Bandwidth Enhancement on Branch Line Coupler Using Magneto-Dielectric Polymer Substrate (PDMS-Fe_30_4)

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***Abstract*—In this paper, a comparative study has been conducted to analyze the bandwidth enhancement on Branch Line Coupler when using magneto-dielectric polymer substrate (PDMS-Fe304) also known as (Polydimethylsiloxane-Iron Oxide). A branch line coupler based on magneto-dielectric polymer substrate was designed and simulated to evaluate the contribution of such promising material in microwave component performance. The purposed branch line coupler was design and simulate to ensure branch line coupler that used magneto-dielectric polymer substrate can achieved higher bandwidth enhancement. All of the branch line coupler will operated on 2.45 GHz operating frequency. The result for (S11) parameter on purposed branch line coupler using magneto-dielectric polymer substrate was show an astonishing enhancement in bandwidth up to 1260 MHz compare to 950 MHz and 720 MHz for Rogers and FR-4 substrate. The phase difference on the magneto-dielectric polymer substrate (PDMS-Fe304) show a significant improvement bandwidth at 2 to 2.7 GHz with 90° ± 5°, better than normal conventional substrate branch line coupler.**

***Index Terms*—Branch Line Coupler; Magneto-Dielectric Polymer Substrate; Rogers; FR-4.**

I. INTRODUCTION

Usually a Branch line coupler or directional quadrature have been implemented in the microwave system such as Beam forming network, power divider and power amplifier [1], [2], [3]. Branch line coupler have been selected widely because of its simple design and also cost effective [4]. But drawback when using branch line coupler as passive microwave element are, it have a very narrow bandwidth and poor on band rejection characteristic [5]. There are many technique or method that have been developed by prior researcher to enhance the bandwidth on the branch line coupler. One of the solution are by cascading the coupler connection with the filter to enhance bandwidth and band rejection characteristic [6]. But this technique will increase dimension of the coupler and also it will degrade performance of each individual component [7]. Another method are by increasing the value of dielectric permittivity of substrate material. By increasing this properties, we can improve the impedance matching on the input port, caused the poorer of feeding point on the radiating patch element will reduced the current distribution on branch line coupler [8].

On 2004 a fellow and member of IEEE have purposed a unique meta-material substrate for electromagnetics application. This new substrate was called Magneto-dielectric. The capability of this substrate are, it can reduce the dimension of RF and Microwave component by adjusting the permeability (μr) and permittivity (εr) value of material [9]. They lowering the permeability (μr) and increasing permittivity (εr) of material, by sandwiching the normal substrate layer with modified substrate layer [9]. By doing this it allowed, the characteristic impedance for multilayer substrate to be closed with the surrounding medium. And produce the substrate that can have much better in term of bandwidth and impedance matching [9].

This paper present a comparative study between new substrate that made of from the polymer magneto dielectric with a conventional substrate that will be implemented on this coupler. The purposed of this study is to analyze the bandwidth enhancement on the branch line coupler when using the polymer magneto dielectric as a new substrate. This paper will be through stage by stage process, to ensure the validity of bandwidth enhancement on branch line coupler can be achieved on the polymer magneto dielectric substrate. The coupler design, will be the first stage of the process. We use CST Microwave studio 2014, as our computer aided design tool. On the second stage we still used the software for simulation and optimization for branch line coupler on each different substrate. And on the third and final stage we analyze and comparing the result.

II. BRANCH LINE COUPLER DESIGN

The purposed coupler will be designed on a copper foil sheet with thickness and electrical conductivity of 0.035mm and 5.88 x 108 S/m, respectively. The length and width of the shunt/series for the coupler are computed using the Transmission-line calculator by taking into consideration the thickness of the copper sheet, and thickness and dielectric constant εr of the polymer magneto-dielectric (PDMS-Fe3O4) substrate. The coupler was design with the conventional geometry to make it easy for evaluating the bandwidth enhancement on three different material substrate. The mathematical Equation 1 and 2 here, have been used to validate the length and the width patch for copper foil patch dimension on branch line coupler.

$$L = \lambda/4, \lambda = v_{\rho}/f = c/f\sqrt{\varepsilon_r} \Rightarrow L = c/4f\sqrt{\varepsilon_\Gamma} \tag{1}$$

$$\frac{W}{d} = \begin{cases} \dfrac{8e^{A}}{e^{2A}-2} & for\ \dfrac{W}{d} < 2 \\ \dfrac{2}{\pi}\left[\begin{array}{l} B-1-\ln\left(2B-1\right)+\dfrac{\varepsilon_r-1}{2\varepsilon_r} \\ \left(\ln\left(B-1\right)+0.39-\dfrac{0.69}{\varepsilon_r}\right)\end{array}\right] & for\ \dfrac{W}{d} < 2 \end{cases} \tag{2}$$

$$where\ A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23+\frac{0.11}{\varepsilon_r}\right)$$

$$and\ B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$$

The geometry of 4 port network [10]. The input will be dedicated at Port 1. The conducting patch element is designed, simulated and optimized in the CST- Microwave studio 2010. Figure 1 shows the geometry design for purposed and comparative design branch line coupler.

