Proceeding of the 2013 IEEE International Conference on Space Science and Communication (IconSpace), 1-3 July 2013, Melaka, Malaysia

Slotted Dipole Microstrip Antenna Embedded on Paper Materials for Long Range Communications

W. N. Zaihasra and M. Y. Ismail

Wireless and Radio Science Centre (WARAS),
Universiti Tun Hussein Onn Malaysia,
Batu Pahat, Johor, Malaysia.
wzaihasra@yahoo.com and yusofi@uthm.edu.my

***Abstract*— Due to the significant limitations of the conventional microstrip antennas which are shown to limit the radiation signals at long range point and narrow bandwidth, a novel slotted dipole element embedded with sustainable and low loss paper materials has been presented in this paper for the first time to be used for long range communications. The loss and bandwidth performances of proposed microstrip antenna designed at C-band (4-8GHz) frequency range have been demonstrated based on sustainable and non-sustainable substrate materials. It has been shown that the sustainable paper based substrate has a lowest return loss of -25.82dB and widest bandwidth of 460MHz as compared to Rogers RT/Duroid 5870 and FR-4. In order to realize a broadband paper based substrate microstrip antenna, slot configurations have been introduced on the surface of the dipole element. It can be observed that there is a trade-off between the return loss and bandwidth performances of the proposed microstrip antenna. Based on the analysis of the proposed microstrip antenna embedded on paper materials, an extensive formulation is established for the expected range for long range communications. A novel algorithm based on Finite Element Method (FEM) is also developed in order to carry out the analysis on the loss and bandwidth characterization of the proposed microstrip antenna. Furthermore, scattering parameter measurements have been performed to verify the analysis from the simulated results.**

Keywords—microstrip antenna; paper materials; slotted dipole element; loss and bandwidth characterization

I. INTRODUCTION

Microstrip antenna is identified as a key technology for long range communications due to its inherent advantages of low profile, ease of fabrication, and compatibility with integrated circuitry [1,2]. However, in previous decades, the use of microstrip antenna for long range communications is primarily limited to a lower radiation signals at long range from its main system. In addition, the operation of the conventional microstrip antenna is limited to a short range due to its narrow bandwidth performance. By considering these significant limitations, a novel slotted dipole microstrip antenna constructed on sustainable and low loss paper materials is proposed to be designed at C-band (4-8GHz) frequency range to be employed for long range communications. In this work, non-sustainable materials of Rogers RT/Duroid 5870 and FR-4 have been used as substrate materials of the proposed microstrip antenna in order to characterize their loss and bandwidth performances. In addition, slot configurations have been introduced on the surface of the dipole element to realize a broadband antenna which capable to be operated at long range from its main system. Slot configurations have been considered as one of the technique that is practical to be applied for miniaturization and also for broadband antenna. By embedding the appropriate slot configurations on the surface of the radiating element, the broadband antenna can be achieved [3]. In order to predict how long the antenna can be operated, a mathematical formulation is required. In this work, a mathematical formulation has been established and the range of communications has been predicted based on the particular parameters of the proposed microstrip antenna. This work also provides a mathematical algorithm which is based on the Finite Element Method (FEM) to verify the analysis from the simulated results. In order to provide with strong analysis of the research findings, scattering parameter measurements have been performed by using a Vector Network Analyzer.

This project is fully funded by Research Acculturation Collaborative Effort (RACE) VOT 1119 Grant and MyBrain15, awarded by Ministry of Higher Education of Malaysia

II. CHARACTERIZATION OF PROPOSED SUBSTRATE MATERIALS

One of the major design considerations for the design of microstrip antenna is the selection of substrate materials. Thickness, dielectric permittivity and loss tangent of substrate materials play an important role to determine the loss and bandwidth performances of a microstrip antenna [4, 5]. Rogers RT/Duroid 5870 and FR-4 are two conventional substrate materials that have been widely used in the design of microstrip antenna for different applications [6-8]. However, the substrate materials are non-sustainable materials which caused a high loss performance of the proposed microstrip antenna and also caused the global warming and global climate change to the earth. In addition, a microstrip antenna for long range

978-1-4673-5233-8/13/$31.00 ©2013 IEEE

communications requires high flexibility of substrate materials so that it can be easily installed according to the structure of the module. Furthermore, Rogers RT/Duroid 5870 and FR-4 are considered as costly materials which limit the production of the proposed microstrip antenna. Due to these requirements, sustainable and low loss paper materials are proposed to be deposited as grounded substrates for the proposed slotted dipole microstrip antenna. The comparison between the conventional and proposed substrate materials is shown in Table I.

