Wideband mm-wave Compensated 90° Bends for Grounded Coplanar Waveguide and Microstrip Transmission Lines on Flexible LCP Substrates

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Abstract

The purpose of this paper is to describe an approach for creating the first truly wideband (10-90 GHz), high performance, compensated 90° bends for planar Transmission Lines fabricated on Liquid Crystal Polymer (LCP) for use with mm-wave applications. These bends are very critical components for the miniaturization of high performance packages used for integrated multi-layer millimeter-wave front-ends on low-cost, organic, flexible substrates. In this paper we describe a method for creating ultrawideband, low-cost, high performance bends for Microstrip and Grounded Coplanar Waveguide (CPWG) lines. The simulated S-parameters demonstrated a Return Loss below -30 dB from 10 GHz-90 GHz for the Microstrip line bends and below -22 dB for the CPWG bends. These bends are capable of operating for applications ranging from X to W-bands.

I. Introduction

Millimeter wave circuits used for applications, such as: automotive collision avoidance radars, short range broadband wireless communications, and mm-wave imagers require low manufacturing costs, excellent performance, a high level of integration and real estate efficiency [1]. In order to achieve all of this, a low cost, high performance substrate needs to be used and that is capable of being fabricated using commercially available specifications. Optimized or minimized circuit real estate needs to be performed as well.

Liquid Crystal Polymer (LCP) offers a unique, low-cost, all-in-one solution for high frequency designs due to its low loss (dielectric loss tangent or tanδ 0.002-0.004 till 110 GHz and a dielectric constant ε_r 2.9-3.1), near hermetic characteristics as a packaging substrate, mechanical flexibility, and thermal stability which are excellent specifications for several applications such as automotive and space [2]. Another excellent property about LCP is that LCP can be engineered to have an x-y coefficient of thermal expansion (CTE) between 0 ppm/°C and 40 ppm/°C. As a result,

this unique process can achieve a thermal expansion match in the x-y plane with many commonly used materials, such as Cu (16.8 ppm/°C), Au (14.3 ppm/°C) Si (4.2 ppm/°C), GaAs (5.8 ppm/°C), and SiGe (3.4-5 ppm/°C).

In order to miniaturize mm-wave components such as microstrip or coplanar waveguide (CPW) transmission lines, the bending of these structures becomes necessary. Another reason that necessitates the bending of these feeding lines is their integration with a T/R module which has stringent

dimension requirements. This is illustrated in Fig. 1 below that shows a conceptual mm-wave RF front-end system.

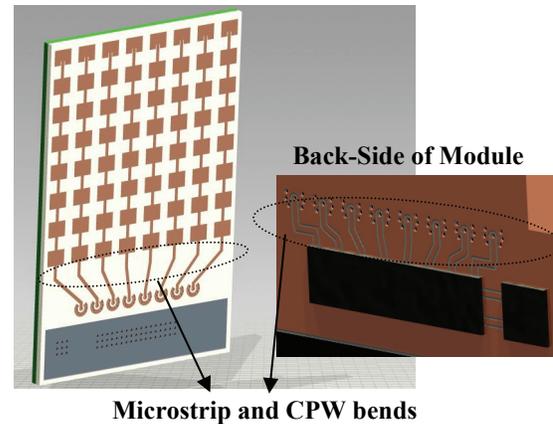

Back-Side of Module

Microstrip and CPW bends

Fig. 1. Schematic of the proposed 3D radar RF front-end showing the location of the microstrip and CPW bends.

The bending of these lines, however must be accomplished in a way that allows us to acquire the optimum performance and must be treated seriously, especially in mm-wave frequencies. Previous work includes [3] the placement of air-bridges near the CPW bends. However, the inclusion of air-bridges adds undesired capacitance on the line which can further deplete the performance of the CPW line. Two methods that have been proposed in the past for further reducing this effect are the chamfering [4] of the bend and the inclusion of high-impedance line sections under the air-bridge which reduces the parasitic capacitance on the line [5].

