What considerations should be made when selecting a connector type?

There are several factors that will determine the choice of connector series and style. Cable and frequency range are the primary factors. It is good engineering practice to try and match the connector size (diameter) and cable diameter as closely as possible in order to minimize reflections. The larger the difference between cable diameter and connector diameter, the worse the performance will be. Reflections will generally increase as a function of frequency, and smaller connectors will generally perform well at higher frequencies. For very high frequencies (above 26 Ghz), precision, airline connectors may be needed.

Frequency range will determine the connector series used. In general, it is advisable to use push-on or bayonet style connectors at low frequencies, typically below 6 Ghz. Threaded connectors should be used for high performance, low noise applications.

The cable that is specified will generally determine the impedance of the connector used. 50 and 75 ohms are the standard impedances used by most designers, and several connector series come in both 50 ohm and 75 ohm versions. At frequencies below 500 Mhz or so, 50 ohm connectors can be used on 75 ohm cable (and vice versa) with acceptable performance levels. The reason for doing this is that 50 ohm connectors are generally less expensive due to their greater usage.

Aside from trying to match the cable and connector as closely as possible in size to minimize reflections, connector interface and dielectric materials are also important considerations. Line to line and air interfaces such as the SMA and Type N give excellent high frequency, low reflection performance. Overlapping dielectric interfaces such as BNC and SMB are usually limited in performance vs. frequency. The usual figure of merit for a connector's performance is its Reflection Coefficient. This is a measure of how much signal is reflected back from the connector. It can be expressed in terms of Reflection Coefficient, VSWR (Voltage Standing Wave Ratio) and Return Loss.

Due to FCC Part 15 regulations that require non-standard interfaces on spread spectrum wireless devices, many designers have chosen to specify common connector types such as BNC and TNC but with reverse polarity interfaces. Reverse threaded interfaces are also sometimes used.

Power or voltage requirements are also a factor determining the connector to be used in a particular application. High power applications will dictate the use of large diameter connectors such as 7-16 DIN and HN for example. Average power handling is normally limited by the cable's power specification and is usually determined empirically. The voltage breakdown level of the connector limits peak power. Power handling capability will diminish as a function of frequency and altitude.

What is VSWR and how is it specified?

VSWR is a measure of the amount of signal that is reflected back from a connector. It is a vector quantity in that it has both amplitude and a phase component. This is important when considering the impact of multiple connectors in a transmission line (see How do I specify the performance characteristics of a cable assembly?, below). Mismatched impedances cause the reflections. If the cable being used has a characteristic impedance of 50 ohms, then the connector must also maintain 50 ohm impedance. The transition from the cable to connector transmission line sizes and captivation of insulators and contacts are the main causes of mismatches within the connector.

There are generally 2 ways in which the VSWR of a connector is specified. The first is a “flat line limit” over the entire frequency range. For example, for a straight BNC Plug on flexible cable, the VSWR limit is 1.3:1 maximum (usually just written as 1.3 max) to 4 Ghz. The second method is to allow for the fact that VSWR is typically a direct function of frequency. A straight SMA plug on RG-142 B/U cable can have a maximum VSWR of 1.15 + .01 * F (Ghz) to 12.4 Ghz. For example, at 2 Ghz, the maximum allowable VSWR would be 1.15+2*.01 or 1.17 max. At 12.4 Ghz it would be 1.15+12.4*.01 or 1.274 max. Naturally, these values can be converted to Return Loss or Reflection Coefficient.

What is Insertion Loss and how is it specified?

Insertion Loss, expressed in dB is defined as 10*log (Po/Pi) where Po= Power Out and Pi=Power In. There are 3 main causes of Insertion Loss: Reflected losses, Dielectric losses and Copper losses. Reflected losses are those losses caused by the VSWR of the connector. Dielectric losses are those losses caused by the power dissipated in the dielectric materials (Teflon, rexolite, delrin, etc.). Copper losses are those losses caused by the power dissipated due to the conducting surfaces of the connector. It is a function of the material and plating used.

