Extending Rigid-Flex Printed Circuits to RF Frequencies

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Abstract

Rigid-Flex circuits, consisting of both rigid and flexible wiring layers, can be engineered to operate into the microwave region. This paper shows that the hybrid construction of flexible polyimide stripline coupled to rigid epoxy interconnect circuitry can operate up to about 5 GHz. Careful design of the external circuitry to the rigid-flex circuit is essential and, in particular, the coaxial interface is addressed in the paper. Design improvements to the interconnects were made by first measuring test circuits using an automatic network analyzer and then modeling the interconnects on Touchstone. Excessive discontinuities were identified and corrected. The paper further discusses potential applications for the rigid-flex circuitry and how this technology can be extended to still higher frequencies.

Rigid-Flex Circuitry

In reviewing the applications of rigid printed circuit boards to the high frequency domain over the past twenty years, a significant amount of characterization and development data can be found. This is not the case, however, when extending such a review to rigid-flex printed circuits. Since the early 1980's, rigid-flex circuits have been finding their way into increasing numbers of military, avionics and commercial products. Rigid-flex is defined as multiple rigid board sections interconnected by integral flex circuit sections. The dielectric and bond film layers can vary between sections, but there is always at least one and usually multiple planes of continuous copper throughout the entire circuit. Rigid-flex's inherent ability to conform to small form factors and to eliminate connectors and multiple assemblies makes it an ideal candidate for portable electronics products, including wireless applications. Examples of applications currently being explored or developed by Teledyne Electronic Technologies (TET) include:

- rigid-flex as a packaging platform for small form factor wireless products
- wireless products incorporating an equivalent 50 ohm coax line (as a flex circuit) into a rigid board assembly
- products integrating a printed circuit antenna into a board assembly and/or cable
- low power microwave assemblies such as VSAT systems
- cellular base stations

High Frequency Testing of Rigid-Flex

Many of the applications under development at TET utilize a REGAL 5 rigid-flex construction, as shown in Figure 1. A controlled impedance test circuit developed for a commercial avionics customer and built with the REGAL 5 technology was chosen as a suitable test vehicle for RF/Microwave characterization. The major

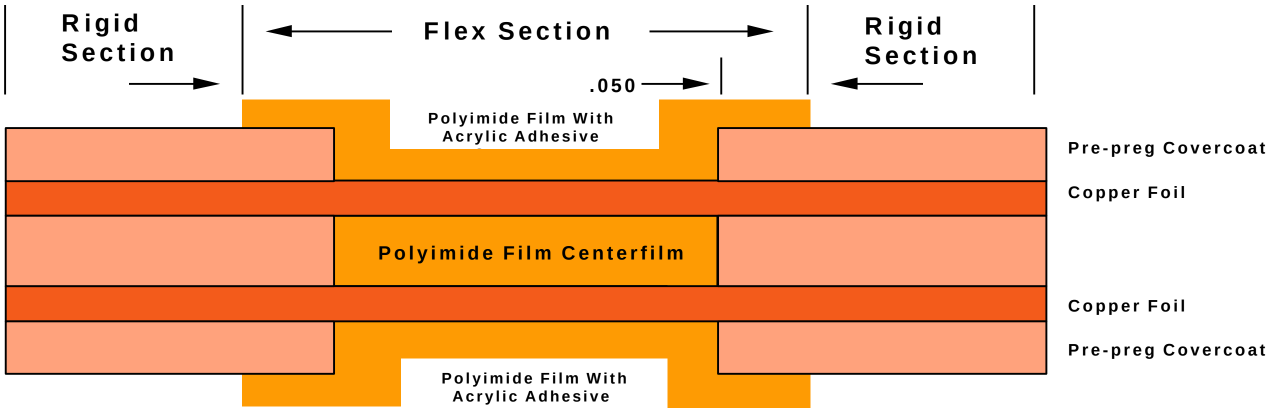

Figure 1.
REGAL 5 Rigid-Flex Circuit Construction

challenge associated with adapting this test circuit to high frequency testing was in the engineering of the connector interface. The circuit was modified to accommodate an Omnispectra Model 2062-0000-00 gold-plated connector in the rigid section, depicted in Figure 2. Testing was done on an HP8510 Network Analyzer.

