

# Narrow Band Ultra Low VSWR Cable Assemblies

This article describes techniques for obtaining the highest possible performance over a limited frequency range

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Occasionally, a customer contacts our company with a request for cables with ultra low VSWR over a narrow bandwidth. This article will discuss methods for achieving the desired VSWR results.

Figure 1 shows a typical VSWR plot for a Kaman Instrumentation SiO<sub>2</sub> cable connected to a 50-ohm load. In this case, the VSWR highs and lows are primarily a result of discontinuities in the connector. Ideally, the connector is designed for 50 ohms. Also, because of variations of the dielectric constant of materials in the connectors, we see impedance variations. It is primarily these discontinuities and impedance variations which prevent broadband ultra low VSWR.

A relatively simple model for an SiO<sub>2</sub> coax cable with imperfect glass seals is shown in Figure 2. The characteristic impedance of the cable is easily controlled and is approximately 50 ohms. Each of the glass seals is 52 ohms.

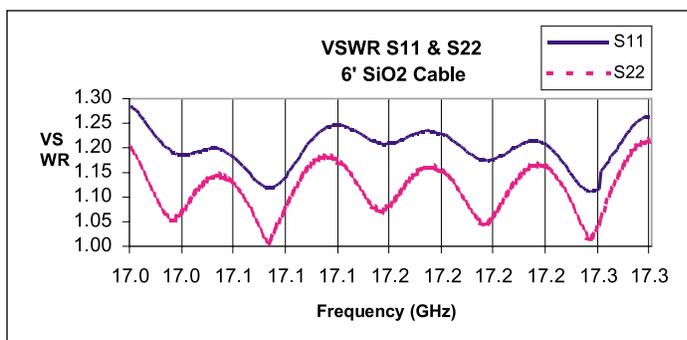
The input VSWR to this cable is calculated using transmission line theory (SI units are used in all calculations). In this model, we assume the cable is mated to a perfect source and load impedances of  $Z_{S,L} = 50$  ohms. The following equations (1) describe the cable

$l_c =$  length of cable

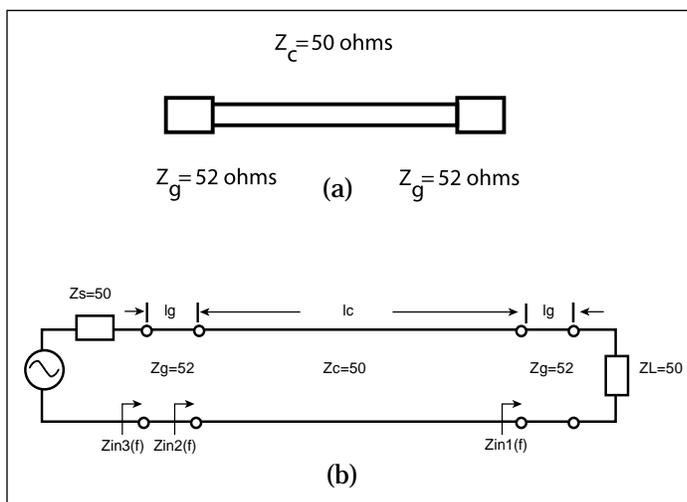
$$Z_{in1} = Z_{0g} \frac{Z_L + jZ_{0g} \tan(\beta_g l_g)}{Z_{0g} + jZ_L \tan(\beta_g l_g)}$$

$$Z_{in2} = Z_{0c} \frac{Z_{in1} + jZ_{0c} \tan(\beta_c l_c)}{Z_{0c} + jZ_{in1} \tan(\beta_c l_c)}$$

$$Z_{in3} = Z_{0g} \frac{Z_{in2} + jZ_{0g} \tan(\beta_g l_g)}{Z_{0g} + jZ_{in2} \tan(\beta_g l_g)}$$



▲ Figure 1. Typical VSWR for a coax cable.



▲ Figure 2. Simplified coax cable model: (a) physical representation; (b) transmission line model.

$l_g$  = length of glass

$$\beta_g = 2\pi f \sqrt{\mu_o \epsilon_o \epsilon_g}$$

$$\beta_c = 2\pi f \sqrt{\mu_o \epsilon_o \epsilon_c} = \frac{2\pi}{\lambda_c}$$

$$\rho_{in} = \frac{Z_{in3} - Z_s}{Z_{in3} + Z_s}$$

$$SWR = \frac{1 + |\rho_{in}|}{1 - |\rho_{in}|}$$

Most readers are familiar with the periodicity of VSWR over frequency. Figure 1 is a typical example of such periodicity. A quick look at the above equations reveals that the dominant factor in the periodicity is the term which appears as the argument of the tangent function. For a given length of cable, the frequency spacing between successive minima is approximated by

$$\beta_{c1} l_c - \beta_{c2} l_c = \pi$$

$$\Delta f = f_2 - f_1 = \frac{1}{2l_c \sqrt{\mu_o \epsilon_o \epsilon_c}} \quad (2)$$

