# Engneering Applications

## A Guideline to select Coax Cable

To select the best RF coaxial cable for your new application, it is better to understand the coaxial cable's construction, performance and cable range for your selection. The best choice can be achieved by fully meeting your systems requirement and balancing your cost. FocuSimple will explanation some suggestion from coaxial cable manufacturer point views by introducing the cable materials, process and related performance. Those will help you to make the best selection.

FocuSimple is a professional coaxial cable company to provide high performance RF cable. We have a wide range cable for your selection. Meanwhile, we also could design unique cable according to your tough requirements.

In order to choose the best coaxial cable your applications, the cable characteristic listed below should be considered. The following sections provide detailed discussions of each characteristic.

1. Characteristic Impedance
2. VSWR & Return Loss
3. Attenuations & Loss
4. Attenuation Stability
5. Phase vs. Temperature
6. Phase stability
7. Velocity of Propagation
8. Average Power Handling
9. Capacitance
10. Cut-off Frequency
11. Operating Temperature Range

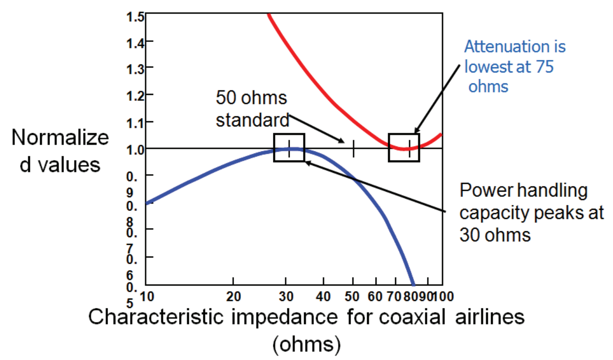
### 1. Characteristic Impedance

The characteristic impedance of a coaxial cable decided-+ by the ratio of the diameter of the outer conductor to the inner conductor and dielectric constant of the insulate materials between the conductors. Because the RG energy always transfers on the surface of conductor, the important diameters are the outside diameter of the inner conductor and inside diameter of the outer conductor. Impedance is selected to match the system requirements.

The most common coaxial cables impedances are the 50 ohms and 75 ohms. Sometimes from 35 ohms to 185 ohms will be used.50 ohms are used in microwave system and telecom systems while 75 ohms are used in CATC and video systems. The 85 ohms and 100 ohms are used in data transmission systems.

For the best system performance, selected cable impedance must be match the impedance of the other assembliess in the system. The system impedance is selected by the balance of the power handling and attenuations. As figure 1 shows，75 ohms impedance provides the lowest attenuation while the 35 ohms impedance provides the highest power handling.

Figure 1 Impedance, Attenuation & Power




So when you select cable, the priority is to choose the right impedance.

### 2. VSWR & Return Loss

When RF energy transfers through the coax cable assemblies, there are three things happened

a. The energy transfers to another end of cable assemblies, this is usually desired.

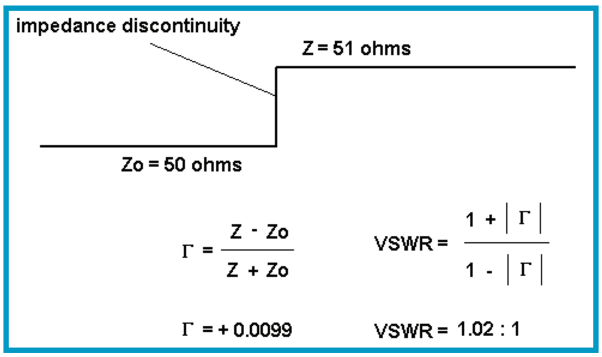
b. It is lost along the cable either by being transformed into heat or by leaking out the cable.

c. It is reflected back towards the input end of the cable.