However; these methods require the addition of short matching networks. There are also few other drawbacks upon using air-bridges. For instance, air-bridges introduce strict fabrication requirements in the form of micromachining which becomes a very challenging task due to the small dimensions at frequencies of 60 GHz and above. In addition, air-bridges are very sensitive to environmental conditions like dust and humidity. Furthermore, high impedance lines necessary to reduce the parasitic capacitance in air-bridges might need to have a width that is less than what commercially available fabrication processes can achieve.

This paper describes a design that achieves a very good RF performance by utilizing a mitering of the microstrip transmission line. For the Grounded Coplanar Waveguide (CPWG) design, good RF performance is demonstrated by mitering of the signal line and of the top ground planes of the CPWG and the addition of vias at critical locations in order to suppress spurious effects. Both proposed circuits take into

consideration the design rules and tolerances that are found in commercially available LCP fabrication techniques.

II. Design Approach

The goals of the design are the following:

- Minimize return and insertion losses for Microstrip and CPWG 90° bends.
- Reduce cost through the use of smallest possible board real estate (minimum number of vias, short traces) and the use of mechanical instead of laser drilled vias.
- Utilize commercially available design rules.
- Achieve ultra wideband operation in order to reduce the sensitivity of the design to fabrication and assembly tolerances.

A. CPWG Line Bends

A design approach which allows wideband, high-performance 90° bends on CPWG is presented in this section. The structure schematic is shown in Fig. 2. In this design approach, both the signal and the ground planes are chamfered. The CPWG line uses periodic vias placed at 750 μm separation with a radius of 3 mils (~ 75 μm) in order to deliver exceptional transmission performance at such high frequencies. This separation distance was chosen as the optimum for: 1) best RF performance and 2) minimum number of vias used. Furthermore, vias are used to suppress the parasitic parallel plate and slot-line modes. The location of the additional vias at the bend (as pointed out in Fig.2) is very critical for achieving the good performance of the bend and significant effort was invested in optimizing this. To the authors' knowledge, this is the first time that such an approach for optimizing CPWG bends has been proposed. The via diameter and inter-via spacing are based on low-cost, commercially available fabrication processes compatible with LCP substrates, and therefore the vias can be easily manufactured. The same figure also includes a field plot of the electric field as it propagates on the CPWG line.

The simulated response of the structures is presented in Figs. 3 and 4. Fig. 3 summarizes the return loss of the structure while Fig. 4 shows the insertion loss. It is clear that the sharp corner bend cannot be used for frequencies higher than 60 GHz due to its Return Loss performance. Upon chamfering the bend, one can observe the improvement in the performance up to 75 GHz but not beyond 75 GHz. The final design that includes both the chamfered bend and the vias is shown to have good performance at frequencies up to 90 GHz.

A sensitivity analysis was performed as well by varying the position of the vias in the x and y directions ranging from -3 to +3 mils with increments of 1.5mils. These specifications are typically provided by fabrication facilities to ensure the validity of the design upon fabrication. It was observed that the worst case scenario result yields a Return Loss that is only 2 dB worse and yet still under the -20dB line. This is illustrated in Fig. 5 below for all variations of via positions.
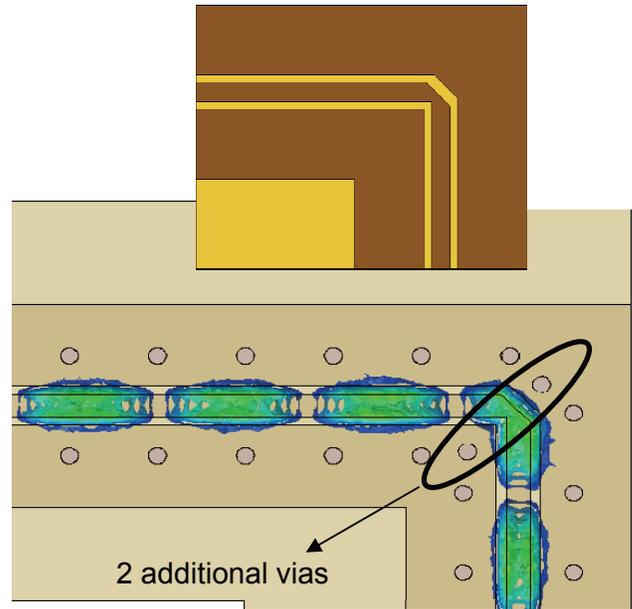
Mitering of signal and ground