In general, the insertion loss of a connector is on the order of a few hundredths to a few tenths of a dB. As with VSWR, it can be specified as a “flat line limit” or as a function of frequency. Using the same examples as the VSWR, a BNC is specified at .2 dB maximum when tested at 3 Ghz. For the SMA, the requirement is .06*SQRRT Frequency in GHz when tested at 6 Ghz. For example, at 4 Ghz, the requirement would be .06*2 or .12 dB max. Although the connectors are specified to operate over a wide frequency range, they are only specified for testing at particular frequency because the test procedure required to obtain accurate measurements of such small losses is a very precise, and time consuming process. The procedure is defined in MIL-PRF-39012 and can be found at:

http://www.dscc.dla.mil/Programs/MilSpec/ListDocs.asp?BasicDoc=MIL-PRF-39012

How do I specify the performance characteristics of a cable assembly?

There are two performance characteristics of cable assemblies that are of interest: VSWR (or Return Loss) and Insertion Loss.

For all but the shortest cable assemblies (less than 6 inches) using extremely low loss cable, the Insertion Loss will be overwhelmingly due to the attenuation of the cable itself and can generally be determined from the manufacturers data sheets.

On the other hand, the VSWR will normally be overwhelmingly due to the connectors. Remembering that VSWR is a vector quantity, as the frequency is swept, the VSWR of each connector will add and then subtract in and out of phase giving a swept VSWR plot that goes up and down. Where these maximums and minimums occur will depend on the length of the cable and its dielectric constant. As a general rule, the maximum can be calculated by determining the Reflection Coefficient of the connectors on each end. Worst case will be the addition of the 2 reflection coefficients. Although small, some amount should be added for the cable. In addition, the attenuation of the cable, if significant, will reduce the VSWR. For this example, we will ignore the attenuation of the cable as a factor in the calculation. As an example, let’s say we have one connector with a VSWR of 1.2 at the frequency of interest and the other connector is a 1.25. The cable VSWR is 1.05. Converting the VSWR to reflection coefficient gives .091, .111 and .024 respectively. The maximum Reflection Coefficient=. 226. This converts back to a VSWR of 1.584 maximum. A quick way of getting the result is to multiply the 3 VSWR values. In this case it would be1.2*1.25*1.05=1.575. This is very close to the previously calculated result. For Return Loss, VSWR can be converted to dB. For Return Loss, if the connectors have the same Return Loss value and the cable Return Loss is at least 6 dB better, then the cable assembly Return Loss can be determined by subtracting 6 dB from the connector Return Loss. For example, if the Return Loss of each connector is 23 dB, then the cable assembly can be expected to have a maximum Return Loss of 17 dB. If the Return Loss of each connector is different or if the cable Return Loss is not insignificant, then each of the Return Losses would have to be converted to Reflection Coefficient, added and then converted back to Return Loss. It is very important to realize that the VSWR of the connectors and cable add vectorially and the resultant VSWR of the cable assembly will be considerably higher than each individual component's VSWR.

<u>How does the manufacturer make certain that the VSWR of a connector will meet the specification?</u>

Two steps are during the design and development phase of connectors. Once the 3-D mechanical drawings are completed, the first step in the RF design process is to model the connectors using High Frequency Structure Simulator (HFSS) software. This is a state of the art computer program that allows us to model the 3-D structure of the connector and simulate its RF performance. This software has no frequency limit and will allow us to view the VSWR (Return Loss) and Insertion Loss of the connector, or any microwave device. In addition, it has the capability if performing Time Domain Reflectometry (TDR). TDR is a technique that allows us to see reflections as a function of distance. This enables us to see "inside" the connector and determine exactly where the discontinuities are located. Corrections can be made, and a new analysis can be performed. In addition, the HFSS software has an "OPTIMETRICS" module that allows us to automatically vary dimensions within the connector and solve for the best VSWR. This process greatly reduces the engineering design cycle time.