The VSWR and return loss is the number to measure the value of RF signal reflect back towards to the source. It is defined by the total number of return signal due to the uneven impedance. The VSWR is expressed by the Voltage Standing Wave Ratio while the return loss is measured how much the RF power reflect to the source by the total energy. It can be converted between VSWR and return loss or it can be found through the chart 1. We can see the high VSWR is not taking big portion of energy loss, for example, the 1.3 VSWR is just taking 1.7% energy loss and it is equivalent to the energy loss by 0.075 dB attenuation loss.

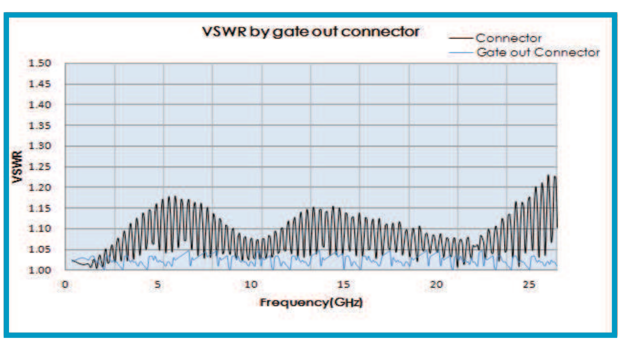
The VSWR and return loss is mainly due to the unmatched impedance. The RF signal will experience the reflection due to the changing impedance during the transmission. Based on the impedance change range we can calculate the reflection ratio. Figure 2 shows the cause of VSWR and the ways to calculate it.

**Figure2 VSWR and Impedance change**




*The inconsistent of impedance is principal caused by the installation of the assemblies' connectors, as the connectors have the balance the surface standard and the cable structure size, which will create some steps, then the steps will cause the change of the impedance. While a good VSWR can be achieved by eliminating some change through the reasonable connector design. But this change can't be completely eliminated, so the connectors and their installation are the key influencing factors for the high frequency of VSWR. It is no doubt that the cable itself will affect the VSWR as well. Figure 3 shows the variation of VSWR when remove the connectors by the internet analyser' "gate"function in the same cable assemblies.*

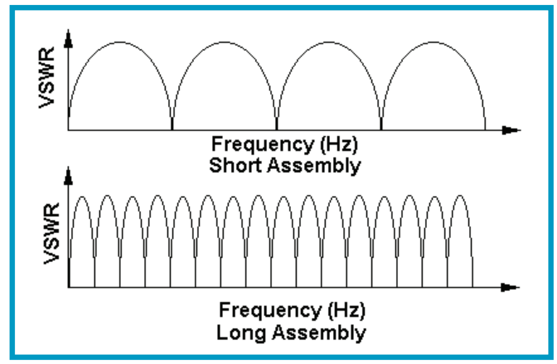
**Figure 3."gate "function , VSWR**




*In additional, by reading through the VSWR wave shape of the cable assemblies we could see that the reflection points caused by the impedance matched are mainly from the connectors. According to the calculation, we could get the conclusion that after concerting the VSWR wave shape's width into wavelength, it is just equal the length of the cable assemblies. In other words, it is the connectors who caused the peak of VSWR which assemblies' length equal wavelength's width. On the other hand, we could understand why the wave shape of long cable assemblies' VSWR is relatively narrow, while the short cable assemblies VSWR is wider. This is because of the variation of width frequency which the cable assemblies length equal the wavelength.*

