RF/MICROWAVE CABLES AND CONNECTORS

Application Note

Introduction

This application note discusses the various types of microwave connectors currently used and their evolution. It contains information about the usable frequency ranges of the various connectors and touches upon multi-moding problems in cables and waveguides.

Cables and connectors are used to provide electrical contact between the researcher's test equipment and the wafer device under test (DUT), with the understanding that the probing equipment is needed to assist with this task. Generally speaking, cable and/or connector requirements are dictated not by the probe station but instead by the DUT and the test equipment, its frequency range, the signal's characteristics (i.e., low noise, low amplitude, impedance, etc.). However, the probe station does interact, and possibly interfere, with these requirements. For example, physical size and location may dictate the lengths of cables. The frequency range and bandwidth of either the test equipment or the DUT will dictate the use of a particular connector and/or a particular probe.

BNC Plug

History of RF Signal Connectors

Historically, the physical size of connectors shrink in size as the frequency of operation increases. Prior to World War II, RF technology was driven by communications needs such as ship to shore radio, (Amplitude Modulation, carrier on or off, Morse code), commercial broadcasting (Amplitude Modulation, voice, AM band) and the start of long distance telecommunications (multi-channel, broadband, TV, narrow-band FM telegraphy). Long distance, narrowband, communications required high power transmitters, 100 watts to 1000 watts in the frequency bands available, <30 MHz. As a result, "UHF" plugs and jacks were invented and they served these communications needs very well for many years. UHF plugs, also called PL-259 after the military designation, are large, reliable, secure connections. They are still used today, but they are limited to lower frequency applications. The screw on terminals were inconvenient for test equipment applications, i.e., fast, temporary connection, so BNC type connectors were invented, as well as many other types. The advantage of the BNC type over the UHF was size and convenience: quarter turn, twist connection, and half the diameter.

UHF Jack

BNC's are very popular and they have been modified in numerous ways; slide on, polarized, twinax, triax, etc. As basic RF connectors, they are used from DC up to 4 GHz, with some applications usable up to 10 GHz. BNC connectors can handle RF power levels up to 5KW, as well as picowatt signal levels.

World War II drove the RF field into the microwave frequency area with the need for short pulse duration, radar applications which could be mounted in ships and airplanes. Radar antennas, small enough to mount into the nose of a B-29, forced the development of higher frequency radars and short pulse duration requirements dictated wider bandwidth systems. As a result, UHF and other types of connectors were not capable of the performance needed for these applications.

Type N

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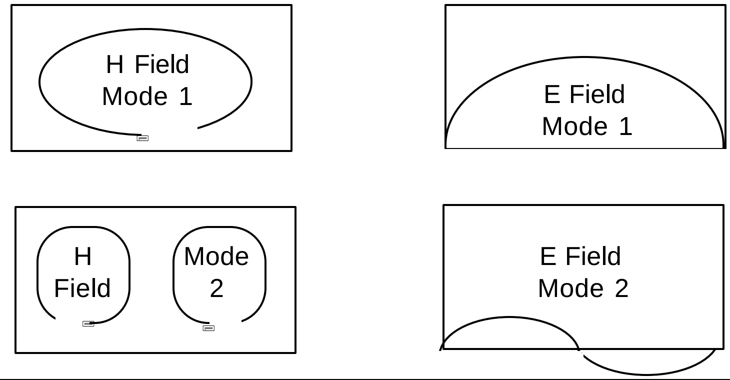
N type connectors, first invented for Navy shipboard applications, increased the bandwidth to 12 GHz. Many test equipment manufacturers standardized on the N connector for HF to microwave frequency applications. Type N's exhibited low insertion loss, wide bandwidth and high reliability characteristics. They have been improved, and now fill many applications up to 18 GHz.

7mm sexless

At some point during this time frame, the 7mm connector was invented. It is specified up to 18 GHz, but it is mostly known as a sexless connector.

During the decades of the 50's and 60's, most communications applications were typically less than an octave wide (two times lowest frequency) and very loss sensitive. Therefore, communications applications tended towards waveguide transmission lines. Waveguides are bulky, heavy, mechanically unwieldy and difficult to use in airborne applications or in general purpose test equipment. Semi-rigid coax cables with SMA connectors were developed and provided good solutions to the mechanical problems associated with waveguide.

Figure 1



Multi-Moding demonstrated within a waveguide applicable to coaxial cable as well

Frequencies have pushed even higher; SMA connectors (invented by Bendix/Scientilla Corp.) and the high performance versions (APC-3.5), have extended the frequency range up to 30 GHz. Wiltron's K connector, is a modification of this basic design, which improves its performance up to 40 GHz, while maintaining mechanical compatibility with the 3.5mm design.

The convenience of quick connect connectors on test equipment has been lost with the increases in frequency range.

Cables Count

The broadband requirements, of instrumentation manufacturers, have pushed the state of the art even higher. Hewlett Packard, Amphenol and Ma/Com collaborated on the design of the 2.4mm connector, pushing the usable bandwidth out to 50 GHz. These connectors have insertion losses of approximately 1 dB and when used with corresponding semi-rigid coaxial cable can guarantee no multi-moding of the RF signal in the frequency range of interest (see figure 1 for a waveguide analogy of multi-moding). However, it should be noted that the smaller diameter coaxial cables typically have a higher insertion loss per unit of length, for any given frequency, which is the trade off for higher operating frequency or wider bandwidth.

