The Design of Balun Control Feed Antenna (BCFA) using Biocomposite Substrate

A.A.Azlan[1], M.T.Ali[1], N.H.Abd Rahman[1] and M.F Jamlos[2]
[1]*Antenna Research Group (ARG), Fakulti Kej. Elektrik,Universiti Teknologi Mara (UiTM),Shah Alam, Malaysia.*
[2]*Advanced Communication Engineering Centre (ACE),Universiti Malaysia Perlis (UniMap),Perlis, Malaysia.*
9m2agc@email.com

***Abstract*—This paper proposes the design of Balun Control Feed Antenna (BCFA) using four different mixtures of biocomposite. The design covered the IEEE 802.11b (2.412 - 2.472 GHz) standard that has thirteen channels, which consist of the parasitic patch (first substrate) and Quarter wave Balun with partial ground (second substrate) and Air Gap separation. To analyze the substrate performance, the resonant frequency was controlled by tuning the Balun and the quarter wave structure, while other dimensions were fixed. The antenna gain reported a decay with the increments of the filler mixture (4.62 to 0.1dBi) while FR4 (1.83 dBi), which resonant frequency occurs between 2.43 to 2.46 GHz. The changes in the gain, bandwidth, frequency response and directivity occur since the loss tangent increased in parallel with the filler composition mixture. The results of the measurement and simulation were demonstrated back to back to emphasize the performance of the proposed four different combination substrates with a direct comparison to FR4.**

***Index Terms*—Biocomposite Substrate; Substrate Sensor; Coaxial Probe.**

I. Introduction

Green Bio-composite material offers a great potential to be served as an alternative material for microwave antenna substrate. The process is simple, cost effective, recyclable, preserves natural resources and produces low greenhouse gas that affects the environment [1]. The technology of wood plastic composite (WPC) based on polypropylene (PP) polymer is not new. The thermosetting composite research has already started somewhere in 1960 [2], but most of the applications at that time and until now have focused on building and mechanical applications [3]. Every fabricated material has their properties suitable for specific applications [4].

Despite of this situation, the characteristic of each substrate defined as dielectric properties data need further measurement that utilizes computer simulation technology (CST) software for antenna modeling. As a simplification, the dielectric properties assumed as the non-electrical conductive material has the capability to store the electrical field, which contains a complex representative of dielectric constant (Dk) and loss tangent (Tan δ) of the material. It has been reported that the patch antennas system is among the modern antenna system due to its low profile, low cost, and support for linear and circular polarization [5]. Besides that, it also supports multiple band frequency operations and mechanically robust when the radiator is mounted on rigid surface material [6]. The significance of this work emphasizes the need of research for a new material as antenna applications stabilized in dielectric properties value across 1 to 20 GH, which Dk value decreases when there is an increasing frequency for the biocomposite substrate, as indicated in Figure 1. As the scope for this research, the design focused on the enhancement of the Omni directional developed by balanced to unbalanced (Balun) and quarter wave with a parasitic patch that changes the bore sight of the antenna to provide a more gain to the existing quarter wave antenna.

II. Antenna Design

Initially, four different mixture antenna substrates were prepared with the polypropylene (PP), and Leucaena leucocephala stem tree (LL) as described in the previous research [7]. The notation of PB9010 indicated that the substrate mixture 90% (PP) and 10% (LL) the composition of PP must be greater than LL since there is no additive used as laminator to hold the interlocking between the wood and the polymer. Then, the substrate went for dielectric constant (Dk) and Loss Tangent (Tan δ) was measured using coaxial probe method. The composition of the other substrates and their properties is indicated in Table 1. The design of Balun control feed antenna (BCFA), consists of two layers of substrate that have a parasitic square patch, radiating patch, partial ground and air gap with coaxial feed probe through the grounding section. Initially, the design applied the method of Omni-directional with effective radiating quarter-wave (ERQW) and Balun acting as impedance matching and partial ground. As the previous researches conducted by [8][9], the partial ground was designed for wider bandwidth and provided Omni-directional characteristic. The disadvantage of the partial ground is that it provides low gain condition due to greater bandwidth characteristic [10].