*Figure 4 shows the wave shape of VSWR of different assemblies length.*

**Figure 4 long and short cable assemblies' wave shape**



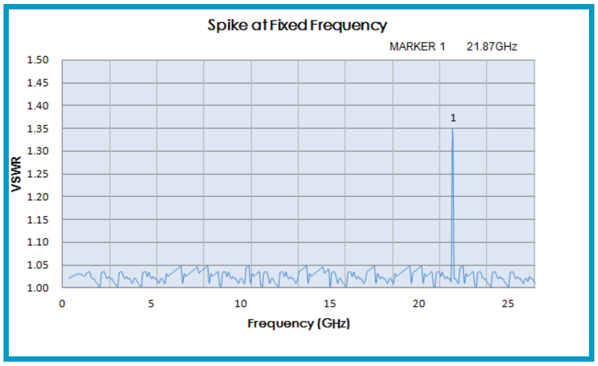

| VSWR (:1) | Return Loss (dB) | Reflection Loss | Mismatch (dB) | Match Eff (%) |
|---|---|---|---|---|
| 1. 01 | 46 | 0. 005 | 0.000 | 100. 00 |
| 1. 02 | 40 | 0. 010 | 0.0000 | 99. 99 |
| 1. 03 | 37 | 0. 015 | 0.001 | 99. 98 |
| 1. 04 | 34 | 0. 020 | 0.002 | 99. 96 |
| 1. 05 | 32 | 0. 024 | 0.003 | 99. 94 |
| 1. 06 | 31 | 0. 029 | 0.004 | 99. 92 |
| 1. 07 | 29 | 0. 034 | 0.005 | 99. 89 |
| 1. 08 | 28 | 0. 038 | 0.006 | 99. 85 |
| 1. 09 | 27 | 0. 043 | 0.008 | 99. 81 |
| 1. 10 | 26 | 0. 048 | 0.010 | 99. 77 |
| 1. 12 | 25 | 0. 057 | 0.014 | 99. 68 |
| 1. 14 | 24 | 0. 065 | 0.019 | 99. 57 |
| 1. 16 | 23 | 0. 074 | 0.024 | 99. 45 |
| 1. 18 | 22 | 0. 083 | 0.030 | 99. 32 |
| 1. 20 | 21 | 0. 091 | 0.036 | 99. 17 |
| 1. 22 | 20 | 0. 099 | 0.043 | 99. 02 |
| 1. 25 | 19 | 0. 111 | 0.054 | 98. 77 |
| 1. 30 | 18 | 0. 130 | 0.075 | 98. 30 |
| 1. 35 | 17 | 0. 149 | 0.097 | 97. 78 |
| 1. 38 | 16 | 0. 160 | 0.112 | 97. 45 |
| 1. 44 | 15 | 0. 180 | 0.144 | 96. 75 |
| 1. 50 | 14 | 0. 200 | 0.177 | 96. 00 |
| 1. 59 | 13 | 0. 228 | 0.231 | 94. 81 |
| 1. 68 | 12 | 0. 254 | 0.289 | 93. 56 |
| 1. 80 | 11 | 0. 286 | 0.370 | 91. 84 |
| 2. 00 | 10 | 0. 333 | 0.512 | 88. 89 |
| 2. 20 | 9 | 0. 375 | 0.658 | 85. 94 |
| 2. 40 | 8 | 0. 412 | 0.807 | 83. 04 |
| 2. 60 | 7 | 0. 444 | 0.956 | 80. 25 |
| 3. 20 | 6 | 0. 524 | 1.393 | 72. 56 |
| 3. 80 | 5 | 0. 583 | 1.806 | 65. 97 |
| 4. 80 | 4 | 0. 655 | 2.436 | 57. 07 |
| 5. 83 | 3 | 0. 707 | 3.011 | 49. 99 |

Table 1 VSWR, Return Loss & Mismatch

*A fixed frequency could cause the cable assemblies' VSWR to reach a high spike, as we could see from the figure 5. Yet the height of the spike has a direct relation with the cable assemblies' length, the longer the cable assemblies is, the higher the peak will reach.*

*Besides, if the peak occurs in the high frequency point, even the short cable assemblies could show the distinct circumstance. This is caused by the echo's over periodic superposed. VSWR's peak is the headache of the cable manufacturers. As it rely strongly on the precision of equipment, material, technology. Usually, some manufacturers could provide a good VSWR in a certain width for their customers by using the "shift spike" technology.*

