Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2014, Article ID 693852, 7 pages
http://dx.doi.org/10.1155/2014/693852

Research Article

Switchable Electromagnetic Bandgap Surface Wave Antenna

Qiang Bai, Kenneth L. Ford, and Richard J. Langley

Department of Electrical and Electronic Engineering, University of Sheffield, Mappin Street, Sheffield S1 3JD, UK

Correspondence should be addressed to Richard J. Langley; r.j.langley@sheffield.ac.uk

Received 3 December 2013; Accepted 20 February 2014; Published 10 April 2014

Academic Editor: Giacomo Oliveri

This paper presents a novel switchable electromagnetic bandgap surface wave antenna that can support both a surface wave and normal mode radiation for communications at 2.45 GHz. In the surface wave mode, the antenna has a monopole-like radiation pattern with a measured gain of 4.4 dBi at ±49° and a null on boresight. In the normal mode, the antenna operates like a back-fed microstrip patch antenna.

1. Introduction

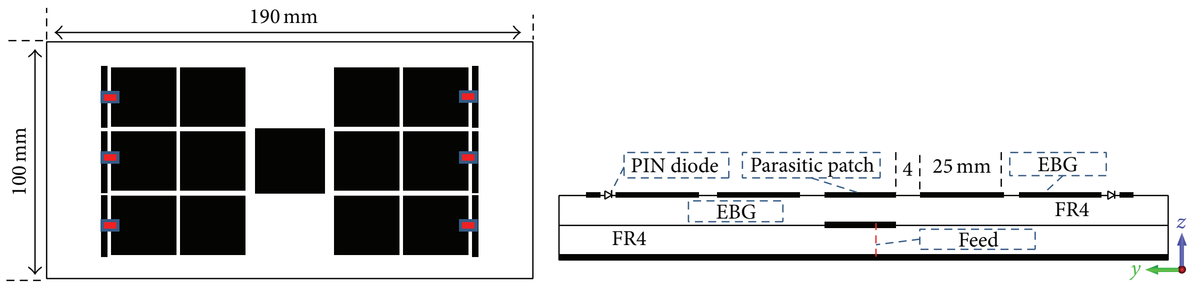
Many types of wearable antennas have been proposed in recent years designed for body area networks (BANs). Antennas may operate in either of two modes, on-body and off-body. On-body communication refers to the transmission of signals across the human body as a surface wave, which requires the wearable antenna to have maximum directivity along the body surface while, in the off-body (normal) mode, the communication occurs away from body to a node such as a base station, which demands that the antenna have the maximum radiation in the boresight direction. Therefore ideally such antennas have to be designed to support each mode of operation. For many antennas, it is useful if they are able to operate without being affected by their environment, for example, radiating into the human body or placing them on metal surfaces such as vehicles. Hence, a large ground plane or electromagnetic bandgap (EBG) structure may be also necessary to reduce the detuning effect and the backward radiation. Some antenna designs using EBGs as artificial magnetic conductors (AMCs) have been reported in [1–5] for off-body communication and in [6–8] for on-body communication. Only a small number of papers have studied a switchable system which can support both on- and off-body communications [9–11].

The mushroom-like EBG structure has been well studied and widely used in various designs to improve antenna performance [1, 12, 13]. Recent research also observed that the surface wave bandgap may disappear when the vertical vias are removed from the mushroom-like EBG structure. Hence instead of being suppressed, a strong surface wave can be exited and radiated on the via-less EBG material. Based on this feature, several surface wave antennas (SWA) have been designed to achieve a monopole-like radiation pattern on a thin, planar structure [14, 15]. However, in previous designs, the antenna could only support surface wave communication, and it was difficult to achieve the normal mode communication feature as the antenna was fully covered by the EBG cells.

This paper presents a novel switchable surface wave antenna based on bandgap materials which keeps the planar structure and low thickness but can support both surface wave (on-body) and normal (off-body) modes of communication at 2.45 GHz. Although not designed on textile materials, this paper shows the techniques for generating a dual mode switchable antenna. The performance of the antennas is investigated based on numerical and experimental methods. CST Microwave Studio was used for the antenna simulations. The surface wave communication mode is further investigated by studying the use of an EBG to couple antennas/sensors together around the body.