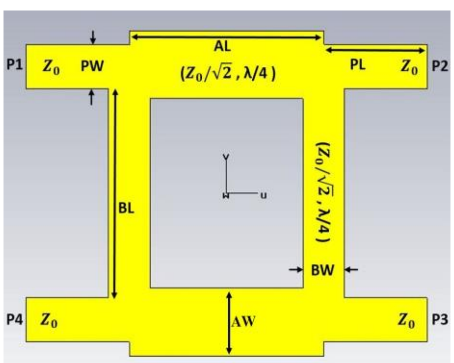

Figure 1: Geometry design of branch line coupler at 2.45 GHz

To do a comparative study on bandwidth enhancement for branch line coupler there are a certain parameter need to be fixed. The parameter that need to be fixed are the thickness of each substrate. The thickness for all substrate including polymer magneto-dielectric (PDMS-Fe_3O_4) are being design at 1.5mm. Another two similar geometry branch line coupler will be design and simulate on FR-4 and Rogers RT5880LZ substrate respectively. Figure 2, shows the complete branch line coupler when sandwiching together with polymer magneto-dielectric (PDMS-Fe_3O_4) substrate.

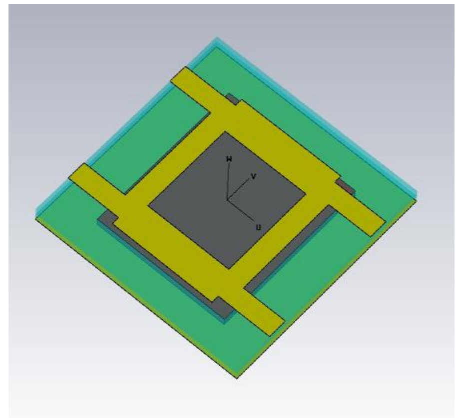

Figure 2: Complete branch line coupler with (PDMS- Fe_3O_4) substrate.

Figure 3 shows, the complete structure layer for the branch line coupler on polymer magneto-dielectric (PDMS-Fe_3O_4) substrate**.** There are 4 different layer that stack together. The first layer will be the coupler patch, design at thickness at 0.035mm. And the conductivity for copper sheet is 5.88 x 10^8 S/m. And the second layer was pure PDMS polymer, at thickness 0.75mm and the dielectric at 2.7. Meanwhile the third layer pure PDMS polymer, was impregnate together with the (PDMS- Fe_3O_4) at the center of the third layer. The fourth layer will be ground patch, this layer complete the circuit form for the electrical connection inside the branch line coupler circuitry. Table 1 shows, the properties dielectric material for polymer magneto-dielectric (PDMS-Fe_3O_4) and other substrate for branch line coupler. The dielectric value for the PDMS that combine with Iron oxide (Fe_3O_4), have increased by 0.15 respectively. This is because the nanoparticle inside the PDMS combine together with Iron oxide particle. It create a new polymer matrix for the PDMS instantaneously, thus it increasing the permittivity and lowering permeability of (PDMS-Fe_3O_4) substrate [11].

Table 1
Properties for dielectric material [12]

Material	εr	μ_r	Dielectric Loss Tangent ($\tan\delta_{d)}$
PDMS	2.70	1	0.022
PDMS_Fe_3O_4	2.85	1.2	0.07
FR-4	4.30	1	0.025
Rogers RT5880LZ	1.96	1	0.0019

III. Result and Discussion

All of the comparative S-parameter result will be shown on Figure 4, 5, 6 and 7 respectively. Figure 4 shows, the reflection coefficient (S_{11}), for proposed branch line coupler using (PDMS- Fe_3O_4) substrate is -38.24 dB. While design branch line coupler on Rogers and FR-4 substrate, are -23.87 dB and -31.13 dB. All coupler operated at 2.45 GHz.