Equation (2) is easily rearranged to relate cable length to frequency spacing between nulls

$$l_c = \frac{1}{2\Delta f \sqrt{\mu_o \epsilon_o \epsilon_c}} \quad (3)$$

Likewise, for a given frequency, the length of cable required to move between successive minima is approximated by

$$\beta_c l_{c1} - \beta_c l_{c2} = \pi$$

$$\Delta l = l_{c1} - l_{c2} = \frac{1}{2f \sqrt{\mu_o \epsilon_o \epsilon_c}} = \frac{\lambda_c}{2} \quad (4)$$

These are only first order approximations. Later measurements indicate second order effects influence the frequency spacing.

### Measured vs. predicted VSWR

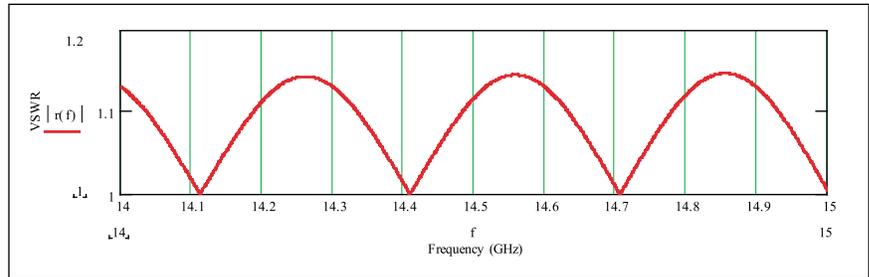
A sample cable with estimated parameters was modeled and tested. The frequency of interest is 14.0 to 15.0 GHz. The relevant parameters are

$$\epsilon_g = 3.8 \rightarrow Z_g = 52 \text{ ohms}$$

$$\epsilon_c = 1.73 \rightarrow Z_c = 50 \text{ ohms}$$

$$l_g = 0.07 \text{ inches}$$

$$l_c = 15 \text{ inches}$$



▲ Figure 3. Theoretical VSWR performance for a 15-inch cable.

The estimated frequency spacing between successive minima is

$$\Delta f = f_2 - f_1 = \frac{1}{2l_c \sqrt{\mu_o \epsilon_o \epsilon_c}} = 300 \text{ MHz} \quad (5)$$

The plot of the theoretical VSWR performance in Figure 3 shows the frequency spacing between minima to be roughly 300 MHz. The measured VSWR data in Figure 4 shows an average frequency spacing of 320 MHz at the low end of the band to 250 MHz at the high end of the band.

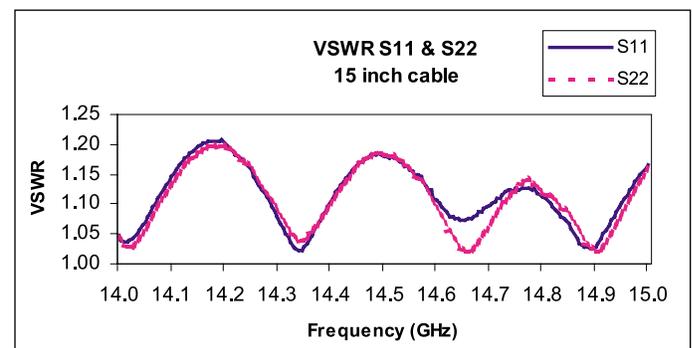
As noted above, the frequency spacing between nulls decreases with increasing frequency. This occurs as the second order effects, such as junction capacitances between the bulk cable and the connectors, become significant. The graphs verify the primary factor for determination of the frequency spacing between successive minima is the length of cable separating the connectors.

Equation (4) predicts that the minima can be moved with frequency; that is, a VSWR low can be tuned to a specific frequency by cutting off or adding a fraction of a wavelength of cable. For example, to move the minimum at 14.65 GHz to 14.86 GHz (an arbitrary choice), the technician would need to cut off approximately