Connector Cleanliness

The cleanliness of connections become an issue as frequency range increases. Oils, films, dirt, tightness, etc. on connectors can cause large changes in return loss or VSWR. For example, a calibration setup with a SMA, 50Ω termination can yield a return loss reading better than 30 db across the band 200 MHz to 8 GHz. Then, using the original 50Ω termination at the same point in the test setup and after various other connections, the original 50Ω data may have degraded to less than 20 db, return loss at some point in this band.

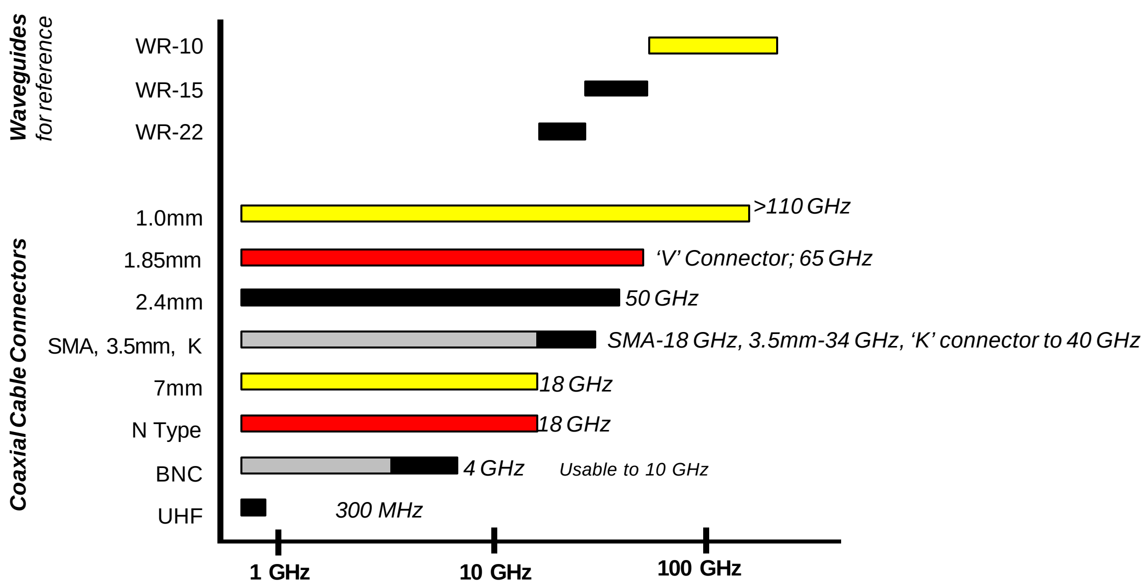
Phenomena, such as this, can be attributed to oils or dirt from handling the various connections. Cleaning the connections with alcohol will usually clear up these types of problems. Also, if compressed air is available, gently blowing out the cleaning solvent will improve the cleaning process.

Lastly, tightening all connections with a torque wrench will help prevent changes in data (8-12 inch pounds of torque are recommended for most microwave connectors). It is best to check with the manufacturer for recommended torque values for each particular connector.

SMA Plug

Application Note

Connector Types Versus Frequency



Size Matters

One can readily see a relationship between the physical size of the connector and its usable frequency range from the previous discussion. This relationship is similar to ones based on F λ=C, i.e., antenna size or length and operating frequency. It is also related to transmission line characteristic impedance, $Z_o=(L/C)^{1/2}$. Any physical discontinuity in the connector will affect the characteristic impedance. Basically either the inductance per unit of length or the capacitance per unit of length will change thus affecting Z_o.

Cable Characteristics

Device/ Cable Type	Cable OD in inches	Cable Impedance	Attenuation dB per 100 ft @ 200 MHz	Propagation constant Vp/C	Capacitance per foot	Typical 3 ft (915mm) Cable	Total Shunt Capacitance
RG6	0.27	75	3.1	0.78	17.3	51.9	52
RG11	0.405	75	3.2	0.66	20.6	61.8	62
RG58	0.195	50	7-7.3	0.66	28.8	86.4	86
RG178	0.071	50	20	0.7	28.4	85.2	85
RG214	0.425	50	3.2	0.66	30.8	92.4	92
RG217	0.545	50	2.1	0.66	29.5	88.5	89
Semi-Rigid Cable							
UT-70-50	0.07	50	12*	0.7*	29		
UT-250-A	0.25	50	3*	0.7*	29		

* Values are estimated from 500MHz measurements.

Transverse Electro Magnetic Mode

Multi-molding or higher order modes in a transmission line cause increased attenuation and reduced power handling capability. The modes of transmission in cables or waveguides depends upon the electromagnetic characteristics and physical size of the medium.

Typically, the signal in a coaxial line is described by its direction of travel and by the direction of the electric and magnetic vectors of the signal, i.e., the E field is perpendicular to the direction of travel and the H field (magnetic field) is also perpendicular to the direction of travel. Under these conditions, the mode is said to be TEM (Transverse Electro Magnetic). The simplest mode is TE_{O1} and if the physical spacing between the two conductors is large enough at the frequency of operation to allow the E or H field to exist in a higher mode then multi-mode operation may occur, See figure 1. If one's goal is to increase the frequency range of a system or piece of test equipment, then the operator needs to reduce the spacing of the conductors in the electrical transmission lines between components to prevent multi-mode transmission from occurring.