Figure 5 VSWR' s pike



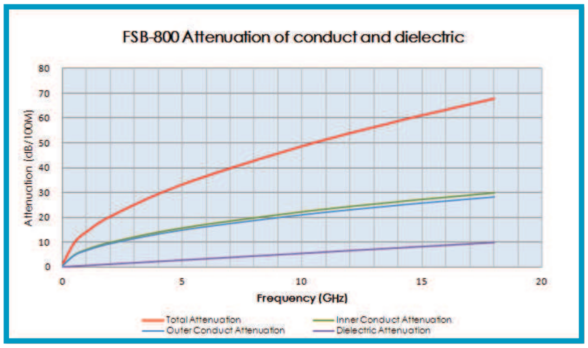

*In order to achieve good VSWR, the design of connectors must match the cable, the installation of connectors must be firm and precisely, testing equipment and system require sound calibration. In general, the professional cable and connector manufacturers could provide low VSWR produces.*

*Attenuation means the loss of energy during the transmission of cable assemblies. RF energy transfers through the coax cable assemblies, it is lost along the cable either by being transformed into heat or by leaking out the cable. We name the total of these two ways of loss as attenuation, or loss. Usually it is expressed by dB, the unit length at a fixed frequency. Because the losses are increasing as the frequency increases,*

*For an RF system, the loss usually have strict target, after all, the loss could strongly weaken the energy 3dB loss means the energy will decreased by 50%. Therefore, reducing the loss of cables and cable assemblies for RF system is very important. By selecting low-loss cable, the cost could far less than increased cost of power amplifier by choosing the high loss cable.*

*Attenuation depends on the conductor and dielectric loss. To some extent, coaxial cable loss is similar to DC the power loss. As the bigger cable comes with bigger conductor, which means the loss of conductor could lower, thereby reducing the loss of the whole cable. While the loss of dielectric is irrelevant to the size of cable. Dielectric loss has a linear relationship with frequency, and the conductor loss has a linear relationship with square root of the frequency. Thus, the proportion of the dielectric loss increases gradually as the frequency increases. Figure 6 shows the relationship of cable FSB-800 from FocuSimple and dielectric loss.relationship of cable FSB-800 from FocuSimple and dielectric loss.*

Figure 6 FSB—800 loss variation




*There are many factors affecting the attenuation, which can be divided into material factors and technological factors. Judging from the material factors, the main factors affecting the attenuation are as following:*

a. *inner conductor structure (single and twisted);*

b. *outer conductor structure (braid, and wrapped);*

c. *conductor material (conductivity variables);*

d. *dielectric materials.*

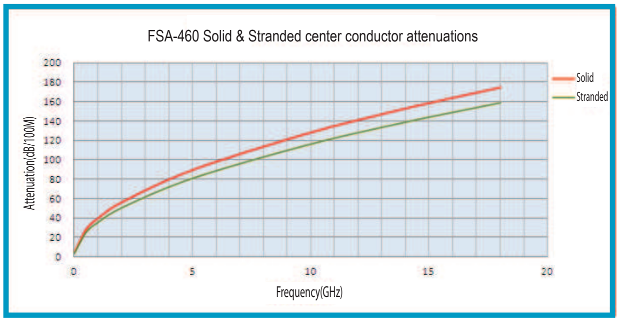
*Let's take FSA-460 and FSD-141from FocuSimple as examples to introduce the detail about material impact on the loss.*

### 3.1 Inner conductor structure affects attenuation

*When we design the coaxial cable, sometimes, according to the customer requirement of the flexible of the cable, we would select single or multiple conductors, and multi-core conductor more flexible than single conductor. However, if choose the flexibility, the same size and structure cable has to sacrifice a portion of loss. This is mainly because the whole surface of the conductor is not round which would lead to an increase in surface resistance.*

*Figure 7 took FSA-460 cable from FocuSimple as example to show the contrast after change the center conductor into core stranded conductor. We can see from the chart that after the center conductor was replaced by multi-core, the loss increased obviously. The attenuation increases by about 10%.*