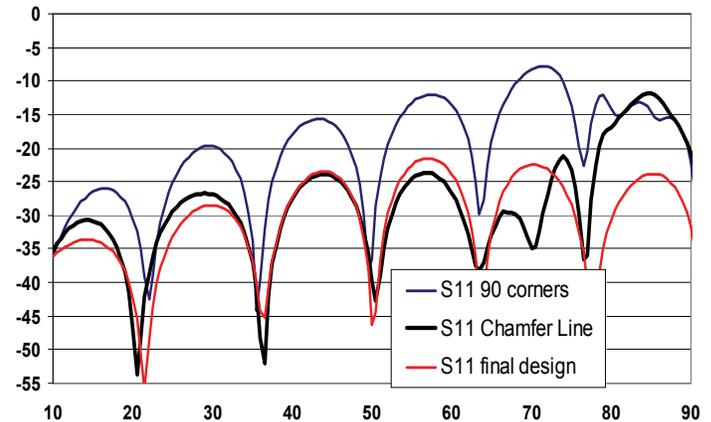Fig 2. Schematic of CPWG bend.

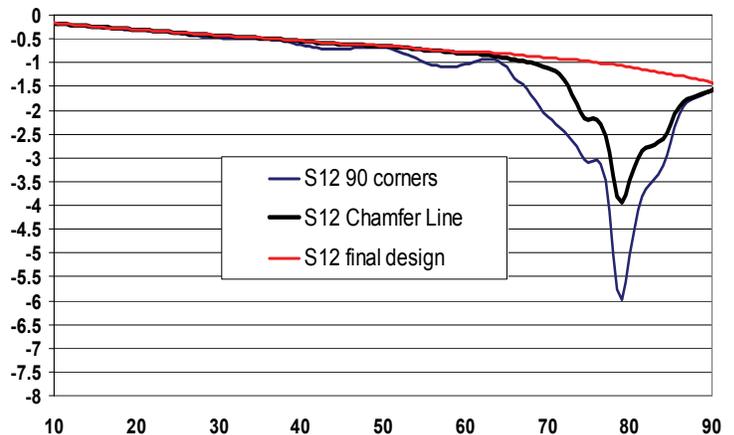Fig 3. Simulated Return Loss (dB) vs. Freq (GHz) of various 90° CPW bends.

Fig 4. Simulated Insertion Loss (dB) vs. Freq (GHz) of various 90° CPW bends.
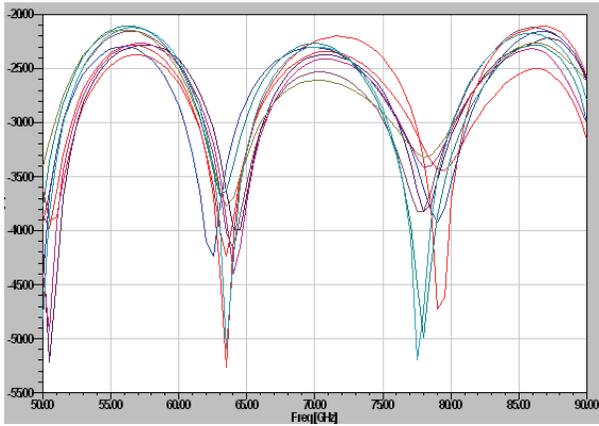
Fig 5. Simulated Return Loss (dB) vs. Freq (GHz) of various positions ofvias (sensitivity analysis).