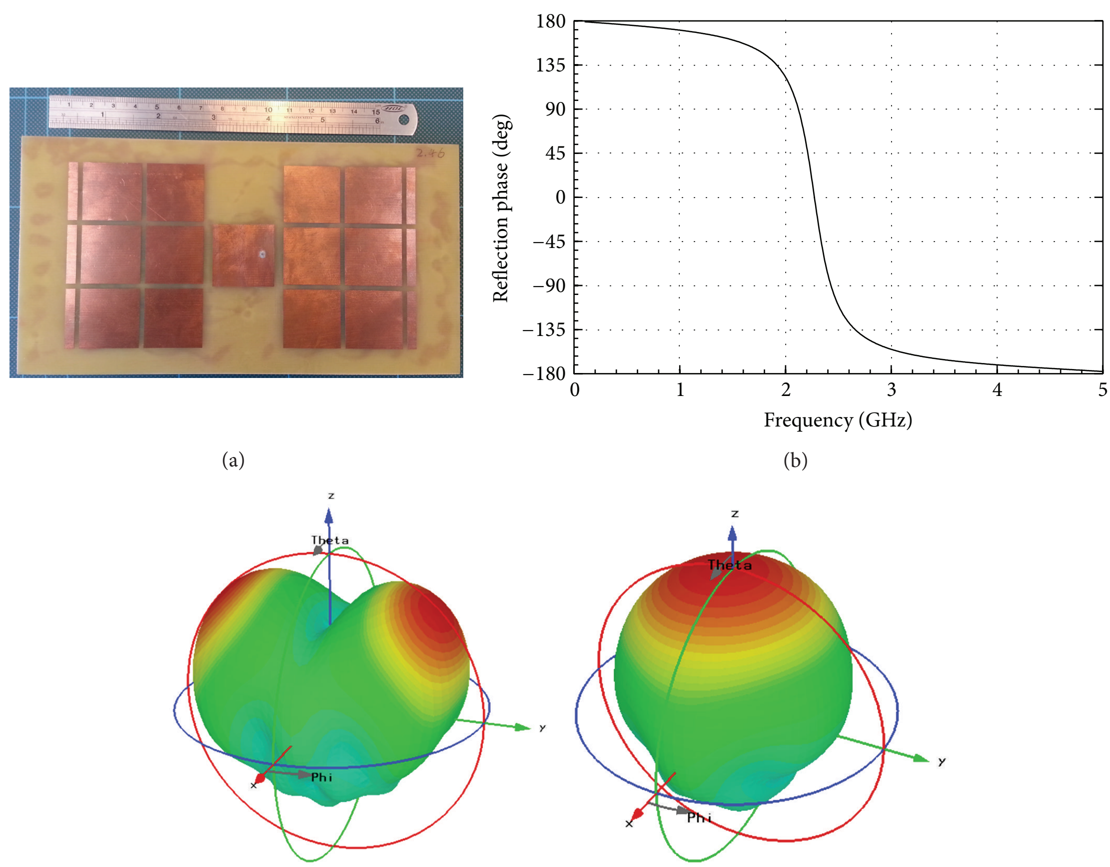
2. Antenna Design

The proposed switchable surface wave antenna comprises three layers. The radiating antenna is a 27 mm × 26.5 mm microstrip patch printed on a grounded slab and back-fed by a SMA connector (Figure 1). The feeding point is 6 mm offset



(a) (b)

Figure 1: Geometries of the switchable SWA: (a) top view, EBG based antenna layer with PIN diode switches, (b) side view.



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

Figure 2: (a) Photograph of the fabricated model (without PIN diodes), (b) EBG reflection phase, (c) simulated radiation patterns for antenna with EBG, (d) simulated radiation patterns for antenna without EBG.

from the patch centre. The top layer consists of a parasitic identical patch aligned above the lower patch antenna and an optimized EBG surface (Figure 1(a)). The EBG, with 25 mm × 25 mm unit cell, was designed, so that a surface wave was excited and propagated when the reflection phase of the EBG cell was approximately -90° (Figures 2(a) and 2(b)) [15]. There are six strips at the edges of the surface and six PIN diodes switching the EBG surface to the strips to give the radiation characteristics. Both layers are made of FR4 material with a total thickness of 3.2 mm and an overall size of 100 × 190 mm. The bias network can be printed on the back side of the top layer to actuate the PIN diodes. And also the PIN diodes can be replaced by varactor diodes to tune the surface response.