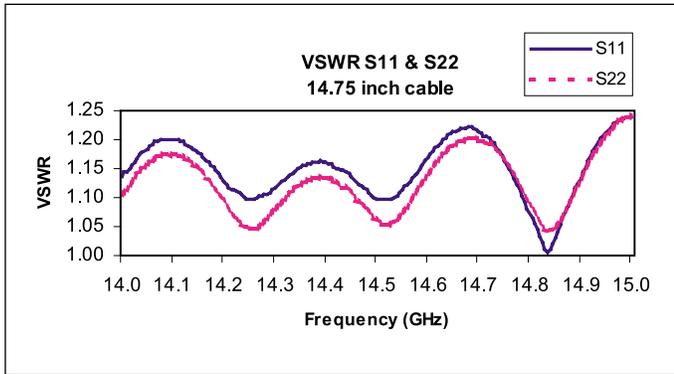
$$\Delta l = \frac{\lambda_{14.86}}{2} \left( \frac{14.86 - 14.65}{0.243} \right) = \frac{0.0153}{2} (0.864)$$

$$= 0.0066 \text{ m} = 0.26 \text{ inches}$$

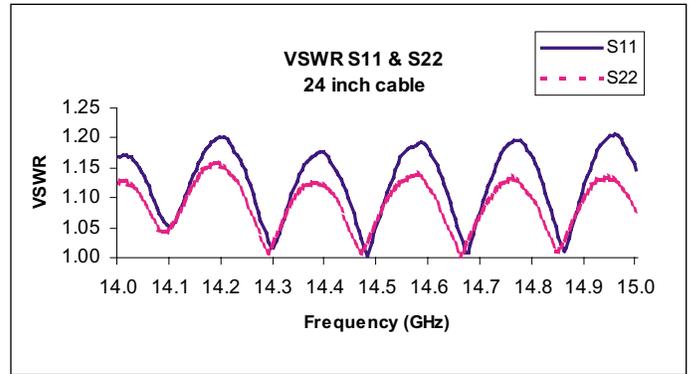
$$\epsilon_c = 1.73 \quad (6)$$



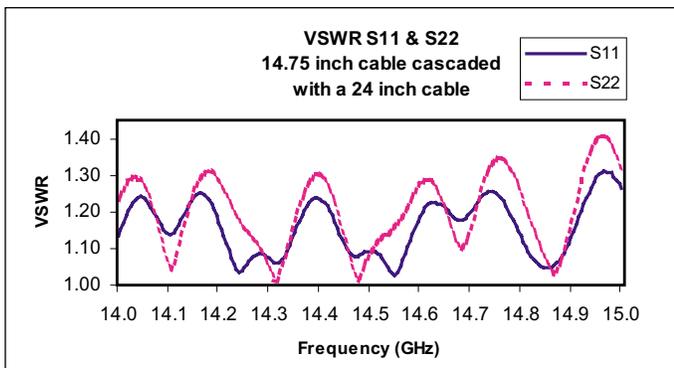
▲ Figure 4. Measured VSWR performance for a 15-inch cable.



▲ Figure 5. Measured VSWR performance for the 14.75-inch cable example.



▲ Figure 6. Measured VSWR performance for the 24-inch cable example.



▲ Figure 7. Measured VSWR cascade for the cables shown in Figure 5 and Figure 6.

The frequencies are determined as follows:

- 14.86 GHz is the frequency for the desired minimum.
- 14.65 GHz is the first minimum to the left of the desired minimum.
- 0.243 GHz is the frequency spacing between the null to the left of the desired minima and the null to the right of the minima. Using the actual frequency spacing accounts for second order effects.

Note that the frequency spacing between nulls is inversely proportional to the cable length; that is, as the cable is shortened, the frequency spacing increases. Thus, any given null will move upward in frequency as the cable is shortened.

## Results

The 15-inch cable was shortened by 0.25 inches. As can be seen in Figure 5, the null at 14.65 GHz has been moved to 14.84 GHz. This not exactly the 14.86 GHz goal, but it is close enough for demonstration.

## Cascade of two cables

The goal in designing cables with nulls at specific fre-

quencies is that the cable is mated to a system with a VSWR which has been minimized at the same frequency. An approximation to such a system is a cascade of two cables with minima at the same frequency. The cable of Figure 5 is mated to a second cable, with a VSWR response shown in Figure 6.

The measured VSWR for the cascade of the two cables is shown in Figure 7. As expected, a VSWR null occurs at roughly 14.85 GHz.

## Theoretical check

Using Equation (1), a cascade of two cables is modeled and performance comparisons made for variations in the connector impedances. The lengths have been chosen to coincide with nulls at 14.7 GHz. In both cases, the output of Cable 2 is mated to a perfect 50 ohm load, and the input of Cable 1 is mated to a perfect 50 ohm source impedance. (Figures are on the following page.)