**Figure 7 FSA-460 single and multiple conductors attenuations**

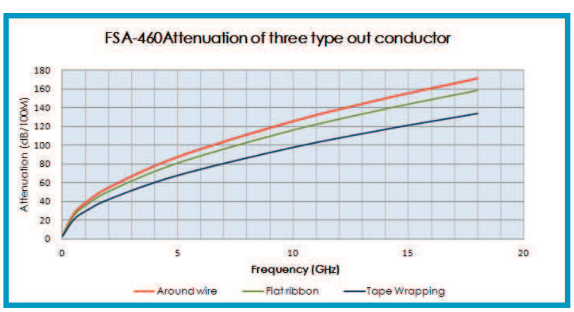



### 3.2 outer conductor structure affects attenuation

*Outer conductor's structure has a relatively richer choice than inner conductor. For the flexible cable, it is usually braided with silver round wire, silver flat wire braided, silver plated copper tape wrapped. Silver round wire braided is the most traditional basic structure of the RG cable, and the cost is very low; silver round wire was invented in the 1960s, which is relatively lower attenuation, good bending stability, relatively stable high temperature tolerance. Silver plated copper tape wrapped was invented in the 1980s, which is characterized by low loss, excellent mechanical phase, but the cost is highest, and it demand for the technology is extremely high. This structure now is mainstream military cables structure*

*Figure8 took FSA-460 from FocuSimple as example to show the attenuations contrast by replaced the outer conductor into silver round wire braided and silver plated copper tape wrapped structures. As can be seen from the comparison, the loss of silver plated copper tape wrapped structure was 20% lower than silver round wire braided. While the silver round wire braided affected by braided wire diameter, root number and knitting machine spindle number, there were some changes*

**Figure 8 FSA-460 Attenuations of difference outer conductors**

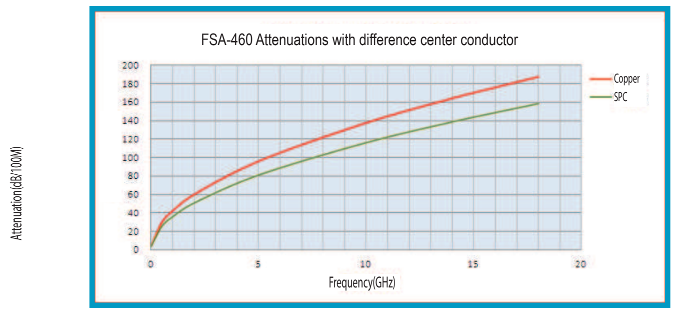



### 3.3 conductor materials affect attenuation.

*For coaxial cable, the current mainstream conductor materials are silver plated copper, oxygen-free copper and aluminum. For high-end cables, mainly in copper and silver-plated copper materials. Copper uses clad aluminum copper to reduce weight and cost, because the RF signal of the "skin effect" is transmitted only in the surface of the conductor, the silver-plated copper or copper clad aluminum silver can be considered as the silver electrical conductivity and copper electrical conductivity, the conductivity will affect level of cable conductor attenuation. For silver-plated copper conductor's silver-plated thickness, FocuSimple will strictly select the silver thickness according to ASTM standard to ensure that the cable under the full-band attenuation.*

*Figure 9 took FSA-460 from FocuSimple as example to show the attenuations contrast with the normal FSA-460 by replaced the center conductor into oxygen free copper, and replaced outer conductor into oxygen free copper flat wire braided. As can be seen from the comparison, by changing the inner and outer conductors oxygen-free copper, the increase in attenuation is relatively large, around 15%*

**Figure 9 FSA-460 Attentions of different conductor materials**




### 3.4 Dielectric materials affect attenuation

*Coaxial cable also has a relatively richer choice. For the military cable, there are solid PTFE material, low-density PTFE material. Solid PTFE material is the traditional main material for RG series cable, the process is relatively simple, high yield, currently mainly used in products for civilian use, especially widely adopted on the smart antenna of mobile communications. While the low-density PTFE material, which was invented U.S. GORE, is a microporous PTFE material, after stretched PTFE material could not only maintain the original characteristics, but also greatly enhance the electrical properties, meanwhile significantly reducing weight of the material, the current military RF cable was made from PTFE material. According to different material density, low density PTFE is divided into 76% and 83% transmission rate.*