The simulated radiation patterns for the antenna are shown in Figures 2(a) and 2(b), with and without the EBG surface. These show that the radiation pattern with the EBG produces a mode that directs the peak radiation away from boresight. Based on this, the next section describes the performance.

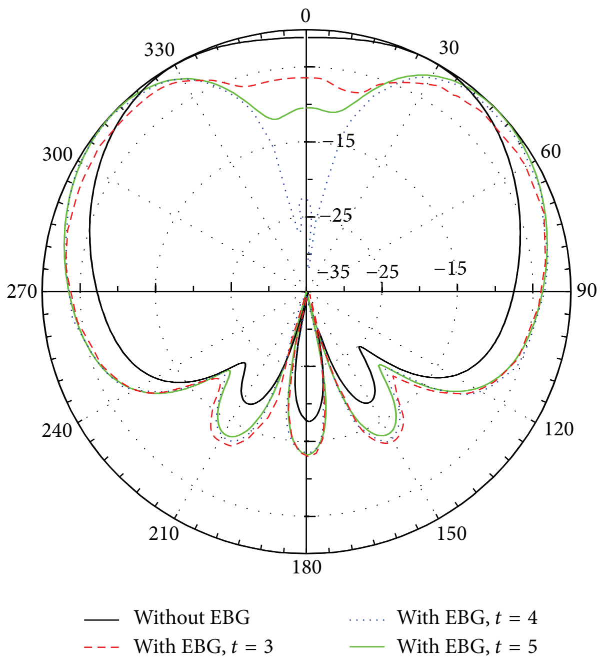


FIGURE 3: Simulated radiation patterns of switchable surface wave antenna (when $t = 3, 4, 5$ mm and without EBG).

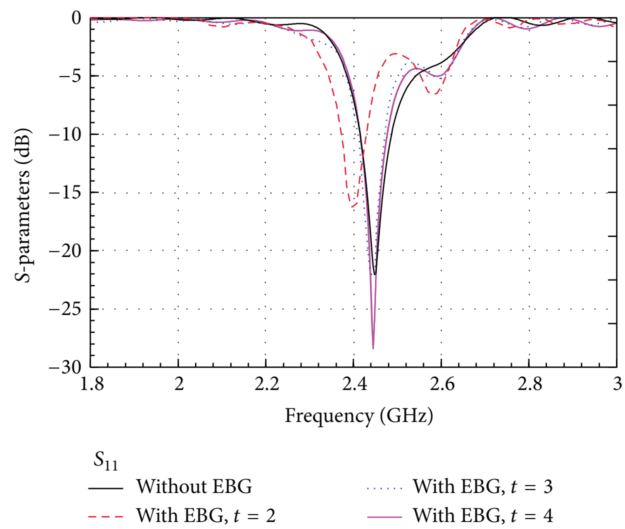


FIGURE 4: S_{11} of switchable surface wave antenna (when $t = 2, 3, 4$ mm and without EBG).

3. Simulation and Measurement

3.1. Simulation. Initially, the EBG layer, with parasitic patch inclusion, was spaced a distance, t, from the fed patch. Figure 3 plots the simulated y-z plane radiation patterns of the patch antenna alone and the patch antenna with the EBG surface for varying distances, t. For easy comparison, all radiation patterns in this paper are normalized. From Figure 3, the peak power from the radiation pattern varies from boresight for the patch antenna to approximately 50° with the EBG when the separation, t, is set to 4 mm and a null appears at boresight. There is an appreciable amount of radiation directed sideways from the antenna, along the EBG. It is also found in Figure 4 that the antenna matching performance was not significantly affected, maintaining the resonance at about 2.4 GHz.

The operation of the EBG antenna is clearly shown by the current distributions on the surface in the two modes (Figure 5). For the PIN diodes shorted in Figure 5(a), the currents are confined to the parasitic patch and the six elements of the EBG closest to it which form the antenna radiating away from the patch. With the PIN diodes open circuit, the whole of the EBG is excited directing the radiation along the antenna surface.