After the modeling is complete and the connector has been prototyped, it will be tested on a Network Analyzer. This is a piece of test equipment that measures the S parameters (VSWR and Insertion Loss) of the connector or cable assembly. Differences between the simulation and actual test data can be evaluated. In general, the simulated data results in an optimized VSWR with enough margin to allow for manufacturing and assembly variations and still meet the customer requirements.

<u>What causes differences between simulated and actual test data?</u>

1. Actual interfaces during testing will be different from the model.
2. Dielectric constants and dimensions of cables are variable and cable is modeled as "perfect".
3. Dielectric constants of different materials used as insulators (i.e.: delrin, lcp) are not precisely known.
4. Calibration kits for all types of connectors are not available and therefore gating is often used in taking data.
5. Small air spaces are usually not modeled as they greatly increase the complexity of the model.. They are typically filled with dielectric.
6. Actual assembly of the device can result in components compressing (ie: press fits) which may cause the longitudinal and relational position of the components to be different from the model.
7. Generally, small radii are not modeled. They are replaced with chamfers or even eliminated completely.
8. Connectors are modeled using nominal dimensions. Actual parts have tolerances.
9. The adaptive frequency is a single frequency usually about 80% of the upper frequency limit, but the analysis is usually swept over a broad frequency range.
10. Crimping can deform cables in an extremely variable manner and this is usually not modeled.

What is Passive Intermodulation Distortion?

Passive Intermodulation Distortion (PIM) is a phenomenon that occurs when 2 signals present on a transmission line mix in a non-linear manner. This mixing creates additional frequency components (where the fim = ± mf1 + ±nf2 and m and n are integers) that may fall within a cellular uplink band, causing interference. Poorly designed or assembled connectors and cable assemblies can generate PIM.

What Is the Difference Between Average and Peak Power?

The amount of power a connector can handle can determine the long term (or even short term) reliability of your system. Using a connector that cannot adequately dissipate the power applied can cause serious problems and failure of your system. There are 2 types of power handling (expressed in watts) that must be considered: Average Power and Peak Power.

Average Power is the input power to a cable/connector which will produce a maximum safe center conductor temperature under steady state conditions when terminated with a matched load. A safe center conductor temperature is one that will not melt the dielectric. When considering Average Power the following points should be noted:

- Average Power is inversely proportional to frequency and must be de-rated accordingly
- Average Power is equal to a Power Rating @ 1 Mhz/v (Frequency in Mhz)
- Connectors generally have higher power ratings than the cable to which they are attached
- Connectors have metal shells whereas cables have braids covered by plastic jackets
- Connectors can be attached to bulkheads which help dissipate heat
- Connectors usually have lower attenuation per unit length due to air sections within the connector

Peak Power is limited by the voltage rating of the connector, and is determined by the equation V^2/Z where V=the peak voltage rating and Z is the characteristic impedance. When considering Peak Power the following points should be noted:

- Peak power generally has a very short duty cycle, but you should calculate the average power of a peak pulse to be certain it does not exceed specifications
- Peak Power is not a function of frequency
- Peak Power is an inverse function of VSWR and modulation schemes and must be derated
- Peak and Average Power are functions of altitude and must be derated
- Maximum power ratings will always be the lesser of the cable/connector combination

What are the key advantages of the GPO vs. the SMA?

The GPO is a push-on style connector. The GPO operates up to 26.5 Ghz with extended performance up to 40 Ghz. The push-on style is blindmatable making modular designs easy to implement. There are no bulky nuts with the GPO. This means that the GPO takes less space and that is a big help to today's engineers who need to achieve compact designs. The GPO push-on design also simplifies manufacturing assembly. The GPO allows for greater axial and radial misalignment providing inherent advantages in designing for manufacturability.