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Via-Hole Less Broadband Conductor-Backed Coplanar Waveguide to Coupled Microstrip Transition

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Abstract—A broadband via-hole less transition from a conductor-backed coplanar waveguide (CBCPW) to a parallel coupled microstrip line (CMS) via microstrip section (MS) is reported in this paper that is realized on a MCL FX-2 substrate (100 μm thick). This transition should find a wide variety of applications due to its demonstrated broadband (from 4.5 GHz up to 39.5 GHz) behavior, ease of fabrication, and low manufacturing cost. In addition, utilization of the MS section between the CBCPW and CMS sections allows putting ground electrode in a different plane than the signal electrodes. This flexibility made possible by electromagnetic field coupling between the bottom and top ground planes simplifies the transition manufacturing and facilitates the characterization of optical components driven with CMS line using coplanar probes.

1. INTRODUCTION

Planar transmission lines are basic elements in integrated microwave circuits and are employed as drivers of the high-speed photonic components. Different transmission line topologies, (e.g., coplanar and microstrip lines) can be used in circuits according to the required performance and functions. Therefore, circuit transitions are then necessary to interface between different transmission lines. High-performance microwave circuits require low losses and low reflections at these transitions interfaces over a large bandwidth for multiband or wideband applications. Coupled microstrip (CMS) lines are used in numerous microwave circuits and components such as filters [1] and directional couplers [2]. CMS line is also used to sample RF analog signals up to 20 GHz in all-optical analog-to-digital converters based on an optical leaky waveguide deflector [3]. However, characterization and connection to generators of functional components are done generally by means of the coplanar (CPW) probes; hence, a CPW to CMS transition is required for many planar components and circuits.

Transitions between the conductor-backed coplanar waveguide (CBCPW) and the parallel CMS line have never been studied to the best of our knowledge. However, the CPW to coplanar strip (CPS) transitions, which is similar to CBCPW-to-parallel CMS transitions, have been reported by various groups [4–10]. Indeed, the CPS transmission lines can be regarded as a particular case of the CMS lines on thick dielectric substrate. Anagnostou et al. [4] have reported a wide bandwidth CPW-CPS transition using multiple wires bonds before each asymmetric section's discontinuity by suppressing any non-CPW mode. They achieved a bandwidth of 55 GHz for back-to-back transition configuration with a CPS section length of only 1.37 mm. In the CPW-CPS transitions studied by Kim et al. [6], the two lateral ground strips of CPW are combined together in the same phase and transferred to the ground strip of CPS, while the signal strip of CPW is connected to the signal strip of CPS by

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using an air bridge. They reported a transition bandwidth of 110 GHz for a CPS section of less than 200 µm. In CPW-to-CPS transitions there is no ground plane in the bottom side of substrate. However, in practice, additional conducting planes are often present in practice below the substrate in order to electromagnetically separate the circuit from its environment. So, a complete study of the CPW-CPS transitions must be considered by taking into account ground plane packaging conditions that is experienced in the CBCPW-CMS transitions.

In this paper, we experimentally demonstrate low loss and ultra-wide bandwidth behavior of the back-to-back CBCPW-CMS-CBCPW transitions including a microstrip (MS) section meeting a particular requirement for smoothly converting the electric field modes. This transition on the MCL-FX-2 substrate (fabricated by Hitachi) with a low dielectric constant of $\epsilon_r = 3.7$ and low loss tangent of $\tan\delta = 0.002$, is made without making via-holes in the substrate or patterning the bottom ground plane or wires bonds. An experimentally measured bandwidth of 4.5 GHz to 39.5 GHz is achieved, which is in good agreement with simulation results predicted from a finite element method (FEM) based full electromagnetic field simulator (e.g., HFSS).

2. PRINCIPLES AND DESIGN CONSIDERATIONS

The CBCPW-CMS transition (cf. Fig. 1) relies on capacitively coupling the lateral ground pads of the input CBCPW with the full plate bottom ground plane, then the bottom ground plane with the ground strip of the CMS line, where the electromagnetic energy is first transferred from the input CBCPW to the MS line, then to the CMS line resulting in a CBCPW-MS-CMS transition. To the best of our knowledge, a via-hole less transition from CBCPW to CMS line has never been studied. The designed back-to-back CBCPW-CMS-CBCPW transition is very easy to fabricate and cost effective since it does not use via-holes to ground or wire bonding or ground patterning.