B. MSTRIP Line Bends

A design approach which allows wideband, high-performance 90° bends on microstrip is presented in this section. The structure schematic is shown in Fig. 6 [6]. The Return Loss is shown in Fig. 7 where the comparison between a sharp corner and a mitered corned is presented. In our design approach, the bend was mitered until the optimum response (lowest S_{11}) was achieved. It is clear from the simulated response that there is a 20 dB improvement at 77 GHz (frequency allocation used for automotive radar application) and 25 dB improvement at 94 GHz (imager application). Fig. 8 shows the variation of return loss (S_{11}) with respect to the chamfer depth. The optimum response occurs at 1.86W.
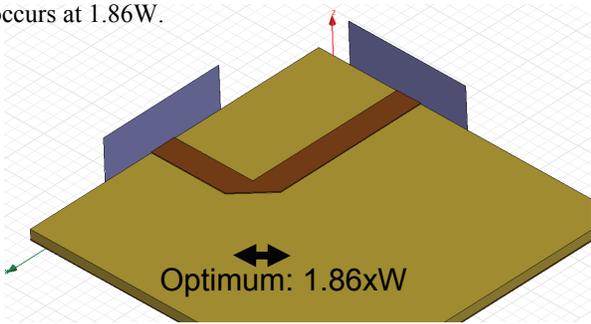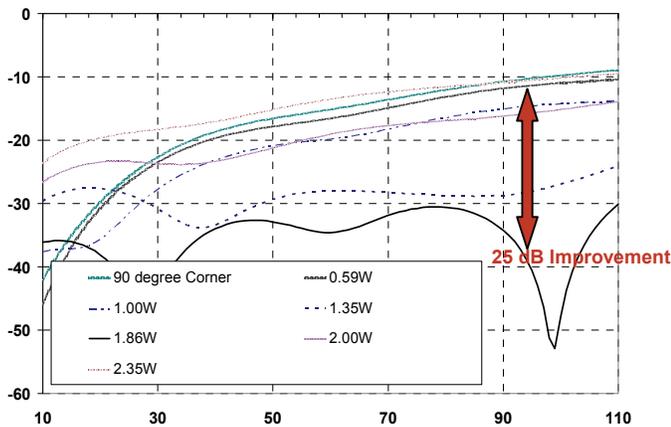

Fig 6. Schematic of optimum 90° microstrip bend.

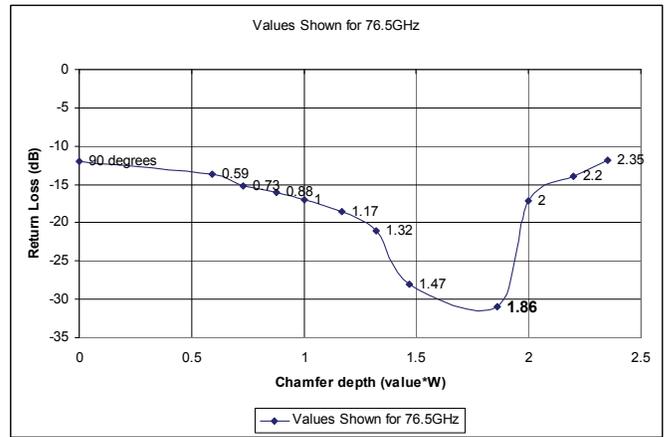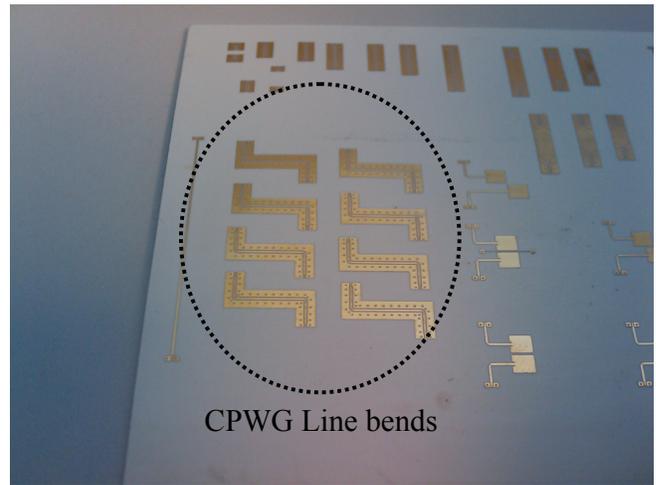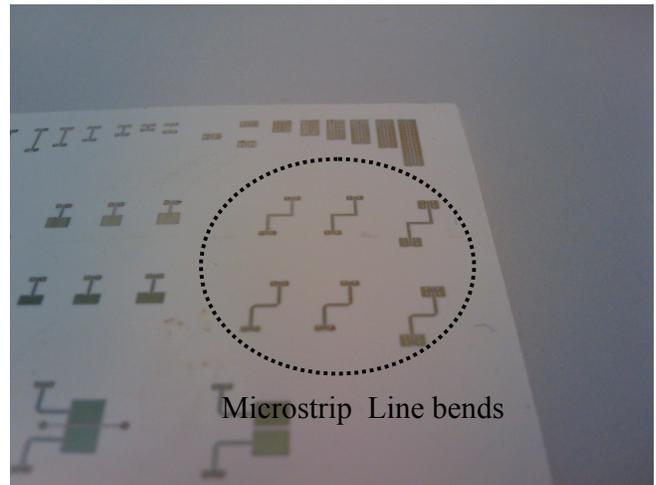Fig 7. Simulated Return Loss Response of several cases of bending microstrip line.

