# Transparent Microwave Crossover for Transparent Butler Matrix using Micro-metal Mesh Conductive Film

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***Index Terms*— Microwave crossover, branch-line coupler, transparent, Butler matrix.**

***Abstract*— This paper presents the design of a novel transparent microwave crossover (MC) for a transparent Butler matrix (BM) using a proprietary self-assembling nano-particle technology based Micro-metal Mesh (MM) conductive film. The transparent MM conductive film has a sheet resistance of 0.7 ohms/sq and a visible-light transmission of 75 %, resulting in high transparency and good conductivity, respectively. The proposed transparent crossover is placed on a 2 mm-thick glass substrate of dielectric 5.7 and designed to operate at 2.45 GHz. A layer of MM film placed at the back of the glass serves as a ground. The transparent MC delivered a measured crossing coupling of 1.5 dB. The transparent MC can be used as a building block for realizing a transparent Butler Matrix (BM) Beam Forming Network (BFN) for inter/intra-vehicle wireless communication (IIVWC) in Intelligent Transport System (ITS). Besides being transparent, the proposed MC has a 0.25 mm profile excluding the glass substrate. These advantages greatly enhance the MC's potential to be used also as a BM building component that can be mounted onto the glass surfaces of buildings for future 5G indoor wireless communications.**

## I. INTRODUCTION

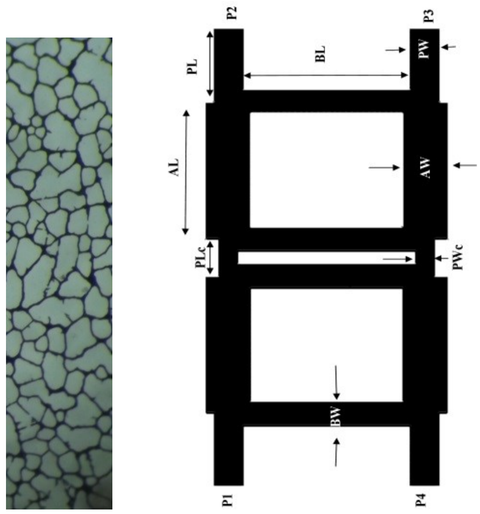
Microwave crossover (MC) is a passive device that allows crossing of two microwave transmission lines carrying different signals while maintaining isolation between them. Besides being used as a building component for many modern-day wireless communication systems (WCS), MC also serves as a major building component in Butler Matrix (BM) designs [1]. MCs can be realized using air bridges or wire bonding techniques [2], [3]. Although these techniques yield desired results, however, the requirement of compact structures stands in the way of utilizing this MC design concept.

In [4], [5], coplanar waveguide based MCs design with improved bandwidth performance is realized. However, the designs are opaque and hence, not suitable for vehicle windscreen integration. Another MC design with good performance is presented in [6]. However, the designs' fabrication difficulties and high profile due to the requirement of slots on the ground planes posed challenges to the design realization. A method of realizing MCs using cascaded branch-line coupler (BLC) is demonstrated in [7] and [8]. In these designs, signal isolation with a fractional bandwidth of around 30% was achieved across the branches of the structure. The designs were, however, also opaque with a high profile.

In this paper, a transparent MC with a very thin profile and loss resistivity when compared with the existing transparent conductive film is introduced for the first time using a MM conductive film [9] on a glass substrate. The design can be used as a transparent BM building component that can be placed onto any glass surface. This type of BM is suitable for vehicular wireless communication (WC) applications as well as 5G indoor WC. The design exhibited good coupling and return loss at the operating frequency of 2.45 GHz. To our best knowledge, this is the first transparent crossover design. It is clearly shown that the materials used do not compromise the good functioning of crossovers.

## II. GEOMETRY AND CROSSOVER DESIGN

To achieve crossing of two transmission line signals with minimal coupling, MC also known as 0 dB coupler is utilized. As shown in Fig. 1, the MC can be achieved by a cascade two sets of BLC [8].




(a) (b)

Fig. 1. (a) Transparent MM conductive film (x200 magnification) (b) proposed transparent MC design layout.

As shown in Fig. 1 (a), the MM film basically consists of a layer of conductive silver micro-metal mesh and is produced using a patented self-assembling silver nano-particle technology and overlaid over a 0.120 mm thick polyethylene terephthalate (PET) substrate having a dielectric constant of $\epsilon_{int} = 4.757$.

The MC layout shown in Fig. 1 (b) is a microwave component that is made up of two cascaded BLCs. Two $\lambda/4$-electrical length, series and shunt transmission line branches are connected together to realize the BLC. The BLC series branch has a line impedance of $Z_0/\sqrt{2}$ while the shunt branch, an impedance of $Z_0$. Generally, the 3 dB BLCs have a degree of freedom where any of the four ports can be used as an input port. The ports opposite to the chosen input port are the output ports while the adjacent port is the isolated port.