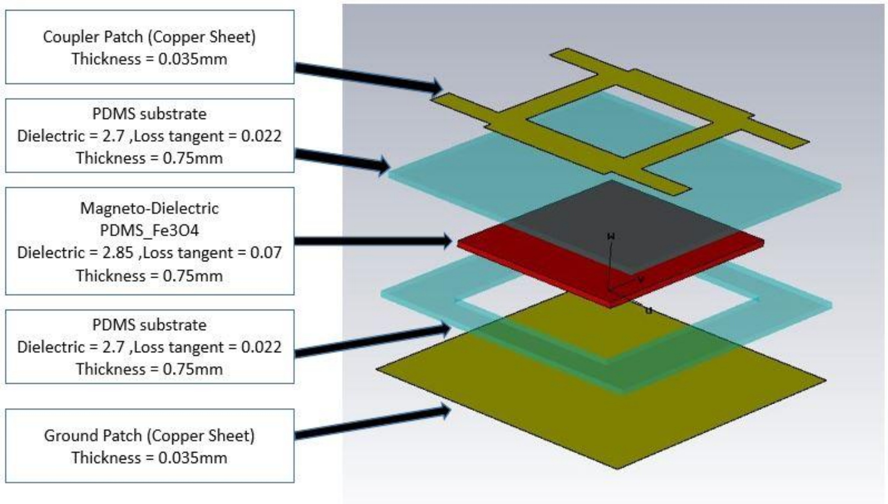

Figure 3: Complete structure layer for branch line coupler on (PDMS-Fe3O4) substrate

Table 2
Comparing the simulated result for Reflection Coefficient (S11) on polymer magneto dielectric, FR-4 and Rogers at 2.45GHz

Substrate	Patch Dimension (W x L) (mm)	Reflection Coefficient (S11) (dB)	BW Enhancement (MHz)	BW Enhancement (%)
PDMS- Fe_3O_4	34.88 x 25.34	-38.24	1260	50.4
Rogers RT5880LZ	41.20 x 31.48	-23.87	950	38.8
FR-4	48.54 x 37.20	-31.13	720	29

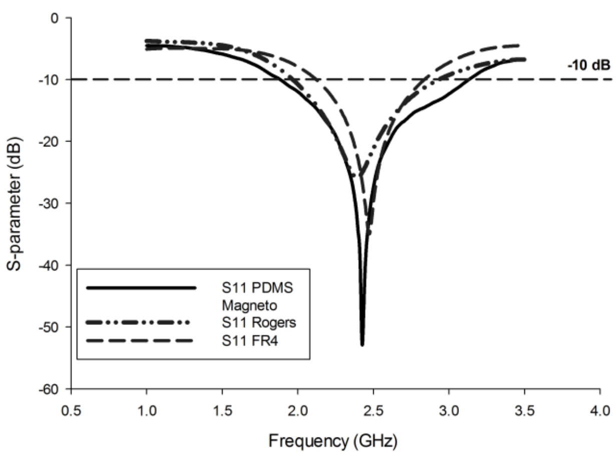

Figure 4: Comparative simulated result for S11 performance operates at 2.45 GHz

As we notice from (S_{11}) graph, the bandwidth for (PDMS-Fe_3O_4) substrate are wider than other substrate. This result validate that (PDMS- Fe_3O_4) substrate can be used for bandwidth enhancement, it increase the impedance matching by lowering the permeability (μr) and increasing permittivity (εr) of material [13]. Table 2 shows the comparison in term of dimension, bandwidth and reflection coefficient (S_{11}) for coupler that used polymer magneto-dielectric, FR-4 and Rogers as a substrate. From the table, we can see, that the coupler size for the polymer magneto dielectric have been reduced significantly compare to other substrate. From this we also validate that, the polymer magneto dielectric substrate can be used to miniaturize the size of coupler [13].

The insertion loss (S_{21}) and coupling (S_{31}) result shown on Figure 5 and Figure 6. The coupler using polymer magneto dielectric substrate have achieve widest frequency band shown from 2.05 up to 2.85 GHz with -3 dB ± 1 dB tolerance. That is 800 MHz bandwidth enhancement. As for Rogers and FR-4, the bandwidth was resonate at 500 MHz and 290 MHz. For coupling (S_{31}) result, the proposed coupler also show significant improvement in bandwidth also, at 1200 MHz compare to Rogers and FR-4.

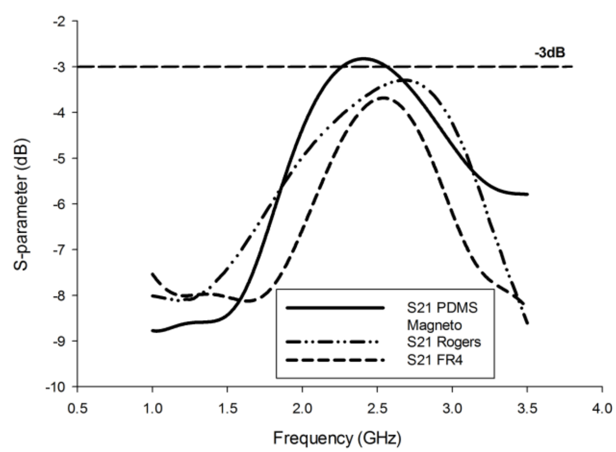

Figure 5: Comparative simulated result for insertion loss (S21) performance operates at 2.45 GHz