**Figure 10 FSD-141Attenuations of different dielectric materials**

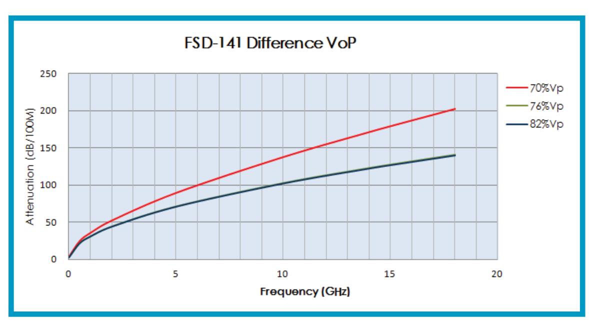


*Figure 10 took semi-steel cable FSD-141 FocuSimple as example to show how the three different dielectric materials affect the cable attenuation. Replaced the traditional solid PTFE core wire's 141 semi-steel cable into low-density PTFE dielectric cable, with the same outer diameter, the loss will increase by approximately 30%. Compared rate 76% and 83% rates, the attenuation showed no obviously difference.*

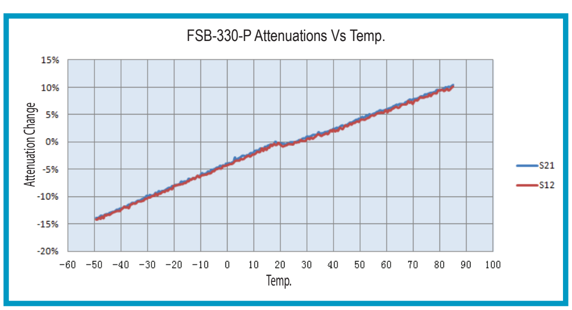
*In addition, attenuation is affected largely by the production technology, the medium around the package, dielectric wrapped, oxidizing materials, weaving and so on, will have some impact on attenuation, good and stable production technology, is the critical method to ensure the stability of cable batch attenuation.*

### 3.5 Temperature affects attenuation

*Attenuation is usually measured at 25 ° C ambient temperature, changing temperature affect attenuation, however .this can be corrected through the correction factor. The major factors that temperature affect attenuation due to conductor resistance increase when the temperature goes up, and increase of dielectric's power factor.*

*Figure 11 is the curve of cable attenuation when the temperature was changing. As can be seen from the curve, attenuation had a substantially linear relationship with temperature variation. Under the room temperature the fission process of PTFE was due to a small point, which could basically ignore. The slope of the curve of structure of each cable attenuation is slight different, so we recommend obtain more comprehensive data from the manufacturers.*

**Figure 11 attenuation change with temperature**

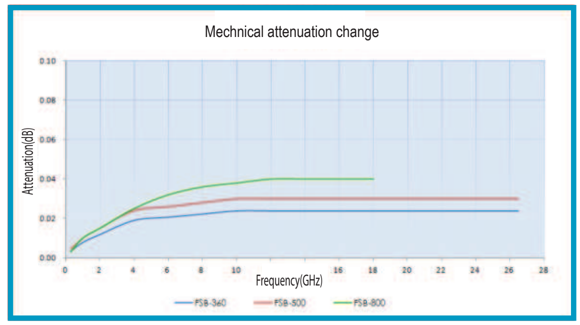



### 4. Attenuation stability

*Attenuation stability refers to the cable assembly attenuation change along with dynamic cable bending radius rotate once. Foreign countries often refer to amplitude stability, while in GB 17738.1, it became insertion loss stability, and this standard gave a detail defines for measuring method.*

*Attenuation stability is crucial for cable assembly, it also affects the accuracy of RF system. Attenuation stability depends mainly on the cable processing technology, forhis point, each manufacturer has its own unique experience and skills.Typically, the structure of silver-plated copper tape wrapped is slightly better than silver flat wire, but with the increase in the number of bending, the reliability of silver-plated copper tape wrapped is far less than silver flat braided structure. In addition, attenuation stability of single center conductor is better than multi-core conductor. But the most critical factor is the cable's processing technology. Figure 12 is the maximum result of testing the FSB series.*