Table 1
Substrate Dielectric properties

Substrate	Dk	Tan δ
PB9010	2.27	0.0099
PB8020	2.63	0.0163
PB7030	3.1	0.0367
PB6040	3.49	0.0781
FR4	4.7	0.014

The purpose of the parasitic element was to provide another bore sight of the radiation pattern from the omnidirectional to narrower bore side radiation pattern. As indicated in Figure 2 (a), the parasitic front patch is situated on the upper substrate with the copper foil 0.035mm, while Figure 2(b) indicates that the ERQW with the Balun is on the second substrate layer. The BCFA antenna used the partial ground method to maintain the omnidirectional to the design [11]. The idea of this partial ground was to create wider bandwidth that can cover the entire IEEE 802.11b (2.412 -2.472 GHz) standard.

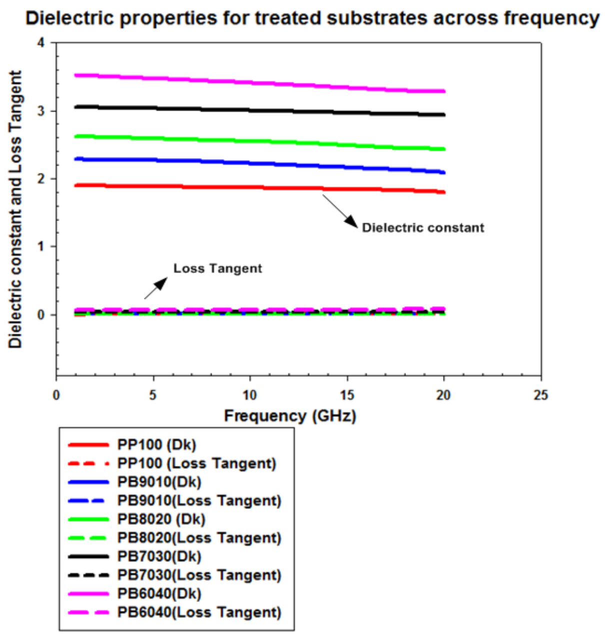
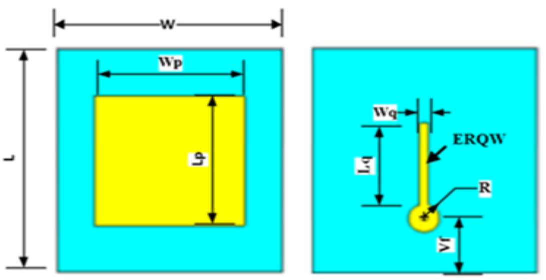
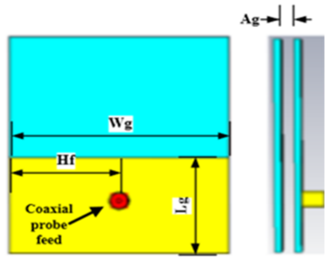


Figure 1: Dielectric properties of biocomposite substrates



(a) (b)

Figure 2: BCFA Design (a) Front Patch (b) ERQW and Balun



(a) (b)

Figure 3: BCFA design (a) Partial ground (b) Air Gap

By adding the parasitic front patch to the design, the enhancement of the gain improved compared to the typical design of the partial ground antenna. The design of the Partial ground and the air gap placement is indicated in Figure 3 (a) and Figure 3 (b), with the feeding of the system, used the coaxial probe feed subminiature type-A (SMA) 3.5mm situated in the center of the partial ground. Since the design used multiple substrates with different dielectric properties as indicated in Table 1, the adjustment of the frequency relies on the ERQW and Balun, as shown in Table 2. The dimension for parasitic front patch, air gap, substrate, coaxial feed position and partial ground are maintained for all the designs to see the performance of the substrate. The dimension in mm of the whole BCFA design is indicated in Table 3.