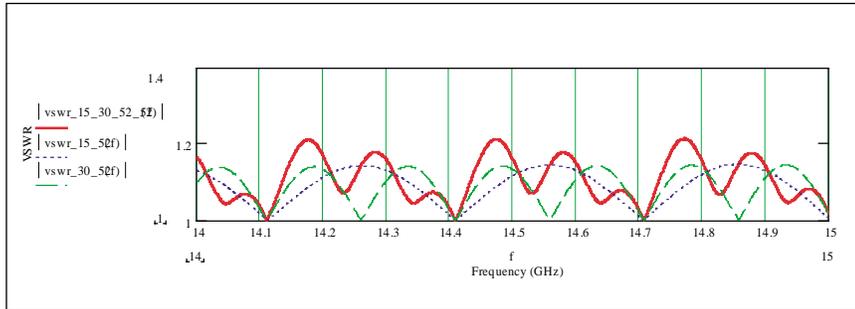
### Case 1 (Figure 8):

Cable 1:	Cable 2:
$Z_{Connector} = 52$ ohms	$Z_{Connector} = 52$ ohms
$Z_{Cable} = 50$ ohms	$Z_{Cable} = 50$ ohms
$length = 15$ inches	$length = 30$ inches

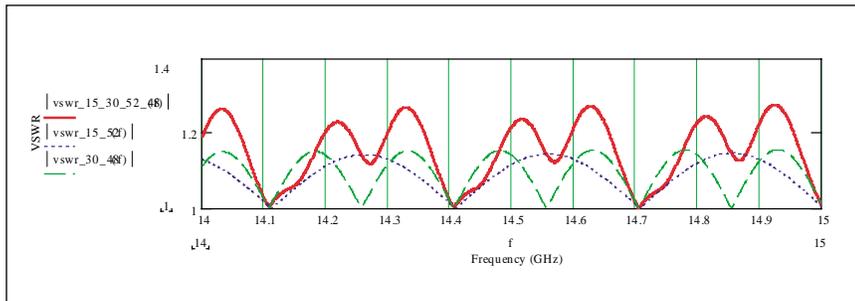
### Case 2 (Figure 9):

Cable 1:	Cable 2:
$Z_{Connector} = 52$ ohms	$Z_{Connector} = 48$ ohms
$Z_{Cable} = 50$ ohms	$Z_{Cable} = 50$ ohms
$length = 15$ inches	$length = 30$ inches

In both cases, the individual cables were tuned for nulls at 14.7 GHz. When cascaded together, a null at 14.7 GHz remained. In Case 1, the impedance mismatches in the connectors were identical and resulted in a lower VSWR for the cascade than shown in Case 2, where the connector impedance of Cable 1 differed from that of Cable 2.



▲ Figure 8. Theoretical cascade of two coaxial cables with similar connector impedances, tuned for 14.7 GHz.



▲ Figure 9. Theoretical cascade of two coaxial cables with dissimilar connector impedances, tuned for 14.7 GHz.

## Bandwidth

We assume that one-sixth of the frequency band between successive minima has VSWR low enough to meet our needs. Therefore, we estimate the maximum bandwidth of ultra low VSWR for a given length of coax cable as:

$$BW = \frac{1}{6} \Delta f = \frac{1}{6} \frac{1}{2l \sqrt{\mu_o \epsilon_o \epsilon_c}} \quad (7)$$

For the 14.75 inch cable that was built, the estimated bandwidth of ultra low VSWR is 50 MHz, which is in agreement with the measured data. In the case of higher frequency bandwidths, this estimate will have to be reduced as the result of second order effects.

## Phase matching

Provided cable of similar dielectric is used, phase matching is possible when two or more cables are matched for VSWR. In general, the absolute phase length of the cables will differ by multiples of 180 degrees,  $n = 0, 1, 2, \dots$ ; VSWR matching and phase matching to  $\pm 20$  percent is easily achieved.

## Practical considerations

The basic model is a function of the glass beads in the connectors and the length of cable. As the length of the

cable becomes shorter, the glass beads will become more influential. Kaman has found through experience that the model works adequately for cables as short as 4 inches. Bandwidth is inversely proportional to cable length. As such, the longer the cable, the narrower the bandwidth.

The cutoff necessary to move the VSWR minima is dependent on the dielectric constant of the cable. The accuracy of the cutoff will be dependent on how closely the dielectric constant of the cable is known, properly accounting for second order effects.

Second order effects such as junction capacitance are significant at microwave frequencies in the range of 14 to 15 GHz. These effects were compensated for in the determination of cut length by measuring the actual frequency spacing between successive minima about the desired frequency minima.

The actual VSWR performance of cascaded devices will depend on the impedance highs and lows, as well as inductive, and capacitive discontinuities of each device. In the case presented, the cable and connectors were very similar.

## Conclusion

VSWR in a coax cable is influenced by the characteristic impedance of the cable, and, generally, the characteristic impedance of the connectors. Building cable and connectors which meet the nominal 50-ohm characteristic impedance will assure good VSWR performance. For applications requiring the best possible VSWR over a narrow band, the cable can be cut to length and VSWR minima can be tuned to a particular frequency. ■

## Reference

1. D. M. Pozar, *Microwave Engineering*, New York: John Wiley & Sons, 1990.

## Author information

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