3.2. Measurement. Figure 6 presents the measured reflection coefficient of the switchable surface wave antenna to be compared with the simulation in Figure 4. In both modes (pin open and short circuit), the antenna has −10 dB bandwidth covering 2.4 GHz to 2.47 GHz. The antenna working band is shifted upwards by 20 MHz, covering the band from 2.42 GHz to 2.49 GHz in the measurements. This may be caused by the inaccuracy of the manufacture as a thin air gap is noticed when the antenna top layer and lower layer are assembled together. Unlike in previous EBG surface wave antennas reported in [14, 15], where the resonant frequency highly depends on the EBG, the matching performance of proposed antenna in this paper is only slightly affected when the top EBG structure is switched, giving an opportunity to tailor the antenna radiation pattern without changing the resonant frequency.

The measured y-z plane radiation patterns for the switchable surface wave antenna are plotted in Figure 7. In the surface wave mode, the antenna has the maximum directivity at ±49° with a measured gain of 4.4 dBi and a null is also obtained in the boresight direction. When switched to the normal mode, the antenna mainly radiates towards the boresight direction (red dotted line in the figure) with a gain of 3.7 dBi. It is also noted, due to the large ground plane, that the antenna has low backward radiation in both modes. Overall, the simulated and measured performance of the antenna are in good agreement.

4. EBG Waveguide

The switchable antenna presented in the previous sections allows reconfiguration of the radiation pattern. For applications such as body worn antennas, there is a need to acquire data from a number of sensors and antennas around the body to a central node for transmission to a base station far away from the body. This is difficult to achieve by line of sight due to blockage by the body and losses tend to be very high at >40 dB. Transmission lines could be used to connect the sensors but in this section, the potential use of an EBG propagating the surface wave mode will be presented. This follows directly from the study above. The concept is shown in Figure 8 where two switchable antennas are connected together using the EBG designed in Section 2 and operating

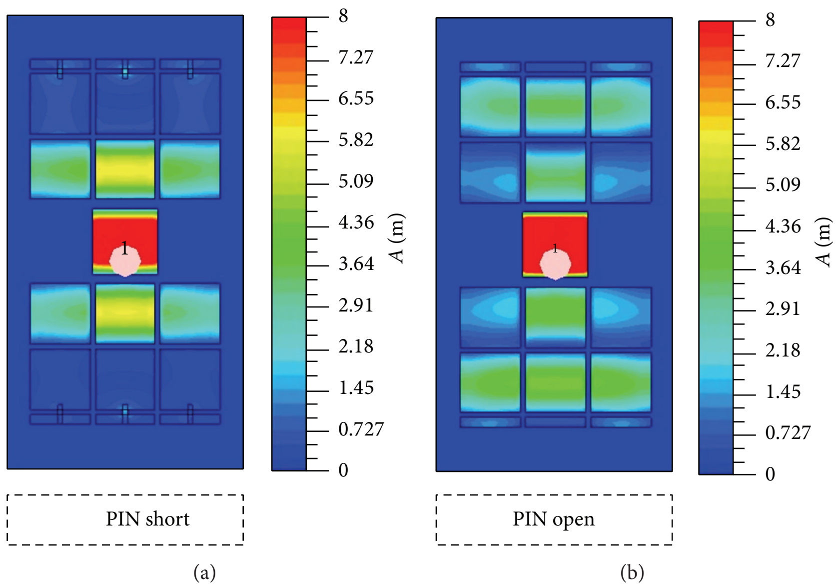


FIGURE 5: Surface currents on EBG antenna. (a) PIN diodes shorted. (b) PIN diodes open.

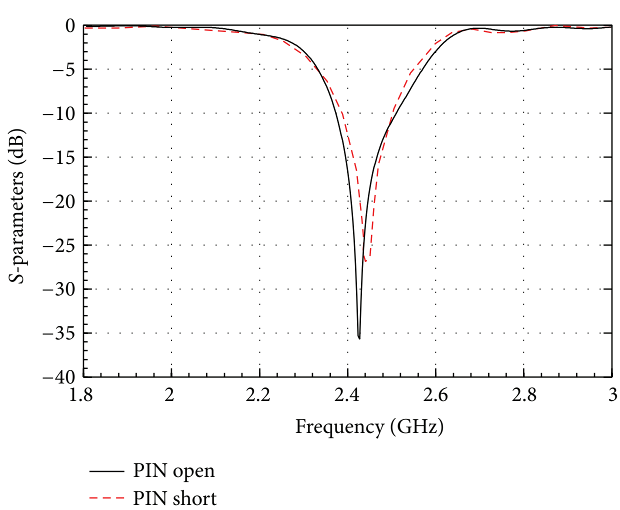


FIGURE 6: Measured S_{11} of switchable surface wave antenna.

