadership in millimeter wave testing with the recent introduction of the MS2760A Spectrum Master Ultraportable spectrum analyzer. By utilizing Anritsu's patented NLTL technology, the MS2760A shatters the cost, size, and performance barriers associated with traditional large form-factor instruments to more efficiently advance technology development. The MS2760A is USB-powered and controlled from a Windows-based PC, laptop, or tablet.

The MS2760A provides continuous sweep from 9 kHz up to 110 GHz, and can sweep the full range in under 11 seconds (processor speed dependent). This can reduce the time to survey spectrum.

The MS2760A has an ultraportable form factor. It is about the size of a smartphone, which makes it small and light enough to be directly connected to many devices under test. It is even equipped with mounting holes to be attached to a bracket for direct connection to a semiconductor wafer probe. This eliminates the cable and all the uncertainty that comes with it, significantly improving system accuracy and repeatability.



16. Anritsu MS2760A connected to a tablet PC

Summary

In the past decade with technology improvements in semiconductors, components, cable, and connectors and test equipment are now making it possible for millimeter wave frequencies to be used for low cost commercial / consumer electronics. This paper has outlined the issues of connector mismatch error and cable loss with making accurate measurements at the new millimeter wave frequencies. It has also described how new ultraportable spectrum analyzers can reduce significantly the millimeter wave measurement challenges and improve measurement performance and accuracy.

Appendix A

Care and handling of millimeter wave cables, reference:
http://www.timesmicrowave.com/documents/resources/Silverline-VNA-R.pdf

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Care and Handling Guidelines:

While armored, 50 & 67 GHz cables are sensitive microwave instruments. Small, flexible cables can easily be forced beyond the recommended minimum bend radius. This will likely degrade or destroy the RF performance. All flexible cables have a limited flex life. Develop procedures that limit flexing. 2.4 and 1.85 mm interfaces are delicate. Keep them meticulously clean and the center contacts concentric within the outer contact. Use a microscope to examine if necessary. DO NOT mate connectors that are dirty, suspected of being damaged or outside concentric tolerances. Connectors must be aligned when mating. Misalignment could damage the interfaces and voids the warrantee. Test equipment makers publish extensive use and handling procedures on their web sites that cover these and other topics.

ALWAYS:

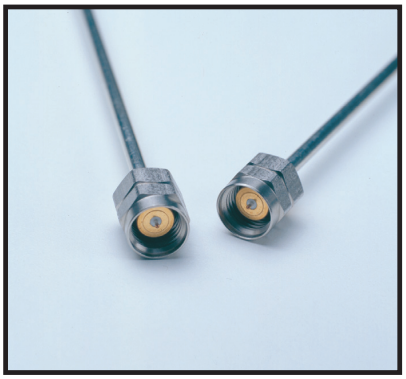
– Inspect interfaces before every mate. Clean if needed.
– Gently start the coupling nut and fully thread with fingers first.
– Hand tighten, but if a calibrated torque wrench is used 8 in-lbs max.
– Limit use to experienced technicians.
– Cap connectors and store cables separately in a protective container.
– Keep a spare pair of cables ready, just in case.

NEVER:

– Force the cable to bend beyond the recommended minimum radius.
– Force two connectors. If any resistance is felt STOP and examine.
– Mate to another series.
– Mate connectors that are not aligned and concentric.
– Put foreign or dirty objects into the interface

V CONNECTOR®

DC to 70 GHz



The V Connector® is a reliable 1.85 mm device that operates up to 70 GHz. It is compatible with 2.4 mm connectors and is assembled using procedures that are similar to those used on K Connectors. It is well suited to applications in components, systems, or instrumentation.

Visit www.anritsu.com for the latest information including installation instructions, outline drawings, and RoHS compliance status.

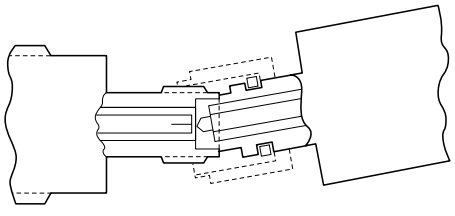
V Connector® features

- *Excellent performance up to 70 GHz*
- *Low VSWR*
- *Superior reliability*
- *Low Loss*
- *Components with -R suffix are RoHS compliant*

Exceptional reliability and repeatability

Microwave connector reliability is affected by insertion force, outer conductor strength, stress relief while mating, and mating alignment. The V Connector exhibits exceptional performance in all of these areas.

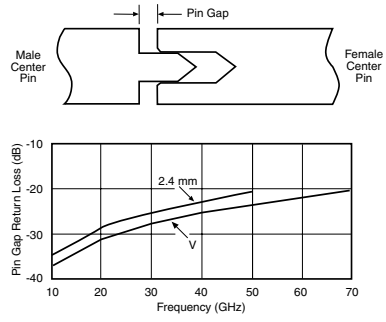
For proper seating, the V Connector requires only 1/2 the insertion force of a 2.4 mm connector. The reduced wear on the center conductor equates to greater reliability. All V Connectors, including the cable connectors, incorporate another feature that eliminates a major cause of connector failure: misalignment of the male pin with respect to the female. To solve the problem, the V Connector male pin is deliberately made sufficiently short to prevent damage to the female connector by misalignment. With this arrangement, the outer housing must be properly aligned prior to the mating of the center conductors. Thus a proper, non-destructive alignment before mating is ensured.



Shortened Male Pin Eliminates Damage to Female V Connector

The effect of pin gap on a connection is often overlooked, but is the dominant source of error in many connection systems. Pin gap is the short length of smaller diameter created when a connector pair is mated. Pin gap causes a discontinuity at the connector interface. The V Connector has considerably less susceptibility to pin gap than 2.4 mm connectors.

Many connector manufacturers specify connector performance assuming no pin gap, an unrealistic assumption. V Connectors are specified assuming pin gap to be at its maximum tolerance, to provide you the assurance of real-world specifications.



Effect of Pin Gap

Launcher design

At the heart of the V Connector product line are the launchers. As their name implies, the launchers make the transition from a microwave circuit (microstrip, suspended substrate, stripline, or coplanar waveguide) to a coaxial connector and an outside transmission line. The key to making the transition without compromising electrical and mechanical objectives is the glass bead in the launcher assembly.

Low-reflection glass bead

The V Connector's standard glass bead has a unique 0.24 mm center conductor and readily connects to fragile devices. The bead is appropriate for most applications employing Duroid and ceramic (Alumina) microstrip, such as the 0.25 mm wide center conductor on a 0.25 mm thick Alumina substrate. Applications using suspended substrate geometry are equally well satisfied. The bead is constructed of Corning 7070 glass and has a gold-plated center conductor and a gold-plated Kovar® collar.

The outstanding design of the bead is largely accountable for the excellent performance of the V Connector launchers. In addition, the design provides for soldering the bead to achieve a hermetic seal. A max soldering temperature of 310°C is recommended. The V Connector® launchers can be removed for repair without removal of the glass bead. This ensures that during removal the critical microcircuit-to-glass bead interface is not disturbed, that hermeticity is preserved, and that the microcircuit will not be subjected to the additional stress caused by heating to soldering temperature. Hardware locking compound such as Removable Loctite® should be used to further secure the launcher in its housing.

Anritsu envision : ensure

Specifications are subject to change without notice.

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