Fig 8. Variation of Return Loss vs. chamfer depth.

(a)

(b)

Fig. 9. Photos of back-to-back fabricated (a) CPWG Lines and (b) microstrip lines on an LCP board.

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VI. Conclusion

This paper described a method of creating high performance (low return loss and insertion loss), wide-band 90° bends for CPWG and microstrip transmission lines on LCP substrate. These structures have been fabricated using commercially available fabrication specs as shown in Fig. 9. Measurements of these structures are underway. These bends are capable of operating for applications ranging from X to W-bands. The proposed design achieves very good RF performance by utilizing a chamfered bend on the signal conductor and the ground plane, and by strategically placing vias in the area of the bend. This method can be extended to any other substrate as long as the possibility to create through vias exists. Such bends are a critical component of the 3D RF front end mm-wave system such as automotive radar RF systems.

References

[1] S. Xiao, M. Zhou, and Y. Zhang, Millimeter Wave Technology in Wireless PAN, LAN, and MAN, CRC Press, 2008.

[2] D. C. Thompson, O. Tantot, H. Jallageas, G. E. Ponchak, M. M. Tentzeris, and J. Papapolymerou, "Characterization of liquid crystal polymer (LCP) material and transmission lines on LCP substrates from 30-110 GHz," *IEEE Trans. Microwave Theory Tech.*, vol. 52, no.4, pp. 1343-1352, April 2004.

[3] P.M. Watson, and K.C. Gupta, "*Design and optimization of CPW circuits using EM-ANN models for CPW components*", IEEE Transactions on Microwave Theory and Techniques, vol. 45, no. 12, pp. 2515-2523, December 1997

[4] A.A. Omar, Y.L. Chow, L. Roy, and M.G. Stubbs, *"Effects of air-bridges and mitering on coplanar waveguide 90° bends: theory and experiment"*, 1993 IEEE International Microwave Symposium, pp. 823-826, June 1993

[5] T. Weller, R. Henderson, K. Herric, S. Robertson, R. Kihm, and L. Katehi, "*Three Dimensional high frequency distribution networks: Part I: Optimization of CPW Discontinuities*", IEEE Transactions on Microwave Theory and Techniques, vol. 48, no. 10, pp. 1635-1642, October 2000.

[6] K.C. Gupta, R. Garg, I. Bahl, and P. Bhartia, Microstrip Lines ad Slotlines, second edition, Artech House