Table 2
ERQW and Balun Dimension (mm)

Substrates	Feed length (Lq)	Balun radius (R)
PB9010	27.21	6.13
PB8020	26.1	6
PB7030	25.19	5.4
PB6040	24.67	4.2
FR4	21.78	4.1

Table 3
BCFA Dimension (mm)

Width (W)	60
Length (L)	68
Patch width (Wp)	40
Patch length (Lp)	39.4
Feed height (Hf)	21.5
Feed length (Vf)	16.6
Width (Wg)	60
Length (Lg)	30
Air gap (Ag)	3
Width feed (Wq)	2.4

The calculation of the first parasitic patch implies the conventional design by the previous researcher [12]. The equation for ERQW adapts the quarter wave calculation as indicated by Equation (1), while the dimension for Balun design used the Equation (2) that adapts the calculation from Guanella balun method [13].

$$Lq = ((3 \times 10^8)/f_0)/4 \qquad (1)$$

The Balun system was installed to the nearest feeding point to minimize the losses due to the parasitic element condition, and the Weffective calculation relies on the dimension of ERQW (Lq) as distributed by Equation (2) to (3).

$$\text{R}= (W_{effective} = /4) \qquad (2)$$

$$W_{effective} = (\text{ L > W use L or W > L use W}) \qquad (3)$$

As indicated by most of the former researcher regarding the partial ground design [14], the dimension alias between fifty to sixty percent of the substrate ground structure. Most of the dimensions were obtained by conducting the optimization process until it suits the required resonating frequency. The 3mm air gap separation on all the designs, was conducted using the nylon bolt and nut M5 type (∅ 5mm).

III. Result and Analysis

As indicated in Figure 4 (a) and Figure 4 (b), the plotting of S11 result showed that the bandwidth covered the whole spectrum for IEEE 802.11b (2.412 -2.472 GHz) on all the biocomposite including the FR4 substrate for both simulation and measurement. The minimum reading for the graph observation for Figure 4 (a) and Figure 4 (b) for S_{11} result started at -10dB as per mentioned in the previous research conducted by [15].

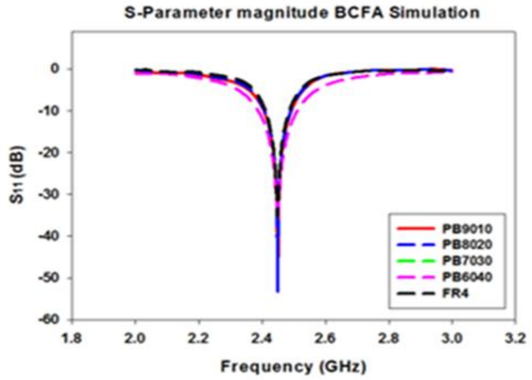


Figure 4 (a): BCFA S-parameter simulation

The return loss reading between 30dB to maximum 50dB was reported for the simulation plotting, while the measurement indicated the slightly lower value of return loss with the value alias between 38 dB to 42 dB. Then, the measurements continued to observe the radiation pattern plotting on all the BCFA design, with the plotting focused into Phi 90° (co polarize) and Phi 0° (cross polarize) to find the radiation polarization of the antenna.