TABLE I. COMPARISON BETWEEN CONVENTIONAL AND PROPOSED SUBSTRATE MATERIALS

Substrate Materials	Conventional Substrates		Proposed Substrate
	Rogers RT/ Duroid 5870	***FR-4***	***Paper***
Dielectric permittivity	2.33	4.4	1.5
Tangent loss	0.0009	0.02	0.06
Flexibility	Non-flexible	Non-flexible	Flexible
Estimated sustainablity	Non-sustainable	Non-sustainable	Sustainable

III. PROPOSED ANTENNA DESIGN

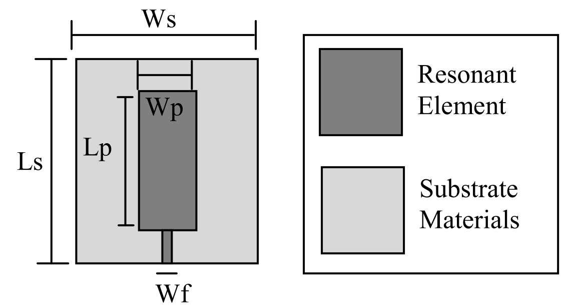


Fig. 1. Proposed microstrip antenna design

Figure 1 shows the proposed design of microstrip antenna with dipole element deposited on a grounded microwave paper substrate. The shape of the resonant element specifies the design complexity of microstrip antenna. Microstrip antenna with simple resonant element and smaller dimensions reduce the design complexity. In this work, a dipole element is proposed to be used as a resonant element of the proposed microstrip antenna. Dipole is well suited for the design of the proposed microstrip antenna because the substrate can be electrically thick and therefore the bandwidth of the dipole can be significant increase for long range communications [9]. In addition, due to smaller dimension of dipole, the cross- polarization will be lowered because the transverse current component on the dipole decreases as the width-to-length ratio decreases thus provides the proposed microstrip antenna with high efficiency of radiation signals to the desired directions. Furthermore, the less resistive area of the dipole is shown to reduce the attenuation factor caused by the conductor loss of the proposed microstrip antenna, thus minimize the loss of the signals. A transmission line feed has been used in order to excite the proposed microstrip antenna with amount of power. The formulas for W_s, L_s, W_p, L_p and W_f are shown in (1-4).

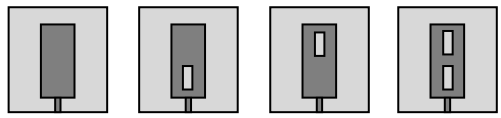
$$L_s = W_s = \frac{\lambda}{2} = \frac{c}{2f} \quad (1)$$

$$L_p = \frac{\lambda}{4} \quad (2)$$

$$W_p = \frac{\lambda}{8} \quad (3)$$

$$\frac{W_f}{h} = \begin{cases} \dfrac{8e^A}{e^{2A}-2} & for\ \dfrac{W_p}{h} < 2 \\ \dfrac{2}{\pi}\left[B-1-\ln(2B-1)+\dfrac{\varepsilon_r-1}{2\varepsilon_r}\left\{\ln(B-1)+0.39-\dfrac{0.61}{\varepsilon_r}\right\}\right] & for\ \dfrac{W_p}{h} > 2 \end{cases} \quad (4)$$

IV. REALIZATION OF BROADBAND ANTENNA



(a) (b) (c) (d)

Fig. 2. Proposed microstrip paper based substrate antenna (a) Without slot (b) Lower slot (c) Upper slot (d) Upper and lower slots

A broadband microstrip antenna is required to be used for long range communications. The broadband microstrip antenna allows the signals to be transmitted at long range from its main system. In order to observe the possibility of realizing a broadband microstrip antenna, different slot positions have been introduced on the surface of the dipole element, as shown in Fig. 2. For microstrip antenna without slot, the maximum current distribution occurs in the centre of the dipole element. The extraction of slot from the dipole of the proposed microstrip antenna causes the effective area of the conducting element to be reduced. This increases the surface current density which results in significant change in return loss performance. The extraction of slots also modifies the current distribution on the surface of the proposed microstrip antenna which caused the changes in resonant frequency and therefore provides the proposed microstrip antenna with enhanced bandwidth. The possibility of using different slot positions on the surface of proposed microstrip antenna to realize a broadband proposed microstrip antenna has been carried out by using Ansoft HFSS^{V12} computer model.