**Figure 12 FSB series cable attenuation stability**

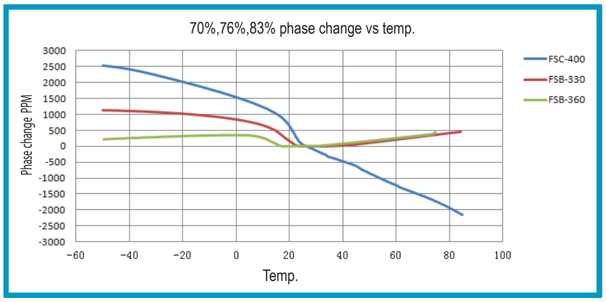



### 5. 5. Phase vs. Temperature

*Phase &.Temperature, was called "phase variation with temperature" in GB-17738.1, it refers to cable assembly work within the operating temperature range, and the electrical length caused the change of phase. GB-17738.1 shows the measurement methods in detail. We know that when the radar system detect target, the positioning of the target is determined by calculating the time of emit and receive signals back to the system. Both emit and receive electromagnetic signals are required to be performed through coaxial cable, but if the electric length of coaxial cable assemblies from different TR unit in a same radar system is differ from each other, which will lead to the received time's inconsistencies transmission time in the cable assemblies, ultimately, this will affect the positioning accuracy of the radar system. Therefore, the phase &temperature change range is the key factor for some RF system's accuracy.*

*Phase &temperature mainly caused by the change of cable's physical length, which was due to the material's expansion and contraction, thus causing changes in the electrical length. For coaxial cable, both of copper conductor's expansion and contraction and dielectric material's deformation lead to the change of electrical length, that is, as the mainly material of coaxial conductor is silver-plated copper material, then the Phase &temperature difference is caused dielectric material. From figure 13 we can see how the different materials affect the Phase &temperature. As can be seen from the figure, with the increase of propagation rate of dielectric material, with the dielectric material's air proportion increased, the change of phase &temperature decreased obviously.*

Figure 13 Phase &.Temperature of different rate dielectric



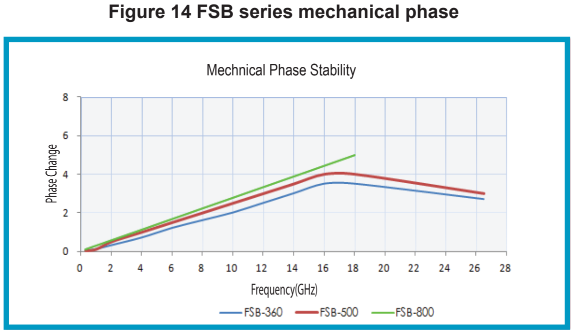

For Phase &.Temperature, we need to concern the fact that there will be more than one cable at the same time. Under these circumstances, still need to study the consistence of phase &temperature between the cable assemblies of the same type of cable. Moreover, Cable's temperature changes from low to high and high to low temperature change is also slightly different, which is the reproducibility of the temperature change. If you need to learn more about these data, you can contact the manufacturer, they can provide detailed test data.

## 6. Phase stability

Phase stability, also called mechanical phase, means the degree of phase variation when the cable is bent in the physical process. This is an important indicator to inspect the cable's accuracy and stability. Mechanical phase mainly determined by the cable's production technology, and also the structure of the cable. Typically, the cable with smaller diameter has a better mechanical phase than those with large diameter, stranded conductor's mechanical phase is slightly better than single conductor.

Figure 14 shows the mechanical phase three type cable of FSB, Test method is along the minimum bending radius of cable to rotate 360 degrees and the test results are obtained.

Figure 14 FSB series mechanical phase




## 7. Velocity of Propagation

Velocity of Propagation refers to the percentage of the speed of electromagnetic wave transmit in the dielectric relative to the light transmit speed. For coaxial cable, it is depending on dielectric constant between center conductor and the outer conductor of the coaxial cable. Meanwhile, Velocity of Propagation has corresponding relationship with cable's delay, three of them can be interchangeable through formula.