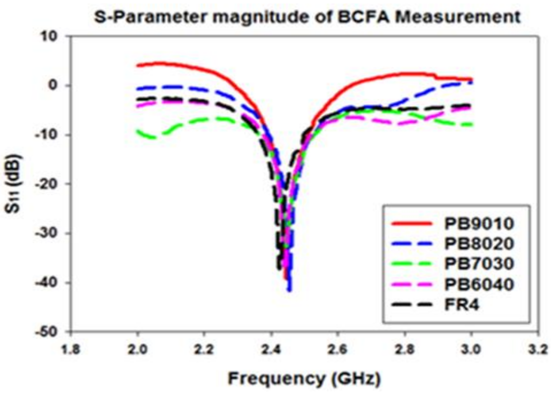


Figure 4 (b): BCFA S-parameter measurement

As indicated in Figure 5 (a) and Figure 5 (b), the E-Plane for all designs reported no major deviation. The differences only occur) at the back lobe of the BCFA between 120° to 150° (simulation), while 150° to 240° (measurement) was due to the changes of the Dk and Tan δ. Even though the deviation exists between simulation and measurement, especially in the back lobe, the overall performance on radiation pattern that is not affected by the variation occurs about 2% only. It can be concluded that the simulation and measurement plotting results are parallel with each other. The analysis of the antenna radiation pattern conducted by using ATENLAB OTA500 anechoic chamber, with the polar radiation plot is indicated in Table 5. The fabricated of four BCFA antenna by using green biocomposite and FR4 substrate with a copper foil thickness of 0.035mm as a conductor is indicated in Figure 8.

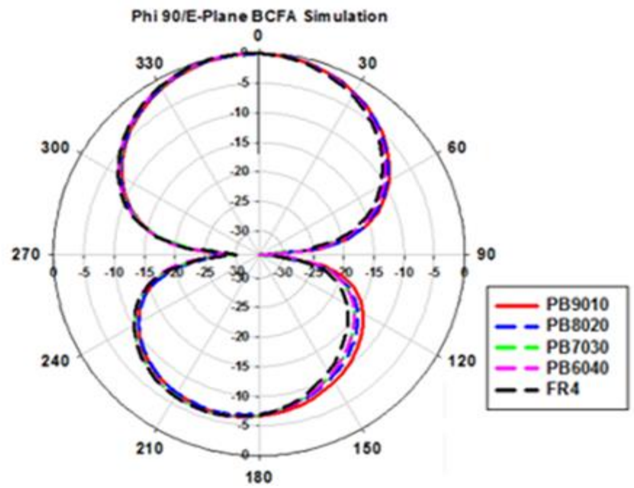


Figure 5 (a): Phi 90 E-plane BCFA simulation

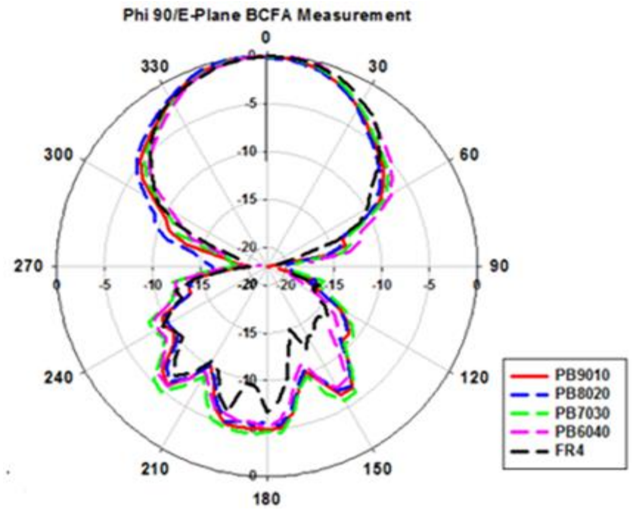


Figure 5 (b): Phi 90 H-plane BCFA measurement

The polar plot radiation pattern for H-Plane Phi 0° is indicated in Figure 6 (a) and Figure 6 (b). The simulation plotting does not show deviation among all the proposed substrate, but the measurement result reported the main lobe deviated for FR4 substrate 122°, while other substrates stated an average at 120.7°. The back lobe of measurement reported decreased from an average of 6.58dB to 5.56dB. The measurement result indicated that there is an improvement of the back lobe reduction of 6.68dB (FR4) to average 5.28dB (all proposed substrate). From the radiation plotting, the antenna performance of vertical linear polarization with the E-Plane was more dominant compared to H-Plane regarding gain. The analysis of surface current for BCFA on all proposed substrates is shown Figure 7 (a) to (e). The decrement of surface current showed the drop in the value from 19A/m (PB9010) to 10.4 A/m (PB6040).