V. MATHEMATICAL FORMULATION FOR RANGE OF COMMUNICATIONS

Based on the analysis of the proposed microstrip antenna using paper substrate, a further formulation for the expected range of the transmission signals by the proposed microstrip antenna has been carried out using Finite Element Method (FEM). The proposed microstrip antenna with broadband performance would be able to operate at long range from the main system. In this work, the mathematical formulation is shown in (5).

$$R \propto \frac{G.BW}{HPBW}$$
$$R = C\frac{G.BW}{HPBW} \qquad (5)$$

Where,

R : Range of communication
G : Antenna gain
BW : Antenna bandwidth
$HPBW$: Antenna half-power beamwidth
C : Arbitrary constant

TABLE II. EXPECTED RANGE OF COMMUNICATIONS

Antenna gain (dB)	**Antenna bandwidth (MHz)**	**Antenna beamwidth (◦)**	**Range (m)**
5.46	80	81.75	120
6.20	320	82.0	280
8.52	520	76.2	320

Table II depicts the expected range of the proposed microstrip paper based substrate antenna to operate with high efficiency of radiation signals to the desired directions. As can be observed from Table II, the proposed microstrip antenna with highest value of 520MHz bandwidth offers long range radiation signals of 320m from its main system as compared to the proposed microstrip antenna with lower values of bandwidth. It can be concluded that, a broadband microstrip antenna based on paper substrate has a close relationship with the range of how far the antenna can be operated to radiate the signals into the desired direction with high efficiency and minimum losses. Therefore, it can be proved that the proposed microstrip antenna based on paper substrate has potential to be used for long range communications.

VI. COMPREHENSIVE ALGORITHM BASED ON FINITE ELEMENT METHOD (FEM)

A novel algorithm based on Finite Element Method (FEM) is developed in order to carry out the analysis on the loss and bandwidth performances of the proposed microstrip antenna. In order to analyze the loss and bandwidth characterization, an important parameter that is important to be taken into account to represent the amount of energy absorbed by the substrate, radiated into desired directions and dissipated into undesired directions is the quality factor, Q. In this work, a new mathematical algorithm based on the quality factor, Q is developed as shown in (6).

$$RL = \begin{pmatrix} \frac{RL_{f_r}}{n\varepsilon_r}, n = 1,2,3......25 \; for\, f < f_r \\ 8.68\left(\frac{\pi y}{Q\lambda_{eff}}\right) \qquad for\, f = f_r \\ \frac{RL_{f_r}}{n\varepsilon_r}, n = 1,2,3......15 \; for\, f > f_r \end{pmatrix} \qquad 6)$$

Where,

RL : Return loss performance
f_r : Resonant frequency
ε_r : Dielectric permittivity
Q : Quality factor
λ_{eff} : Effective wavelength

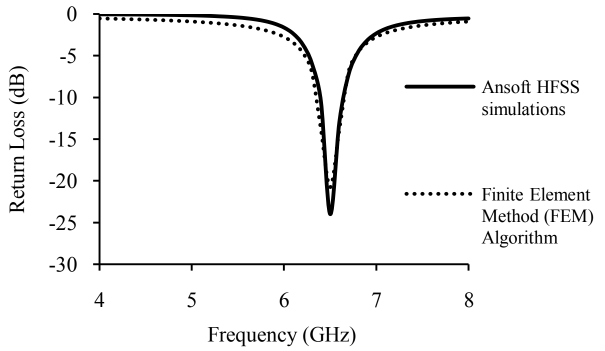


Fig. 3. Results of loss and bandwidth performances based on HFSS simulations and FEM algorithm

The new FEM algorithm has been modeled in MATLAB[V7.5] and the results are shown in Fig. 3. Based on the results, FEM algorithm and HFSS simulations are shown to have the return loss values of -20.74dB and -25.82dB respectively at a resonant frequency of 6.5GHz. The bandwidth of the proposed microstrip antenna has been measured at 20% from the resonance point. From Fig. 3, the bandwidth of the proposed microstrip antenna based on FEM algorithm is 500MHz while HFSS simulations is shown to have the bandwidth of 460MHz. It can be observed from Fig. 3 that the trend of loss and bandwidth characterization of the proposed microstrip antenna based on FEM algorithm has a reasonably good agreement with the simulated result based on Ansoft HFSS predictions.