Fig. 2 illustrates the cross-section view of the multi-layered substrate interface of the proposed transparent MC. The basic structure comprises of a glass substrate sandwiched between two MM films. The glass substrate has a dielectric constant of $\varepsilon_{sub}$. The effective dielectric constant $\varepsilon_{eq}$ of the stacked substrate structure of PET: Glass: PET can be computed using (1) [10].

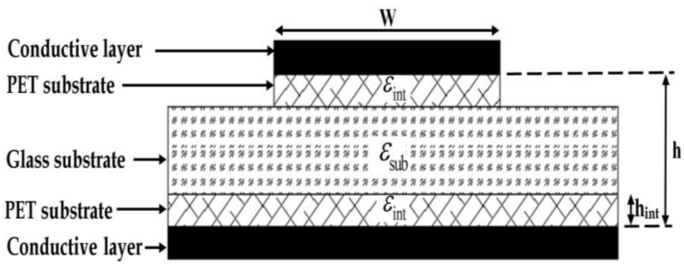



Fig. 2. Cross–sectional view of the proposed transparent MC.

$$\varepsilon_{eq} = \frac{(1/u)}{\left(\frac{2/u_{int}}{\epsilon_{int}}\right) + \left(\frac{(1/u) - (2/u_{int})}{\epsilon_{sub}}\right)} \quad (1)$$

Where $u_{int} = \frac{w}{h_{int}}$ and $u = \frac{w}{h}$

The material's properties are tabulated in Table I.

TABLE I
MC MATERIAL PROPERTIES

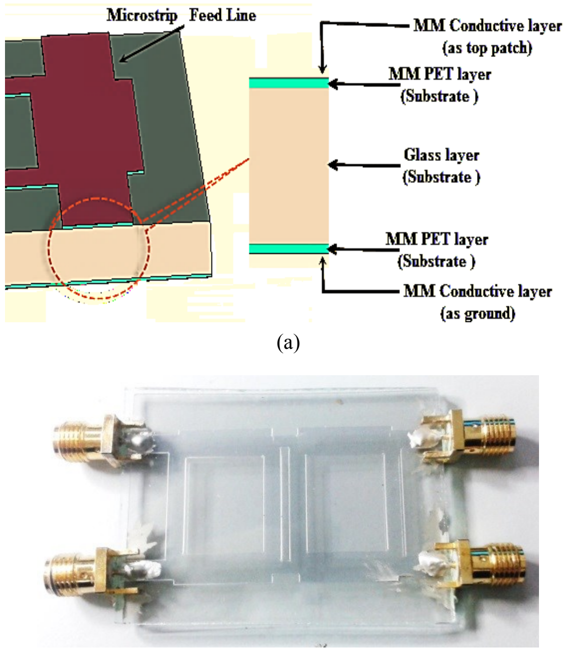
| Material | Thickness(mm) | Dielectric | Resistivity (Ohms/sq) |
|---|---|---|---|
| Glass Substrate at 2.45GHz | 2.0 | 5.7 | – |
| MM PET Substrate at 2.45GHz | 0.120 | 4.757 | – |
| MM Conductive layer | 0.005 | – | 0.7 |

The value of $\varepsilon_{eq} = 5.57$ of the effective dielectric constant is obtained using (1). Initially, a transmission-line calculator was used to obtain the proposed BLC dimensions to construct the MC. The interpolated quasi newton optimizer in the time domain solver of CST-MWS 2013 is used to obtain the final dimensions via simulation optimization. The MC dimension parameters are tabulated in Table II.

TABLE II
MM TRANSPARENT MICROWAVE CROSSOVER DESIGN PARAMETERS

| Parameters | Length (mm) | Parameters | Length (mm) |
|---|---|---|---|
| AL | 15 | AW | 4.5 |
| BL | 19 | BW | 2.75 |
| PL | 8 | PW | 3.3 |
| PLc | 4 | PWc | 2 |

Fig. 3 illustrates a close-up view of the MC design in the CST simulation software with a 3.3 mm microstrip feed line. Fig. 3 (b) shows the proposed transparent MC prototype.




(b)

Fig. 3. Transparent MC (a) close-up view in the CST design software (b) prototype.

## III. RESULT AND DISCUSSION

The simulated and measured S-parameter values for the proposed transparent MC are shown in Fig. 4 (a) and (d). As shown, the values of $S_{11}, S_{21}, S_{41}$ are below -10 dB within the operating frequency. This indicates that the signal in the MC is maximally transmitted. The crossing transmission $S_{31}$ has a measured value of -1.5 dB at 2.45 GHz. This is obtained as a result of the MM's resistivity.