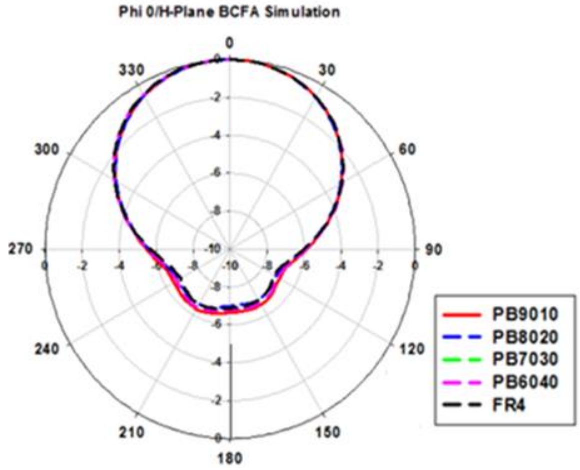


Figure 6 (a): Phi 0 E-plane BCFA simulation

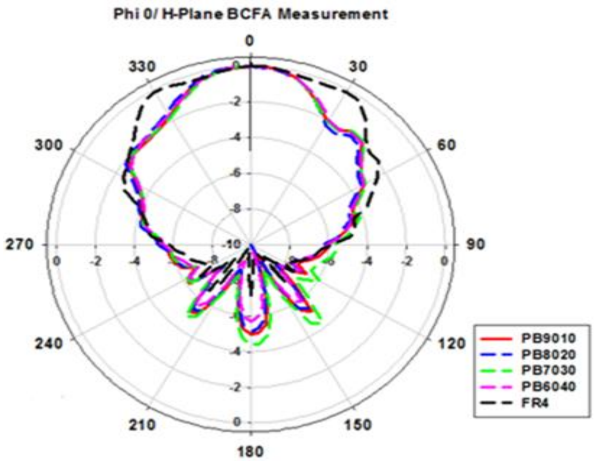


Figure 6 (b): Phi 0 E-plane BCFA measurement

The result reveals that the increment of wood filler contents decreases the amount of surface current periodically. This behavior happened due to the increase in carbon content [16] that absorbs more signal; hence, reducing the amount of surface current. The result is in line with the previous research that carbon content will absorb more signal; thus, providing higher Dk and Tan δ that lowers down the signal performance [17]. As indicated in Figure 7 (c), FR4 gives 15.4 A/m surface current only, which implies that the PB9010 (Figure 7 (a)) and PB8020 (Figure 7 (b)) outperformed the FR4. This result indicated that the optimal proposed treated substrate that can be comparable to FR4 substrate, PB9010, and PB8020. As noted in Figure 7 (c), PB7030 showed mediocre performance but PB6040 (Figure 7 (d)) was stated to be underperformance when compared to the FR4 substrate.