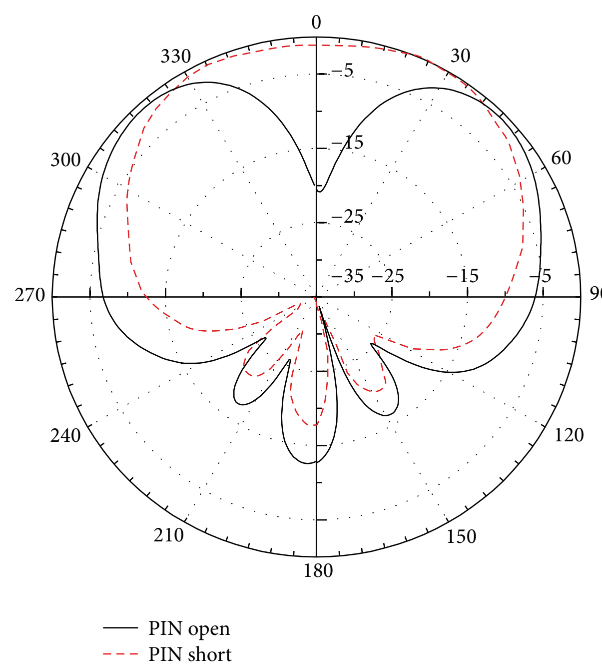


FIGURE 7: Measured radiation patterns of switchable surface wave antenna in y-z plane for pin diodes open and short circuit.

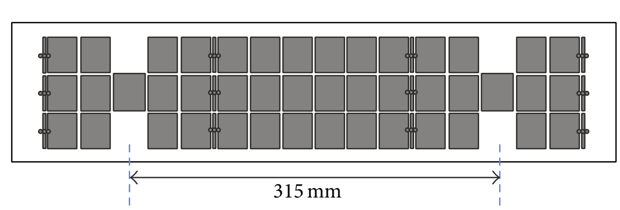
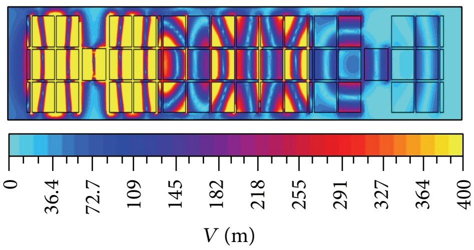


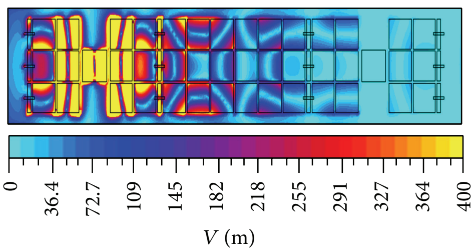
FIGURE 8: Antennas coupled using an EBG.

in the surface wave mode. The antennas remain switchable and are separated from centre to centre by 315 mm. The bandgap surface is shown as 3 elements wide by 6 elements long but this is for demonstration only and can be extended lengthwise as required. Three unit cell elements in width are sufficient for the EBG to operate satisfactorily rather than 2 elements. Five-element width was also tested, but there was no significant improvement obtained on transmission performance.

Figure 9 shows the surface currents for the cases with the PIN diodes both open and short circuit and it is clear that the EBG propagates a wave from one antenna to the other when the diodes are open circuit. The transmission coefficients, S_{21}, for both cases are plotted in Figure 10 where simulations and measurements are compared. When the PIN diodes are



(a) Upper plot PIN open circuit



(b) Lower plot PIN short circuit

Figure 9: Surface currents on EBG coupled antenna system.

