A PHASE COMPENSATED, MOTION INSENSITIVE COAXIAL CONNECTOR

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Abstract

A new and unique connector design is presented that employs a novel circuit element to compensate for phase changes that occur with connector movement. The connector design is capable of providing better than 40 dB of improvement over the conventional connector in the modulation sideband levels caused by relative motion such as that seen under mechanical vibrations. This improvement may be achieved with practical designs over moderately large bandwidths up to 20% or more at microwave frequencies.

Introduction

The concept of a phase compensated coaxial connector [1] was developed out of concern for spectral purity problems previously experienced with T/R module connections on an electronically scanned phased array antenna. Blind mate connectors, designed for easy connect/disconnect operations, have the disadvantage that motion, between the connector pairs is possible if both ends of the pair are not securely mounted. With this motion the electrical characteristics of the connector may vary sufficiently to degrade system performance. For example, phase modulation sidebands caused by mechanical vibrations (or other causes) are typically required to be below -110 dBc for many modern radar systems. To meet this requirement, using conventional connectors, the relative movement between connector pairs would need to be kept to less than 10^{-6} wavelengths. At 10 GHz, this distance is about 1.2 micro inches. One approach to solving the modulation problem is to hard mount both ends of the connector pair in such a way as to virtually eliminate the relative motion between the connector ends or to reduce this motion below some acceptable level. This approach, however, may not be possible for some mechanical structures or may be too difficult or expensive to implement. An alternate approach is to use a connector that is insensitive to this motion, i.e., designed not to produce phase shifts as the connector pair separates under vibration. Such a connector was developed as a part of a Westinghouse IR&D task and is described in the following paragraphs.

Design Concept

Figure 1 shows the connector concept. The connector uses a series open circuited stub, nominally a quarter-wavelength long, to couple

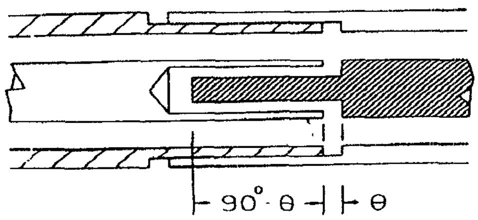

Figure 1

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the two inner coaxial conductors. The design makes use of this coupling in such a way as to keep the transmission phase constant with relative motion between the ends of the connector pair. As the connector separates, the length of the series stub decreases which tends to compensate for the increased phase length caused by the separation.

Figure 2 shows the equivalent circuit of the connector. The circuit is a series open

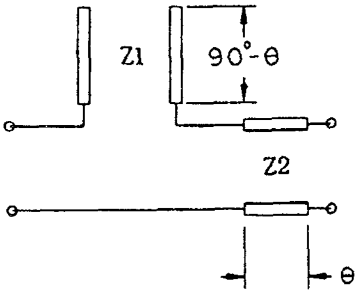

Figure 2

circuited length of transmission line of normalized characteristic impedance Z1 followed by a short section of line of normalized characteristic impedance Z2. The electrical length of short section of line Z2 is θ. The electrical length of the series stub is $90^o - \theta$ at the design center frequency. If we compute the transmission coefficient of the circuit, S_{21}, we find that the transmission phase can be written as:

$$\phi_{21} = \tan^{-1}[-(Z2 - Z1 + 1/Z2) \tan \theta/(2 + (Z1/Z2) \tan^2 \theta)]$$

By setting the factor (Z2 - Z1 + 1/Z2) equal to zero, ϕ_{21} becomes zero, independent of θ. Thus, the circuit is phase compensated, i.e. does not change phase as θ is varied.

The example above clearly demonstrates that, in principle, a connector can be made to eliminate entirely, changes in phase with separation. Several things, however, must be pointed out. First, to satisfy the impedance relationship between Z1 and Z2, the normalized impedance of the stub, Z1, must be at least 2. (This requires a 100 ohm stub impedance for a 50 ohm connector). A high stub impedance results in awkward or unrealizable dimensions for the coaxial conductors. Also, the bandwidth of the circuit is small and decreases as Z1 is made higher. For the minimum value of Z1 = 2 (100 ohm), the bandwidth in which the return loss is better than 20 dB (V.S.W.R. = 1.22), for example, is only about 12%.