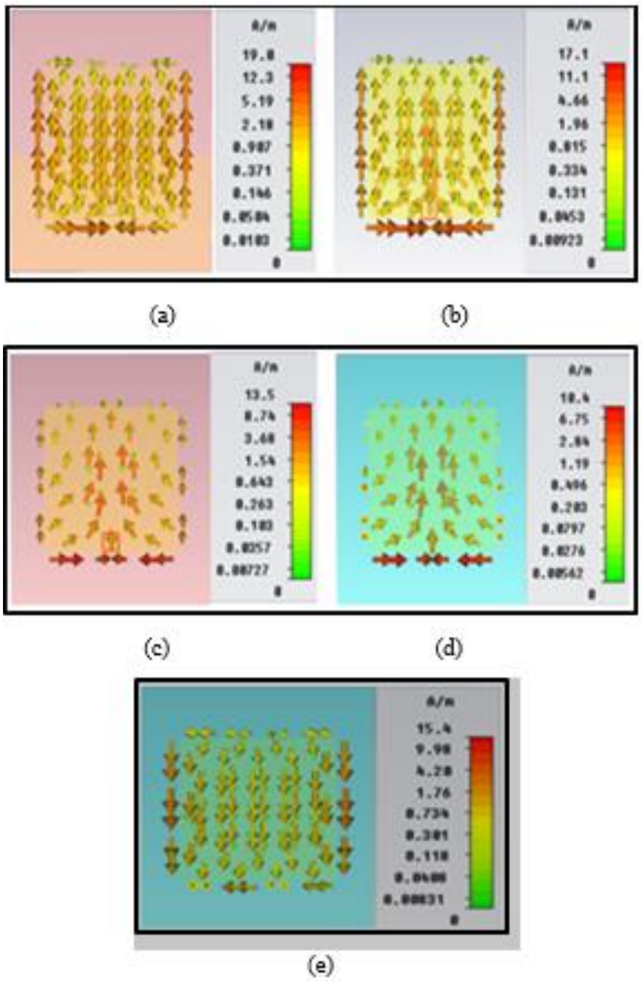


Figure 7: Surface current (a) PB9010 (b) PB8020 (c) PB7030 (d) PB6040 (e) FR4

The measurement and fabrication of BCFA antenna were then compared to see the differences in term of the standard antenna performance parameter tabulated in Table 4 for simulation and Table 5 for measurements result with back to back comparison to the commercial FR4 substrate. As indicated in Table 4 and Table 5, the antenna gain was reduced while the wood filler increased with the reduction from 4.73dBi to 1.2dBi (simulation) and 4.62 to 0.1dBi (measurement). The substrate PB9010 and PB8020 outperformed the FR4 BCFA antenna with a gain indicated over than 2.45 dBi (simulation) and 1.83 dBi (measurement). Beside antenna gain, the efficiency also plays an important characteristic of the radiation performance of the antenna. As tabulated in simulation (Table 4) and measurement (Table 5) the whole composition decreases when there is an increase in the wood filler.

Table 4
Simulation of BCFA antenna

Parameter (measurement)	PB9010	PB8020	PB7030	PB6040	FR4
Gain (dBi)	4.73	4.4	1.24	1.2	2.45
Efficiency (%)	86.9	79.3	61.2	38.5	55
Directivity (dBi)	5.34	5.44	5.45	5.392	5.474
Front to back (dB)	6.56	6.58	6.31	6.49	6.96
-3dB beam width (degree)	119	120.4	120.7	120.1	122
Centre frequency (CF) (GHz)	2.45	2.45	2.45	2.45	2.45
Operating frequency (GHz)	2.406-2.492	2.408-2.491	2.37-2.52	2.38-2.53	2.37-2.49
S-parameter magnitude (dB)	-47.6	-53.3	-35.9	-35.9	-35.4
Bandwidth (MHz)	86	83	122	125	74

Table 5
Measurement of BCFA antenna

Parameter (measurement)	PB9010	PB8020	PB7030	PB6040	FR4
Gain (dBi)	4.62	4.0	0.9	0.1	1.83
Efficiency (%)	84.3	62.9	57.8	38	50
Directivity (dBi)	5.91	5.93	5.94	5.94	5.32
Front to back (dB)	5.22	5.41	4.78	5.69	6.68
-3dB beam width (degree)	119.9	120.6	121.0	119.5	121.1
Centre frequency (CF) (GHz)	2.43	2.46	2.43	2.44	2.42
Operating frequency (GHz)	2.39-2.5	2.39-2.51	2.37-2.52	2.38-2.53	2.37-2.49
S-parameter magnitude (dB)	-39.2	-41.6	-32.6	-37.1	-35.1
Bandwidth (MHz)	110	120	150	150	120