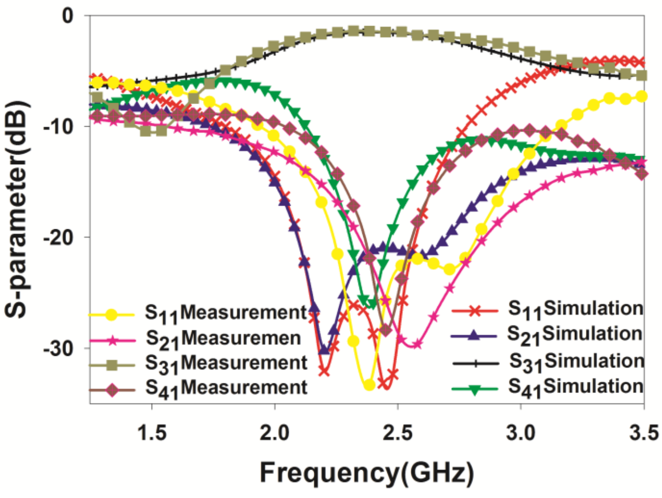



Fig. 4 0° simulated and measured S-parameters of the Crossover.

Hence, these recorded S-parameter values of the cascaded pair of BLCs show that signal is coupled from the input port to the diagonal output port. However, the undesired effects of the insertion loss' slight increase are recorded. Good design is achieved by optimizing the length and width of the interconnected ports to obtain optimum isolations. However, this will be at the expense of poor reflections and coupling which resulted in discrepancies between the simulation and measured results.

## IV. CONCLUSION

The proposed novel transparent MC design using a self-assembling nano-particle technology based MM film with high transparency is achieved by cascading two BLCs. The proposed transparent low profile MC has high potential to be used as building blocks for BM BFN applications in future IIVWC in ITS to make wireless communication between mobile vehicles, as well as between mobile vehicles to base station a reality. The transparent low profile MC is also a promising candidate for future 5G indoor wireless communications.

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## REFERENCES

[1] H. Hayashi, D. A. Hitko, and C. G. Sodini, "Four-element planar Butler matrix using half-wavelength open stubs," Microwave and Wireless Components Letters, IEEE, vol. 12, pp. 73-75, 2002.

[2] C. Kim and Y. Kwon, "Thick-copper-buried inductors using anodized aluminum package substrates," *IEEE Trans. Compon. Packag. Manuf. Techno!.,* vol. 2, no. 8, pp. 1260-1264, Aug. 2012.

[3] J. M. Lannon, C. Gregory, M. Lueck, J. D. Reed, C. A. Huffman, and D. Temple, "High density metal-metal interconnect bonding for 3-D integration," *IEEE Trans. Compon. Packag. Manuf. Techno!.,* vol. 2, no. 1, pp. 71-78, Jan. 2012.

[4] A. Abbosh, S. Ibrahim, and M. Karim, "Ultra-wideband crossover using microstrip-to-coplanar waveguide transitions," *IEEE Microw. Wireless Compon. Lett.,* vol. 22, no. 10, pp. 500-502, Oct. 2012.

[5] Y. Wang, A. M. Abbosh, and B. Henin, "Wideband microwave crossover using double vertical microstrip-CPW interconnect," *Progr. Electro-magn. Res. C,* vol. 32, pp. 109-122, Sep. 2012.

[6] K. U-yen, E. Wollack, S. Moseley, T. Stevenson, W. Hsieh, and N. Cao, "Via-less microwave crossover using microstrip-CPW transitions in slot-line propagation model," in *Proc. IEEE Int. Microw. Symp.,* Jun. 2009, pp. 1029-1032.

[7] D. Kholodniak, G. Kalinin, E. Vernoslova, and I. Vendik, "Wideband 0-dB branch-line directional couplers," in *Proc. IEEE Int. Microw. Symp.,* vol. 3. Jun. 2000, pp. 1307-1310.

[8] J. Yao, C. Lee, and S. Yeo, "Microstrip branch-line couplers for crossover application," *IEEE Trans. Microw. Theory Tech.,* vol. 59, no. 1, pp. 87-92, Jan. 2011.

[9] Available: www.cimananotech.com

[10] H. T. Vo, C. Davidson, and F. G. Shi, "New effective dielectric constant model for ultra-high speed microstrip lines on multilayer dielectric substrates: effect of conductor-dielectric interphase," in *Electronic Components and Technology Conference, 2002. Proceedings. 52nd*, 2002, pp. 86-89.