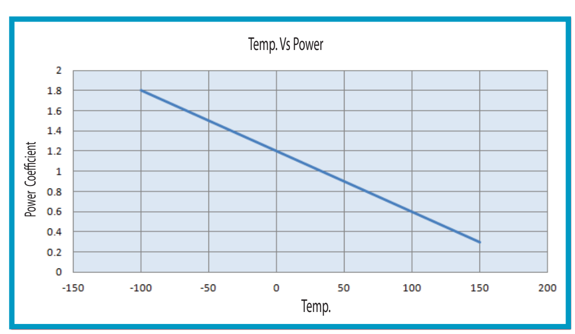
The consistency of velocity of propagation is also very important, especially in the production of phase matched cable assembly. The consistency of velocity of propagation could directly impact the physical length of the phase matching cable and the electrical length. Besides, when choose the cable of delay wire, after meet the requirement of attenuation, try to choose low propagation velocity of the cable to reduce the length and cost.

## 8. Average Power Handling

When coaxial cable is transmitting signal, cable's attenuation producing heat between the inner and outer conductors of it. Cable's Power Handling ability is mainly indicated on bearing the heat which was produced by attenuation. There are two most important factors affect cable's average power handling: First, the cable's maximum operating temperature; Second, the attenuation of the cable itself. That is, the better the cable's attenuation is, the lesser the heat will be produced. Meanwhile, under the same conditions, the higher operating temperature that cable can withstand, the greater power cable can withstand.

In demanding situations, in considering the effective average power, it also needs to consider the ambient temperature, as the ambient temperature will directly affects the cooling capacity of the cable, which directly affects cable's transmission power. Figure 15 shows the affecting factors of PTFE dielectric cable under different ambient temperature. This need to be considered in engineering applications

Figure 15 Average Power Handling temperature affect factors



### 9. Capacitance

*Coaxial cable's capacitance is related to cable's dielectric constant and cable's characteristic impedance, Once these two parameters determined, the capacitance of the cable has been determined. Capacitance has nothing to do with cable's structure, size. When measuring dielectric strength in an AC voltage, it needs to think about the cable capacitance values, with the growth of cable length, the capacitance value increases, so that the leakage current increases, it is recommended to use DC measurements or measuring short cable.*

### 10. Cut-off Frequency

*Coaxial cable's cut-off frequency means energy can be transferred below a frequency. When the signal frequency is higher than this cut-off frequency, the signal can be passed; when the signal frequency is lower than the cut-off frequency, the signal output will be substantially attenuated. Cut-off frequency related to cable conductor's diameter and propagation rate, the larger cable's diameter is, lower the cut-off frequency will be. When beyond the cut-off frequency, VSWR and attenuation are not significantly increased, but we strongly recommend that the cable should be select below the cut-off frequency.*

### 11. Operating Temperature Range

*Cable operating temperature depends on its dielectric material and sheathing materials. In addition, only the silver-plated conductor is suitable for long working environment than 80 °C. Different dielectric material and sheathing materials operating temperature is as follows:*

| | |
|---|---|
| *Polytetrafluoroethylene PTFE* | *-75°C to +250°C* |
| *Polythene PE* | *-65°C to +80°C* |
| *Foamed polyethylene PE* | *-65°C to +80°C* |
| *Fluorinated ethylene propyleneFEP* | *-70°C to +200°C* |
| *Polyvinyl chloridePVC* | *-50°C to +85°C* |
| *ETFE* | *-65°C to +150°C* |
| *PFA* | *-65°C to +250°C* |
| *Nylon* | *-40°C to +105°C* |
| *Silastic* | *-70°C to +200°C* |

*The temperatures listed above are the temperature range for conventional models, detailed data must be provided by material manufacturers*

*In addition, some material's maximum operation temperature can be increased by irradiation method.*