VII. MEASUREMENT SET UP

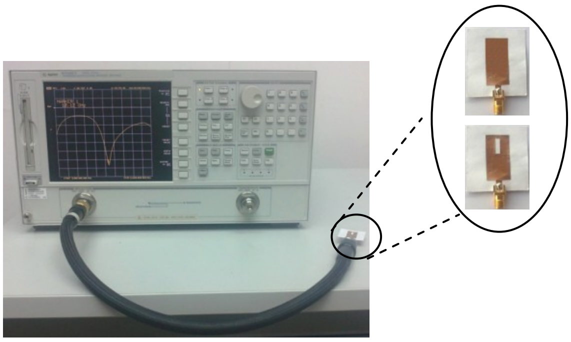


Fig. 4. Measurement set up for scattering parameter measurements

The scattering parameters measurements of the proposed microstrip antenna have been performed by using a Vector Network Analyzer. The measurement set up is shown in Fig. 4. The frequency range has been set up from 4-8GHz which allows the proposed microstrip antenna to be operated within the C-band frequency range. The fabricated samples of the proposed microstrip antenna without slot and with upper slot have been used in order to perform the scattering parameter measurements.

VIII. RESULTS AND ANALYSIS

A. *Simulated results of proposed microstrip antenna based on different substrate materials*

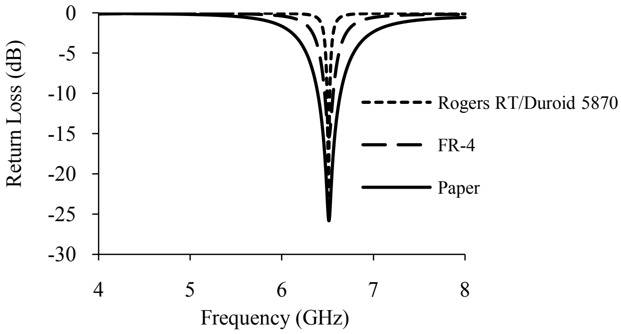


Fig. 5. Simulated results of proposed microstrip antenna based on different substrate materials

Figure 5 shows the loss and bandwidth performances of the proposed microstrip antenna with dipole element embedded on different substrate materials of Rogers RT/Duroid 5870, FR-4 and paper. The entire proposed microstrip antenna based on different substrate materials have been simulated at a resonant frequency of 6.5GHz using Ansoft HFSS^{V12} computer model. Different substrate materials have different values of material properties which result in different return loss performances. From Fig. 3, it can be observed that paper has the lowest return loss of -25.82dB as compared to Rogers RT/Duroid 5870 and FR-4 which have the return loss values of -22.77dB and -15.44dB respectively. This is due to the lowest value of dielectric permittivity of paper which is 1.5 and highest loss tangent of 0.06 as shown in Table I. The bandwidth of proposed microstrip antenna has been measured at 20% from the resonance point. It can be observed from Fig. 5 that the proposed microstrip antenna based on paper substrate offers a widest bandwidth of 460MHz as compared to Rogers RT/Duroid 5870 and FR-4 which are shown to offer the bandwidth of 80MHz and 320MHz respectively.