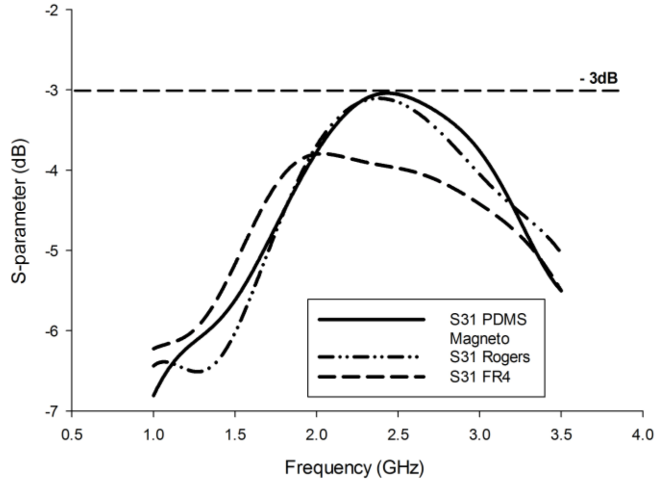

Figure 6: Comparative simulated result for coupling (S_{31}) performance operates at 2.45 GHz

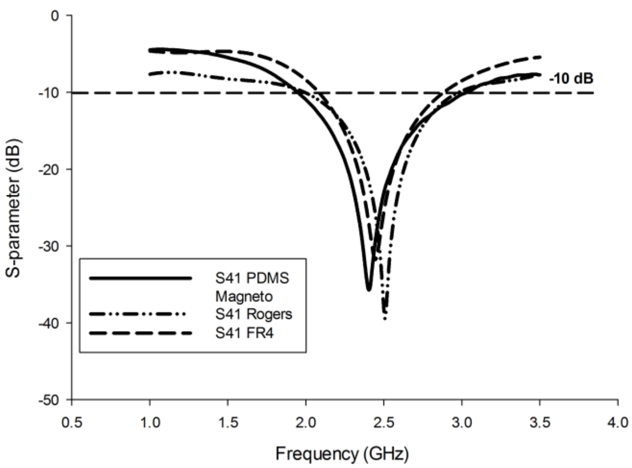

Figure 7: Comparative simulated result for (S_{41}) performance operates at 2.45 GHz

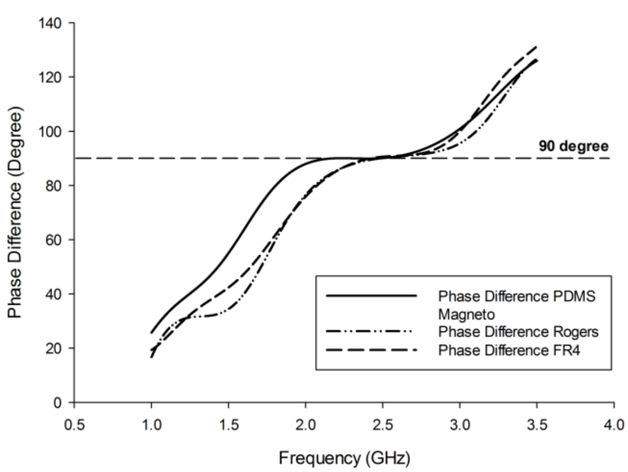

Figure 8: Comparative simulated result for phase difference operates at 2.45 GHz

Table 3
Comparing the simulated result for Isolation (S41) on polymer magneto dielectric, FR-4 and Rogers at 2.45GHz

Substrate	Isolation (S41) (dB)	BW Enhancement (MHz)	BW Enhancement (%)
PDMS- Fe_3O_4	-28.59	1070	43
Rogers RT5880LZ	-26.48	980	39
FR-4	-31.64	800	32

Table 3 shows, isolation (S41) for three different substrate. And the proposed coupler also a bandwidth enhancement at 43%. Figure 8 shows, the phase difference for polymer magneto dielectric coupler is 90° ± 5° between frequency 2 GHz and 2.7 GHz. Meanwhile for Rogers and FR-4, it cover range across 2.40 GHz to 2.60 GHz and 2.42 GHz to 2.62 GHz at 90° ± 5°. The polymer magneto dielectric (PDMS-Fe_3O_4) shows a better and acceptable performance in term of phase difference.

IV. Conclusion

The polymer magneto dielectric (PDMS- Fe_3O_4) can be used as a new substrate for branch line coupler to improve the bandwidth and reduce the dimension of branch line coupler, better than other conventional substrate such as Rogers and FR-4. And by using the polymer substrate on coupler, it enable these microwave circuit to be used for conformal application. Because the polymer substrate provide flexible and stretchable capability that not usually have on the conventional substrate.

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