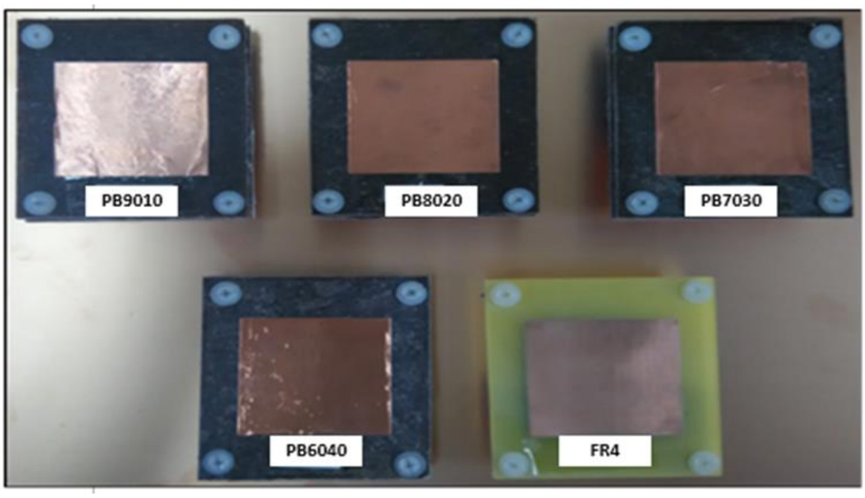


Figure 8: BCFA antenna design by using green biocomposite and the FR4 substrate

The decreasing behavior occurs due to the filler that consumes a lot of carbon and water that increases the loss tangent (Tan δ) of the substrate [18][19]. As the substrate composition increases, the front to back and directivity of the BCFA increases for both simulation and measurements. The front to back increased from 6.56 dB to 6.49dB (simulation) and 5.22dB to 5.69dB (measurement) with FR4 substrate reported (6.96dB) in the simulation and 6.68dB for measurement. The directivity simulation reported increased from 5.91 to 5.94dBi (measurement) and 86.9dBi to 5.392dBi (simulations). The increments of the front to back data and directivity distributed by the increasing on the dielectric constant (Dk) value enhances the capacitive condition to the substrate behavior that changes the phase delay to the radiation inside of the substrate. The phase delay radiation was in line with the increments of the dielectric constant and improved the directivity and front to back characteristic of BCFA antenna. The other simulated and measurements antenna parameter are tabulated in Table 4 and Table 5 with the measurements conducted using OTA 500 Atenlab anechoic chamber that has the capabilities to reveal result parameter as the same as computer simulation software (CST).

IV. Conclusion

As a conclusion, the proposed PB9010, and PB8020 substrate outperformed the performance of FR4 substrate with BCFA antenna analysis, while the PB7030 substrate showed moderate performance compared to the FR4 substrate with 24% of performance efficiency reduction (measurement). The last substrate that contained wood filler showed the worse result with unacceptable efficiency performance. The content of 40% of wood filler distributed higher value of Dk but increased the number of Tan δ, hence degrading the overall antenna performance. As indicated in the antenna analysis, the maximum mixture of wood acceptable to be used as antenna substrate was at 30% only, while 40% showed the mixture underperformed as antenna substrate when compared to the FR4 substrate with BCFA antenna analysis

V. Acknowledgement

The authors would like to acknowledge Malaysian Timber Industry Board (MTIB), Fidec (Banting, Malaysia), especially En. Zulkepli bin Abd Rani, Director of Fibre and Bio-composite center (FIDEC), for allowing the author to use the facility in FIDEC lab that possible of accomplishment of this article.

References

[1] S. S. Suhaily, H. P. S. A. Khalil, W. O. W. Nadirah, and M. Jawaid, “Bamboo Based Biocomposites Material , Design and Applications,” *Mater. Sci.*, p. 549, 2013.

[2] M. Chlosta, “Feasibility study on fibre reinforcement polymer cylindrical truss bridges for heavy traffic,” Delft University of Technology, 2012.

[3] Kishor S. Joshi and Sunita M.Bagewadi, “Analysis Of Properties Of Artificial Biological Composite Materials,” *Int. J. Eng. Res. Gen. Sci.*, vol. 4, no. 1, pp. 566–578, 2016.

[4] G. Gupta, A. Kumar, R. Tyagi, and S. Kumar, “Application and Future of Composite Materials : A Review,” *Int. J. Innov. Res. Sci. Technol.*, vol. 5, no. 5, pp. 6907–6911, 2016.