B. *Simulated results of proposed microstrip antenna based on paper materials with different slot positions*

Proposed microstrip antennas with different slot positions have been analyzed based on Finite Element Method (FEM) and the results are shown in Fig. 6. Based on the results generated in Fig. 6, it has been shown that the proposed microstrip antenna without slot as shown in Fig.2 (a) has a return loss value of -25.82 at 6.5GHz. However, it has a narrow bandwidth of 460MHz. Due to this narrow bandwidth, a single slot is introduced at the lower position of the dipole element as shown in Fig. 2(b). From the simulated results shown in Fig. 6, the lower slot is shown to offer a wider bandwidth of 520MHz at 7.01GHz. However, the return loss value of -21.93dB of lower slot is shown to be not suitable for high efficiency of radiation signals. Due to the high return loss value of the lower slot, a single slot is then proposed at the upper position of proposed microstrip antenna as shown in Fig. 2(c). As depicted in Fig. 6, the upper slot is shown to offer an improved return loss and bandwidth performances of -31.33dB and 410MHz respectively at 6.86GHz. In order to miniaturize and also to achieve a broadband antenna, both upper and lower slots have been proposed on the surface of dipole element as shown in Fig. 2(d). From Fig. 6, it has been shown that this proposed design has a return loss value of -34.19dB with a bandwidth performance of 400MHz. Based on the simulated results generated using Ansoft HFSS^{V12} computer model as shown in Fig. 6, it has been observed that an improvement in the bandwidth performance will increase the return loss performance of the proposed microstrip antenna and vice versa. It can be concluded that there is a trade-off between the return loss and bandwidth performances of the proposed microstrip antenna.

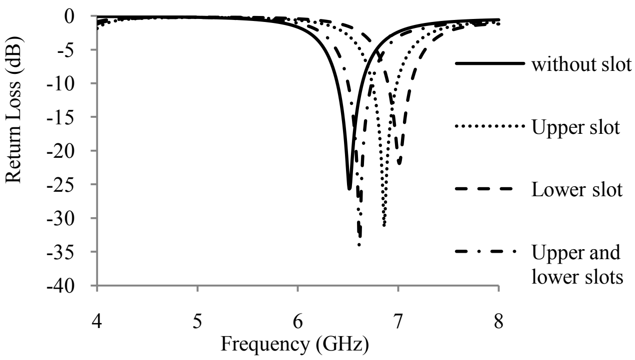


Fig. 6. Trends of resonant frequency with return loss and bandwidth performances based on different slot positions

C. Comparison between simulated and measured results of proposed microstrip antenna without slot

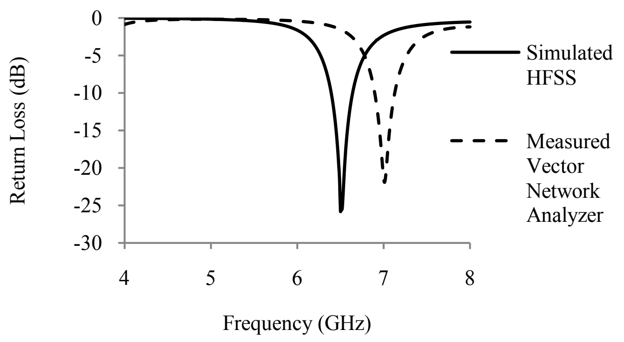


Fig. 7. Simulated and measured results of the proposed microstrip antenna without slot

Figure 7 shows the comparison between the simulated and measured results of proposed microstrip antenna based on paper substrate without slot configurations. It has been shown that the resonant frequency of the measured result has been shifted towards the higher frequency of 6.88GHz as compared to the simulated result which resonates at 6.5GHz. As can be observed from the results generated in Fig. 7, the simulated result is shown to have a lower return loss of -34.19dB as compared to the measured result of only -19.10dB. There is also a significant change in bandwidth performance between the simulated and measured results. It has been shown that the simulated result has a wider bandwidth of 400MHz as compared to measured result which has the bandwidth of 320MHz. The discrepancies between the measured and simulated results are due to some factors. One of the factors is that the material properties of the paper have been taken from the datasheet. In order to investigate the material properties of the paper materials, further material characterization will be involved.