To overcome the shortcomings of the circuit of Figure 1, the circuit of Figure 3 was

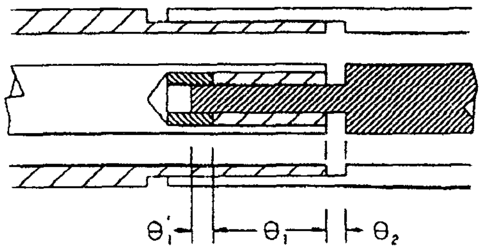

Figure 3

developed. This circuit allows an extra degree of freedom to choose the dimensions of the stub to allow for convenient values. In this circuit, two different dielectric materials are used to load the series stub. At the end of the stub, a high dielectric constant material (ε_1') is used to provide a low impedance and a high sensitivity to changes in length. In the inner section, the dielectric constant (ε_1) of the material is chosen to properly transform the low impedance at the end of the stub to the required high impedance at the input of the stub. (The required impedance is the same as that for the circuit of Figure 1). The length of the inner section is made approximately a quarter wavelength. The particular choice of dielectrics depends on the desired bandwidth as well as to achieve realizable coaxial dimensions. An impedance match at the band center is achieved if the lengths are chosen by the relationship

$$\tan \theta_1 \tan \theta_1' = (\varepsilon_1 / \varepsilon_1')^{1/2}$$

The circuit of Figure 3 was analyzed for several combinations of dielectric materials and dimensions for the coaxial conductors. It was found that a wide range of designs that achieved both wide bandwidths and convenient dimensions were possible. Bandwidths of 30 - 40% were achieved for some designs with better than 20 dB return loss. The phase shifts for these designs were reduced dramatically over those produced by conventional connectors (uncompensated) for the same separations. Improvements of 100:1 were achieved over bandwidths of 15%.

Prototype Connector Design

To demonstrate that the design concept could be put into practice, a prototype connector was fabricated at Gilbert Engineering [2]. The prototype connector built by Gilbert was designed to the configuration of Figure 3. The connector uses a Delrin dielectric (εr = 3.8) at the tip of the stub. The remaining portion of the stub is filled with air. The dimensions of the inner and outer stub conductors were made equal to 32 mils and 64 mils respectively. The stub extends 10 mils into the Delrin in its initial position. The air filled section is 264 mils long. The characteristic impedances of the stub are 39.7 ohms in the air filled section and 22.2 ohms in the Delrin. The 50 ohm sections of the connector are air filled with inner and outer diameter dimensions of 65 mils and 150 mils respectively.

Figure 4 shows the computed results of the Gilbert connector. The connector was designed to operate at a center frequency of 10 GHz.

Freq GHz	DB (S11) Intl	DB (S11) Final	DB (S21) Delta	Ang (S21) Delta
6.5	-12.53	-11.60	-0.062	0.796
7.0	-14.06	-13.03	-0.048	0.622
7.5	-15.79	-14.62	-0.037	0.465
8.0	-17.85	-16.46	-0.027	0.327
8.5	-20.44	-18.68	-0.020	0.209
9.0	-24.02	-21.54	-0.013	0.112
9.5	-30.04	-25.67	-0.007	0.039
10.0	-69.59	-33.48	-0.002	-0.007
10.5	-30.22	-40.69	0.004	-0.023
11.0	-24.12	-28.11	0.010	-0.006
11.5	-20.51	-23.18	0.018	0.052
12.0	-17.91	-20.04	0.028	0.156
12.5	-15.84	-17.72	0.040	0.315

Figure 4

The 20 dB return loss (VSWR - 1.22) bandwidth for this design is approximately 3.3 GHz. The computations were made for an initial setting, with the connector fully engaged, and for a final setting where the connector is disengaged by 8 mils. (The 8 mil separation was chosen arbitrarily for the purpose of measurement only. In actual practice, the separations would be only a few micro inches under mechanical vibrations.) The computed phase shift for the 8 mil separation was less then 0.1 degree over a 2.5 GHz bandwidth, and less than 0.025 degrees over a 1.5 GHz bandwidth. The conventional connector would produce a 2.5 degree phase shift for the same separation. The new design provides better than a 100:1 improvement over the conventional connector for the 1.5 GHz bandwidth. Figure 5 shows the computed phase shift for the 8 mil separation and for three intermediate settings over the frequency band from 6.5 to 12.5 GHz.