Due to the inhomogeneous dielectric configuration of the CMS line, two quasi-TEM modes of even or odd order can propagate as illustrated in Fig. 2(c). In the optical leaky waveguide deflector application [3], only the CMS odd-mode is desired, where most of the electric field propagates between the top strips of the CMS line. The CBCPW-CMS transition is designed for gradually converting electric field from CPW-mode to MS mode (cf. Fig. 2(a)) then to CMS odd-mode and avoiding excitation of CMS even-mode. A substrate thickness of h smaller than the CBCPW gap of G_{CBCPW} results in a smooth conversion from CPW-mode to MS-mode, while excitation of CMS even-mode is avoided in the case of $G_{\mathrm{CMS}} < h$ (cf. Fig. 2(c)). This optimum condition assures an overall smooth conversion from CPW-mode to CMS odd-mode, which results in low insertion losses. Indeed, in CBCPW structures, the electric field spreads into three modes due to the bottom ground plane: i) MS-mode, ii) CPW-mode and iii) coplanar microstrip mode (CPM). The CPM mode is excited between the bottom ground plane and the lateral pads of the CBCPW, which it obviously does not exist in a CPW configuration in which no bottom electrode is present. The CPM mode causes the resonance peaks in the transmission response curve by diverting input electromagnetic energy from the CPW mode [11].

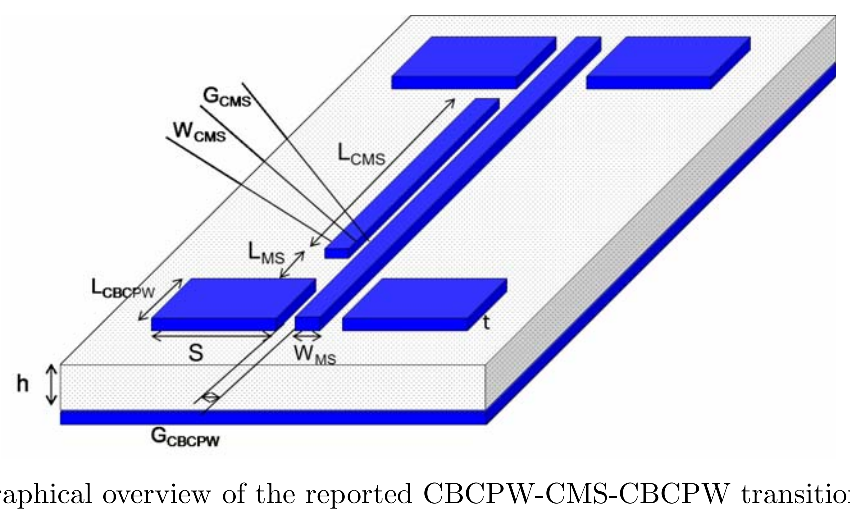

Figure 1. Topographical overview of the reported CBCPW-CMS-CBCPW transition.

The proposed transition, shown in Fig. 1, was designed on a $h = 100\,\mu\text{m}$ thick MCL-FX-2 substrate with low dielectric constant of $\epsilon_r = 3.7$ and low loss tangent of $\tan\delta = 0.002$. All transverse dimensions are calculated using the Agilents Advanced Design System LineCalc to achieve a $50\,\Omega$ characteristic impedance in each of CBCPW, MS and CMS sections. The designed physical dimensions as follows: center strip width $W_{\text{MS}} = 150\,\mu\text{m}$, coplanar gap $G_{\text{CBCPW}} = 100\,\mu\text{m}$, ground strip width $W_{\text{CMS}} = 50\,\mu\text{m}$ and gap $G_{\text{CMS}} = 50\,\mu\text{m}$ in the CMS section.