D. Comparison between simulated and measured results of proposed microstrip antenna with upper slot.

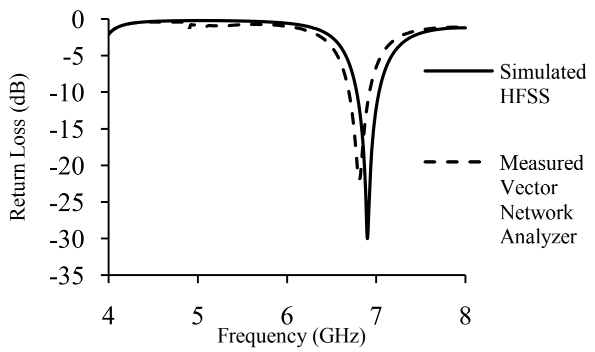


Fig. 8. Simulated and measured results of the proposed microstrip antenna with upper slot

Figure 8 shows the simulated and measured results of the proposed microstrip antenna with upper slot. It can be seen from the simulated result that the proposed microstrip antenna resonates at 6.86GHz with return loss of -31.33dB whereas from the measured result, the proposed microstrip antenna resonates at 6.7GHz with return loss value of -22.12dB. Based on the Fig. 8, the proposed microstrip antenna is shown to have the bandwidth of 410MHz from the simulated result and 490MHz from the measured result. It can be observed from Fig. 8 that the measured result of the proposed microstrip antenna with upper slot has reasonably good agreement with the simulated result. However there is a small discrepancy between them which caused by some factors including the material properties of paper has been taken from the datasheet and the dimensions of the fabricated sample is not exactly same from the actual design in Ansoft HFSS computer model.

IX. CONCLUSION

A detailed analysis on the slotted dipole microstrip antenna based on sustainable and low loss paper materials have been demonstrated. It has been shown that the paper materials offer low loss and broadband performances as compared to Rogers RT/Duroid 5870 and FR-4. In addition, by embedding the slot on the surface of the dipole element based on paper substrate, there is a trade-off between the loss and bandwidth performances of the proposed microstrip antenna. Furthermore, as can be observed from the mathematical formulation, a wider bandwidth offers the long range of up to 320m as compared to the narrower bandwidth. Based on the mathematical algorithm that has been developed based on Finite Element Method (FEM), the FEM algorithm has a reasonably good agreement with the simulated result based on Ansoft HFSS predictions. Moreover, scattering parameter measurements have been performed and the results have been compared with the simulated results.

ACKNOWLEDGMENT

This project is fully funded by Research Acculturation Collaborative Effort (RACE) VOT 1119 Grant and MyBrain15, awarded by Ministry of Higher Education of Malaysia. We would like to thank the staff of Wireless and Radio Science Centre (WARAS) of Universiti Tun Hussein Onn Malaysia for technical support.

REFERENCES

[1] K. F. Lee and K. F. Tong, " Microstrip patch antennas-basic characteristics and some recent advances," Proceedings of the IEEE , vol.100, no.7, pp.2169-2180, July 2012.

[2] C. A. Balanis, Antenna Theory: Analysis and Design, 2nd Ed, John Wiley & Sons, Inc, New York, 1997.

[3] K. L. Wong, "Compact and Broadband Microstrip Antennas, John Wiley & Sons, Inc, New York, 2002.

[4] D. H. Schaubert, D. M. Pozar, and A. Andrian, "Effect of microstrip antenna substrate thickness and permittivity: comparison of theories with experiment,", IEEE Transactions on Antennas and Propagation, vol.37, no.6, pp.677-682, Jun 1989.

[5] R. Garg, P. Bhartia, I. Bahl and A. Ittipoboon, Microstrip Antenna

Design Handbook, Artech House, London, 2001.

[6] Nasimuddin, X. Qing and Z. N. Chen, "Compact circularly polarized symmetric-slit microstrip antennas," IEEE on Antennas and Propagation Magazine, vol.53, no.4, pp.63-75, Aug 2011.J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68-73.

[7] K. Oh, B. Kim, J. Choi, "Novel integrated GPS/RKES/PCS antenna for vehicular application," IEEE Microwave and Wireless Components Letters, vol.15, no.4, pp. 244- 246, April 2005.

[8] Z. Ali, V. K. Singh, A. K. Singh and S. Ayub, “E-Shaped microstrip antenna on Rogers substrate for WLAN applications," 2011 International Conference on Computational Intelligence and Communication Networks (CICN), pp.342-345, 7-9 Oct 2011.

[9] A. A. Deshmukh, K. P. Ray, S. Ranka, F. Shah, M. Parekh and A. Kadam, "Shorted plate slot cut proximity fed broadband microstrip antenna," 2011 Annual IEEE on India Conference (INDICON), pp. 1-4, 16-18 Dec 2011.