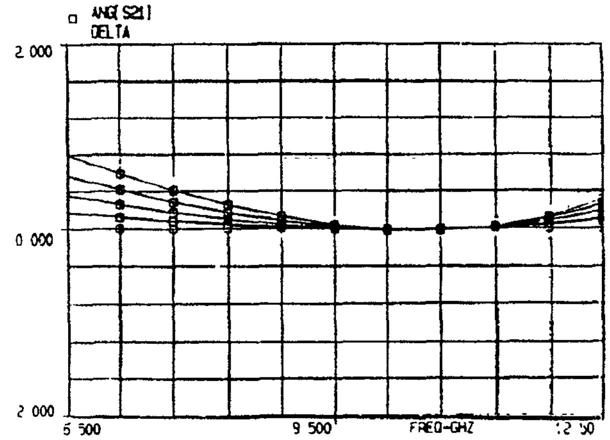

Figure 5

Figure 6 shows the measured results of the prototype connector. The measurements were made form 6.5 to 12.5 GHz for four connector settings, an initial setting, where the connector is fully engaged, and for four settings, an 8 mil separation and three intermediate positions.

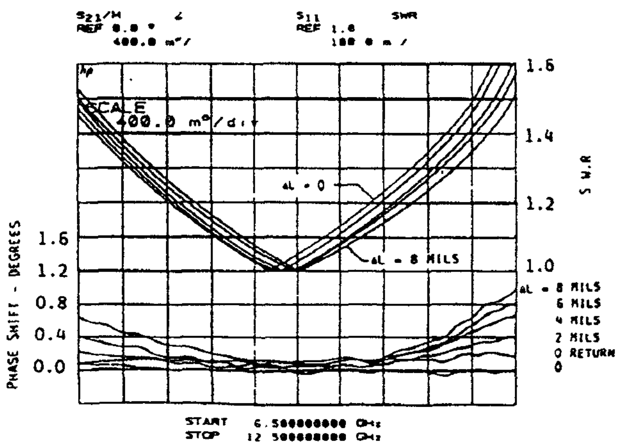

Figure 6

The results compare very well with the computed results of Figure 5. The maximum phase shift is less than 0.2 degree over a 2.5 GHz band and about 0.1 degree at the band center. The 0.1 degree error is believed to be within the repeatability of the measurement. (The measurement required that each time the connector was set to a new position it was necessary to disconnect and reconnect the test connector to the measurement equipment.) The connector V.S.W.R. measured less than 1.20 over a 30% bandwidth and was virtually matched (V.S.W.R. = 1.00) at the band center. The V.S.W.R. response moved in frequency, as predicted, as the connector separated; however, the transmission loss modulation caused by the V.S.W.R. change is small. The A.M. sidebands caused by the loss modulation are significantly lower than the P.M. sidebands, and are usually not of concern. (In actual use, the separations would be orders of magnitude less than those in the measurement and the operating band would remain virtually fixed/in frequency.)

Conclusions

The excellent agreement between the measured and computed results demonstrate that a phase compensated connector is indeed feasible as a practical device. Better than a 25 to 1 reduction in the phase shift over the conventional connector was measured with the prototype connector. It is believed that the actual improvement is better since the repeatability of the measurement appeared to be about only 0.1 degree. It is also believed that the 100:1 improvements that are calculated can be achieved in practice. Potentially, the new connector design could improve by as much as 40 dB or better, the P.M. sidebands experienced under mechanical vibrations.

Acknowedgements

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References

[1] U.S. Patent No. 5,327,111

[2] Gilbert Engineering, 5310 W. Camelback, Glendale, AZ 85301-7597 USA