The proposed transition behaves as a bandpass filter due to the high-pass capacitive coupling characteristics between top and bottom grounds. Lower cut-off frequency of the transition bandwidth depends upon the surface area of the coplanar pads ($A = S{\cdot}L_{\text{CBCPW}}$) [11] through the circuit capacitance of $C = \epsilon_0\epsilon_r A/h$ between top and bottom grounds (where $\epsilon_0 = 8.85\times10^{-12}\,\text{F/m}$ is the physical constant representing permittivity of vacuum), therefore the coupling loss between these electrodes decreases with increasing frequency. A higher capacitance C results in a smaller cut-off frequency of this bandpass transition. To reduce the transition lower cut-off frequency, the coplanar pads surface A is to be increased for the given substrate parameters of ϵ_r and h. However, with larger dimensions of the coplanar pads, S and/or L_{CBCPW}, the CPM-mode are being excited at a lower frequency that results in resonance peaks in the transition transmission response and hence reduces the upper cut-off frequency. Therefore, a compromise of coplanar pad area of A has to be made to obtain the broadest bandwidth. The coplanar pads width of $S = 1\,\text{mm}$ and length $L_{\text{CBCPW}} = 1\,\text{mm}$ are selected to optimize this transition bandwidth. The MS section length is fixed to $L_{\text{MS}} = 250\,\mu m$, which is enough for establishing the MS quasi-TEM mode. The length of the functional CMS line is also set to $L_{\text{CMS}} = 5\,\text{mm}$.

3. PERFORMANCE RESULTS

The back-to-back CBCPW-CMS-CBCPW transition was realized on a MCL-FX-2 substrate coated on both sides with a copper layer of thickness $t = 17\,\mu\text{m}$ (cf. Fig. 3). The fabrication was done at the

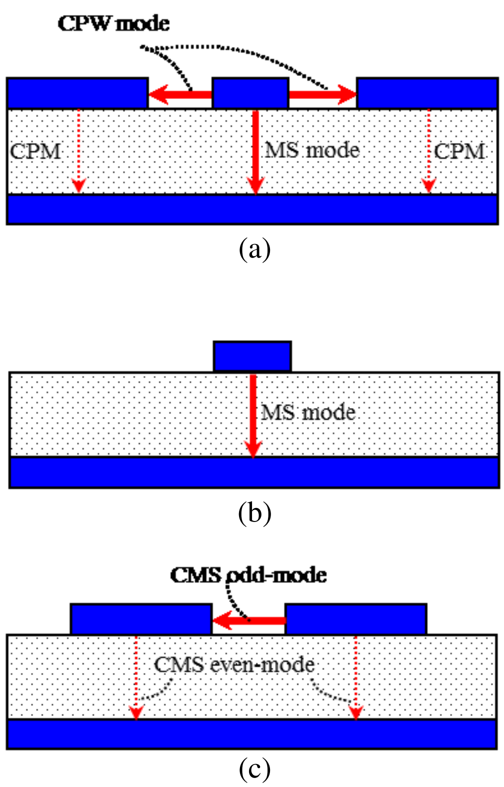

Figure 2. Electric field modal distribution for (a) the CBCPW line, (b) the MS and (c) the CMS line.

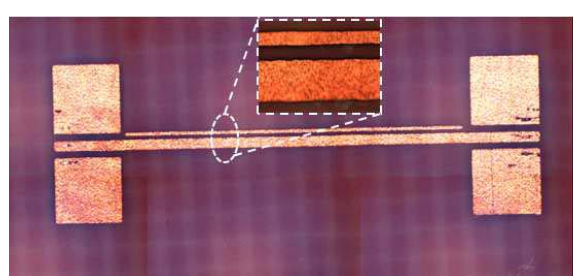

Figure 3. Picture of the fabricated CBCPW-CMS-CBCPW transition.

cleanroom of IETR from University of Nantes using a photolithography technique using a Karl Suss MJB3 mask aligner. Measured and simulated magnitudes of S-parameters are presented in Fig. 4 for the realized transition circuit. An Agilent E8364B network analyzer with the GSG probes (bandwidth 40 GHz for a 500 μm pitch and 30 μm pad) and a CSR-4 calibration substrate from Cascade Microtech. Simulations results were obtained with the finite element method (FEM) based electromagnetic field software, e.g., High Frequency Structure Simulator (HFSS V15). A good agreement is achieved between experimental and simulation results. Some discrepancy is often observed at certain frequencies between simulated and measured results because that one cant take into account all connecting elements used with their exact characteristic parameters in simulations and the manner in which they are used in experiment. The transition presents a very wide bandwidth of 4.5 GHz to 39.5 GHz. The two resonant peaks at 20 and 40 GHz are caused by excitation of the even-mode in CMS line. The first resonance is shallow despite a CMS length of $L_{\mathrm{CMS}} = 5\,\mathrm{mm}$ and present a measured insertion loss of $-2.5\,\mathrm{dB}$ at 20 GHz. So, it doesn't cut the bandwidth unlike to the second peak at 40 GHz which sets the upper cut-off frequency of the bandwidth at 39.5 GHz. The highest discrepancy value of 1.22 dB is observed between simulated and measured $|S_{21}|$-parameters at 27 GHz, which is fairly good performance prediction of this transition over a wide bandwidth.