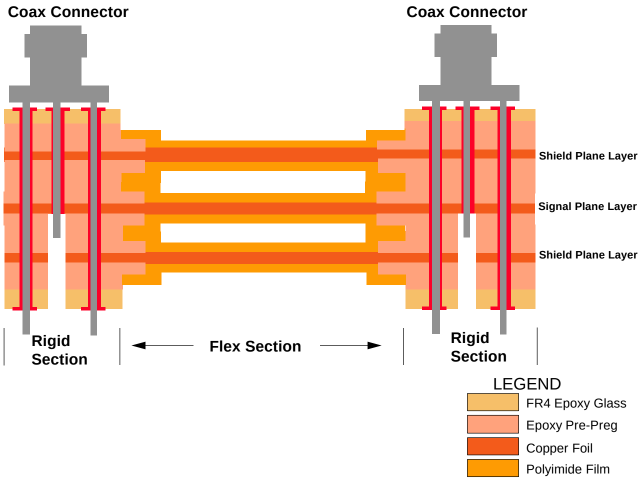

Figure 2.
Original Test Coupon

Figure 3.
Time Domain Response for Original Coupon

The circuit was originally designed as a five-layer rigid. three-layer flex. In the original assembly, the connector shell was placed on top of the rigid portion’s outer dielectric layers and the ground pins were allowed to extend through plated-through-holes beyond the bottom of the circuit. The time domain response for this assembly is shown in Figure 3; the response is the same as what would be obtained with a time domain reflectometer. Peaks are shown for mismatches at times equal to the propagation time from the input to the mismatch and back. The input port exhibits a large reflection of about -4 dB when the bandwidth is 0.5 - 10 GHz, which would not be acceptable for many high speed digital and microwave signals.

To improve the performance of the test coupon assembly, modifications were made to the connector/rigid board interface by soldering the connector shell flush down onto the board surface and machining the ground and signal pins flush with their respective conductor planes in the circuit. (See Figure 4.) In this configuration, the time domain reflection from the input connector is -9.5 dB, which is acceptable for many applications. The next

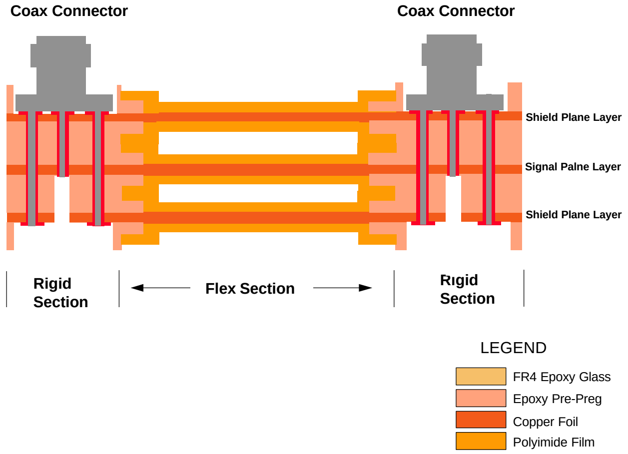

Figure 4.
Improved Test Coupon

Figure 5.
Time Domain Response for Improved Coupon

reflection shown in Figure 5 is the interface of the rigid portion to the flex portion. This value is -34 dB, illustrating the excellent matching characteristics of the REGAL 5 construction. The third value is the other rigid-to-flex interface and the fourth is the output connector. These improved performance characteristics have allowed a calculation to be made of a complete coupon equivalent circuit, which appears in Figure 6.

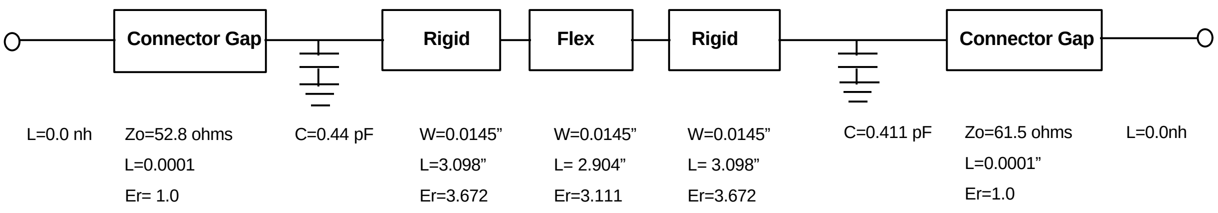

Figure 6.
Equivalent Circuit for Rigid-Flex Test Coupon

The connector to stripline interface calculates as a simple 4.4 pF capacitor to ground. Equivalent loss tangents for the rigid and flex sections have been obtained and are presented as a function of frequency in Table 1. At 5 GHz, the overall coupon loss has been reduced from 10 dB for the original assembly to 5 dB for the improved assembly.