[5] N. Nkordeh, F. Idachaba, and O. Oni, “Microstrip Patch Antenna : Comparing Performance of a Rectangular and a Circular Patch at LTE Bluetooth and GSM Frequencies,” in *Proceedings of the World Congress on Engineering 2015*, 2015, vol. I, pp. 3–6.

[6] N. Bajaj, “A Review on Fundamental of Microstrip Patch Antenna,” *Imp. J. Interdiscip. Res.*, vol. 2, no. 8, pp. 55–60, 2016.

[7] A. A. Azlan, M. K. A. Badrun, M. T. Ali, Z. Awang, Z. M. Saad, and

A. H. Awang, “A Comparative Study of Material Leucaena Leucocephala Stem Wood Plastic Composite (WPC) Substrate with FR4 Substrate throughout Single Patch Antenna Design,” *Prog. Electromagn. Res. B*, vol. 59, no. April, pp. 151–166, 2014.

[8] M. Tareq, D. . Alam, M. Islam, and R. Ahmed, “Simple Half-Wave Dipole Antenna Analysis for Wireless Applications by CST Microwave Studio,” *Int. J. Comput. Appl.*, vol. 94, no. 7, pp. 21–23, 2014.

[9] M. A. Sulaiman, M. T. Ali, I. Pasya, N. Ramli, H. Alias, and N. Ya’Acob, “UWB microstrip antenna based on circular patch topology with stepped blocks (wing),” *IEEE Symp. Wirel. Technol. Appl. ISWTA*, pp. 262–265, 2012.

[10] S. Rawat and K. K. Sharma, “A compact broadband microstrip patch antenna with the defective ground structure for C-Band applications,” *Cent. Eur. J. Eng.*, vol. 4, no. 3, pp. 287–292, 2014.

[11] J. Kumar and S. S. Shirgan, “Compact partial ground plane 1x2 patch antennas,” in *Proceedings - 2014 6th International Conference on Computational Intelligence and Communication Networks, CICN 2014*, 2014, no. November 2014, pp. 33–37.

[12] T. Mukherjee, P. V. Rao, M. V. L. Bhavani, and A. K. Sinha, “Micro-Strip Patch Antenna Characteristics Using Different Dielectric Substrates,” *Int. J. Adv. Res. Electr. Electron. Instrum. Eng.*, vol. 4, no. 5, pp. 3813–3818, 2015.

[13] M. Kim, W. Lee, J. Bae, H. Lee, K. C. Hwang, K. Y. Lee, C. S. Park, and Y. Yang, “Balanced/Unbalanced Wideband: A Wideband, Bifilar Transmission-Line Balun,” *IEEE Microwave Magazine*, vol. 17, no. 1, pp. 65–69, 2016.

[14] A. Majumder, “Rectangular microstrip patch antenna using coaxial probe feeding technique to operate in S-band,” *Int. J. Eng. Trends Technol.*, vol. 4, no. April, pp. 1206–1210, 2013.

[15] S. Karkare, K. Tewari, and E. Department, “Enhancing Return Loss of Rectangular Microstrip Antenna Using AMC Ground Plane,” *Int. Res. J. Eng. Technol.*, vol. 2, no. 4, pp. 1045–1048, 2015.

[16] J. P. Peng, H. Zhang, L. C. Tang, Y. Jia, and Z. Zhang, “Dielectric properties of carbon nanotubes/epoxy composites,” *J. Nanosci. Nanotechnol.*, vol. 13, no. 2, pp. 964–969, 2013.

[17] X. Liu and Q. Li, “Microwave Dielectric Characteristics of Single-walled Carbon Nanotubes,” *Mod. Appl. Sci.*, vol. 3, no. 1, pp. 51–56, 2009.

[18] V. Komarov, S. Wang, and J. Tang, “Permittivity and Measurements,” *Encycl. RF Microw. Eng.*, pp. 3693–3711, 2005.

[19] X. Junming, J. Jianchun, and K. Sun, “An investigation of wood-plastic novolac modified by biomass pyrolysis oils,” *Iran. J. Chem. Chem. Eng.*, vol. 30, no. 1, pp. 83–87, 2011.