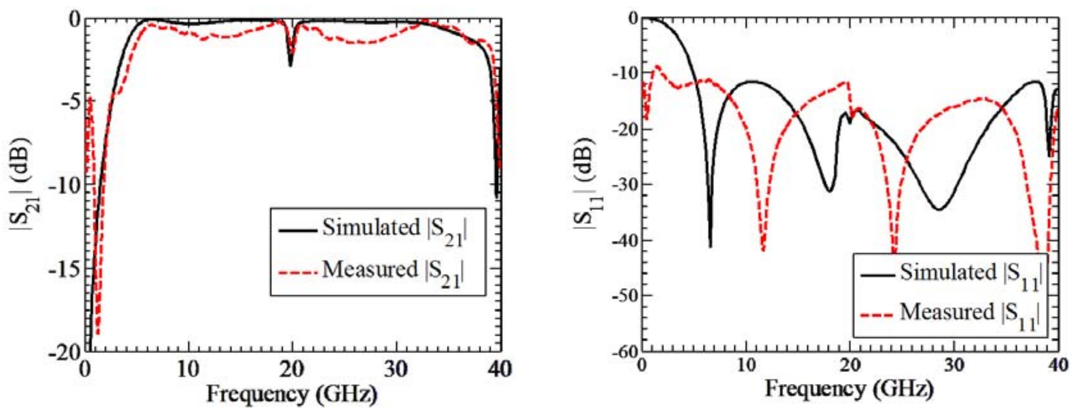

Figure 4. Measured and simulated magnitude of 2-port $|S|$-parameters in dB for the realized CBCPW-CMS-CBCPW transition on a MCL FX-2 substrate fabricated by Hitachi.

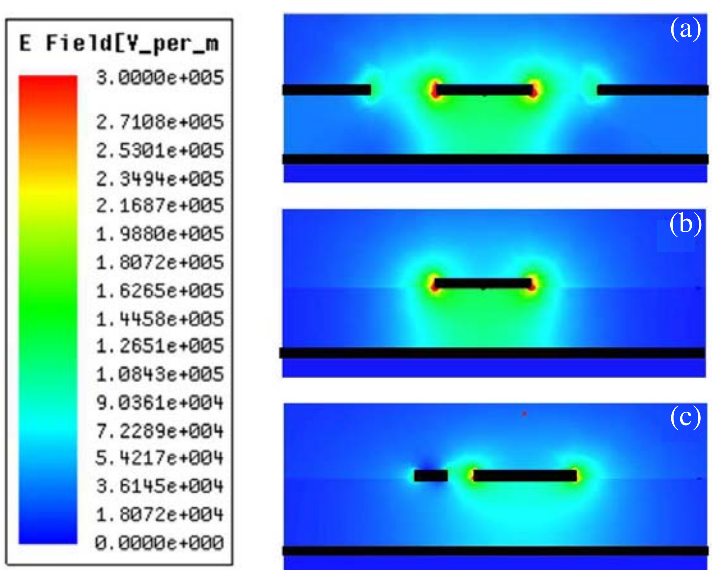

Figure 5. Electrical field intensity distribution for a 1 Watt RF source in 50 Ω system at different positions of the proposed transition at 15 GHz. (a) The CBCPW section, (b) the MS section, (c) the CMS section.

As rendered in Fig. 5, electric field undergoes mode conversion from the input of the CBCPW section to the CMS section and then back to the output CBCPW section. The electromagnetic energy is almost totally transmitted from each section to the others.