COMPOSITE LOSS TANGENT CALCULATED FROM THE OPTIMIZED TOUCHSTONE FILE			
Frequency (MHz)	**Loss Tangent**	**Frequency (MHz)**	**Loss Tangent**
50	0.0118	4050	0.0158
100	0.0124	5050	0.0161
200	0.0130	6050	0.0163
400	0.0136	7000	0.0164
1050	0.0145	8050	0.0166
2000	0.0151	9050	0.0167
3050	0.0155	10050	0.0168

Table 1. Loss Tangents from Rigid-Flex Test Results

In most circuits, the coaxial interfaces will not be used; instead the microstrip circuit on top of the rigid board will interface with the rigid-flex stripline. The same considerations must be applied in keeping groundplane and signal spacings very short and higher mode generation prevented. Plated through via holes surrounding the signal interface is one way to accomplish the higher mode generation prevention.

Future Work

For further improvements in rigid-flex circuit performance, lower loss dielectrics and higher frequency connectors must be employed. The majority of low loss dielectric materials available or under development for rigid printed circuit boards are compatible with rigid-flex circuit manufacture. Examples of two materials being evaluated by TET for rigid-flex applications are Rogers RO2800 (commercially available) and Superex LCP-TL-100, a balanced liquid crystal polymer film currently being offered in development quantities. The dielectric constant and dissipation factors for these materials are shown in Table 2, in comparison with the more conventional materials used in the tested rigid-flex constructions. In some cases, the laminate form available for these materials necessitates the use of a separate bond film material, such as Arlon 6700. This creates an asymmetrical cross-section, from the perspective of equivalent dielectric constant. Stripline impedance formulae require the same dielectric constant on either side of the center conductor. To permit a synthesis of a proper 50 ohm line, a compensation needs to be calculated for the bonding film(s). One relatively simple correction technique is to make an equivalent spacing for the side containing the bond film based on the parallel plate capacitance formula. If X_1 is the bond film thickness and X_2 the dielectric thickness, then one side has a spacing of $X_1 + X_2$ and the other side has a spacing of X_2. The stripline is treated as offset, and formulae exist for uniform offset striplines. For these calculations, therefore, the spacing $X_1 + X_2$ must be made equivalent to X_{eq} to allow a dielectric constant of the primary dielectric material to be used for both sides. If ε_{r1} and ε_{r2} are the dielectric constants of the bond film and primary dielectric, respectively, then the equivalent spacing on the bond film side is $X_{eq} = \varepsilon_{r2}(X_1/\varepsilon_{r1} + X_2/\varepsilon_{r2})$. Using this equivalent spacing on the bond film side with the same ε_{r2} dielectrics on both sides should yield a near correct result when the offset stripline formulae are applied.

Material	**Dielectric Constant (ε_r)** (@ 10 GHz)	**Dissipation Factor**
FR4 (Epoxy/Glass)	4.3	0.027
Polyimide	3.4	0.018
RO 2800	2.7	0.003
LCP-TL-100	2.6*	0.006*
CuClad 6700	2.35	0.0025

* (@ 1 GHz)

Table 2. Materials Comparisons

Additional work may include the calculation and measurement of signal propagation characteristics when a rigid-flex circuit is tested in a tight bend radius or folded configuration, as is the case in many constrained product form factors. The results of the work described in this section will be published in the near future.

Summary

A rigid-flex printed circuit coupon assembly has been electrically tested up to a frequency of 10 GHz. Early results identified the source of significant losses in the test assembly. Improvements in the connector-to-multilayer rigid section interface were made during the testing program, allowing for the effective characterization of the circuit construction. Results showed that, after minimizing losses at the connectors, the rigid-flex construction exhibited excellent impedance matching characteristics, with loss values acceptable into the microwave domain (~5 GHz). These data provide encouragement for the utilization of rigid-flex circuitry as an interconnect medium for wireless products, particularly those applications benefiting from the inherent advantages of rigid-flex in small form factors. The testing and associated modeling also have helped to define an approach to calculating performance in constructions employing newer materials with asymmetrical cross-sections.