4. CONCLUSION

A via-hole less CBCPW-CMS-CBCPW transition was designed, analyzed, realized and experimentally characterized for the first time. The realized transition on a commercial MCL-FX-2 substrate shows a very broad bandwidth of 4.5 GHz to 39.5 GHz, proving high performance potential of the proposed transition including a MS section. In addition, the proposed transition does not require either wire bonding or patterning the bottom ground, which makes it very easy and low cost to fabricate. The bandwidth can be significantly increased by building such via-hole less CBCPW-CMS-CBCPW transitions on dielectric substrate of optimized thickness. According to our new simulation results of the via-hole less CBCPW-CMS-CBCPW transition on 20 µm-BCB (polymer Benzocyclobutene, dielectric constant $\epsilon_r = 2.8$ and loss tangent $\tan\delta = 0.008$), the achieved bandwidth can be as high as 65 GHz with $G_{\mathrm{CBCPW}} = 38\,\mu\mathrm{m}$, $W_{\mathrm{MS}} = 53\,\mu\mathrm{m}$, $W_{\mathrm{CMS}} = 10\,\mu\mathrm{m}$ and gap $G_{\mathrm{CMS}} = 4\,\mu\mathrm{m}$ in the CMS. Performance optimization and realization of this transition circuit is currently underway.

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REFERENCES

1. Garcia-Garcia, J., F. Martin, F. Falcone, J. Bonache, I. Gil, T. Lopetegi, M. A. G. Laso, M. Sorolla, and R. Marques, "Spurious passband suppression in microstrip coupled line band pass filters by means of split ring resonators," *IEEE Microw. Wirel. Compon. Lett.*, Vol. 14, No. 9, 416–418, 2014.
2. Islam, R., F. Elek, and G. V. Eleftheriades, "Coupled-line metamaterial coupler having co-directional phase but contra-directional power flow," *Electron. Lett.*, Vol. 40, No. 5, 315–315, 2004.
3. Hadjloum, M., M. El Gibari, H. W. Gundel, H. W. Li, and A. S. Daryoush, "Ultra-wideband GCPW-CMS-GCPW transition for characterization of all-optical ADCs based on leaky waveguide deflector," *21st Telecommunications Forum (TELFOR)*, 356–359, 2014.
4. Anagnostou, D. E., M. Morton, J. Papapolymerou, and C. G. Christodoulou, "A 0–55-GHz coplanar waveguide to coplanar strip transition," *IEEE Trans. Microw. Theory Tech.*, Vol. 56, No. 1, 1–6, 2008.
5. Butrym, A. and S. Pivnenko, "CPW to CPS transition for feeding UWB antennas," *Ultrawideband and Ultrashort Impulse Signals, Second International Workshop*, 107–108, 2004.
6. Kim, S., S. Jeong, Y. T. Lee, D. H. Kim, J. S. Lim, K. S. Seo, and S. Nam, "Ultra-wideband (from DC to 110 GHz) CPW to CPS transition," *Electron. Lett.*, Vol. 8, No. 13, 622–623, 2002.
7. Yu, D. and R. Zhu, "A new wideband vertical transition between coplanar waveguide and coplanar stripline," *PIERS Proceedings*, Beijing, China, Mar. 23–27, 2009.
8. Li, K., D. Kurita, and T. Matsui, "An ultra-wideband bandpass filter using broadside-coupled microstrip-coplanar waveguide structure, in microwave symposium digest," *2005 IEEE MTT-S International*, 675–678, 2005.
9. Mao, S. G., C. T. Hwang, R. B. Wu, and C. H. Chen, "Analysis of coplanar waveguide-to-coplanar stripline transitions," *IEEE Trans. Microw. Theory Tech.*, Vol. 48, No. 1, 23–29, 2000.
10. Wu, P., Z. Wang, and Y. Zhang, "Wideband planar balun using microstrip to CPW and microstrip to CPS transitions," *Electron. Lett.*, Vol. 46, No. 24, 1611–1613, 2010.
11. El-Gibari, M., D. Averty, C. Lupi, H. Li, and S. Toutain, "Ultra-wideband GCPW-MS transitions for characterising microwave and photonic components based on thin polymer," *Electron. Lett.*, Vol. 47, No. 9, 553–555, 2011.