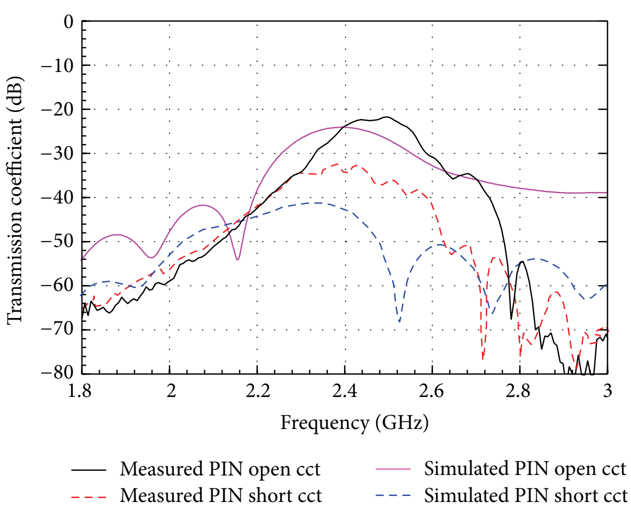


Figure 10: Measured and simulated transmission coefficients (S_{21}) between switchable mode antennas.

open circuit, the measured transmission was −21 dB between the antennas while the calculated value was about −23 dB. When the PIN diodes were short circuited, the transmission between the antenna and the EBG is considerably reduced (see Figure 5(a)) and hence the EBG carries little signals to the other antenna and the measured transmission falls to −33 dB for the measurement and −41 dB in the simulation. Manufacturing difficulties probably account for the discrepancy between the measured and calculated results as there was a small uneven air gap between the layers of the structure. In addition, for the simulation, the PIN diodes are assumed to be perfect switches.

Figure 11 shows the simulated 3D radiation pattern from the whole structure when operating in the normal mode showing that the full structure with the EBG was able to switch between the normal mode (radiation away from antenna) and the surface wave mode with the EBG acting as a transmission medium as in Figure 9.

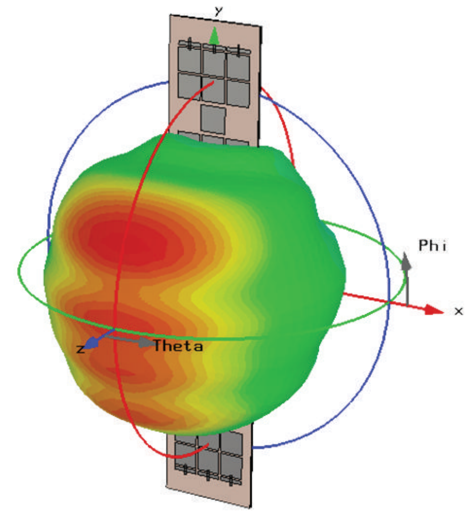


Figure 11: Radiation pattern for complete antenna/EBG with PIN diodes short circuit, normal mode.

To further demonstrate propagation across the antennas with and without the connecting EBG, the antenna system is bent around a tissue equivalent phantom [6] with a diameter of 100 mm as shown in Figures 12(a) and 12(b) respectively. In Figure 12(c) the surface currents excited on the antenna structure are shown in both cases. From Figure 12(c), it is clear that the EBG propagates the wave around the bend to the second antenna.

The simulated transmission coefficients (S_{21}) are plotted in Figure 13 for the bent geometry and compared with the value when the surface was flat. The coupling for the curved surface with the EBG increases from −45 dB without the EBG to −23 dB, although it does not reach the value of −18 dB for the flat surface with EBG. Typical S_{21} between antennas located at top and bottom of this tissue equivalent phantom is below −40 dB [6].

5. Conclusion

This paper presents a novel EBG surface wave antenna which can be switched by PIN diodes to support surface wave and normal mode communications at 2.45 GHz. In the surface wave mode, a monopole-like radiation pattern is obtained with a measured gain of 4.4 dBi at ±49°. In the normal mode, the antenna mainly radiates towards the boresight direction. Coupling two antennas together using the EBG design in surface propagation mode allows the wave to travel round a bent surface while maintaining the radiation pattern switching ability. Due to the thin and planar structure, the EBG surface wave antenna could be easily incorporated into clothing for body worn applications. Coupling losses using the EBG are better than direct radiation coupling between the antennas (typically −50 dB) when the signal travels round the torso.

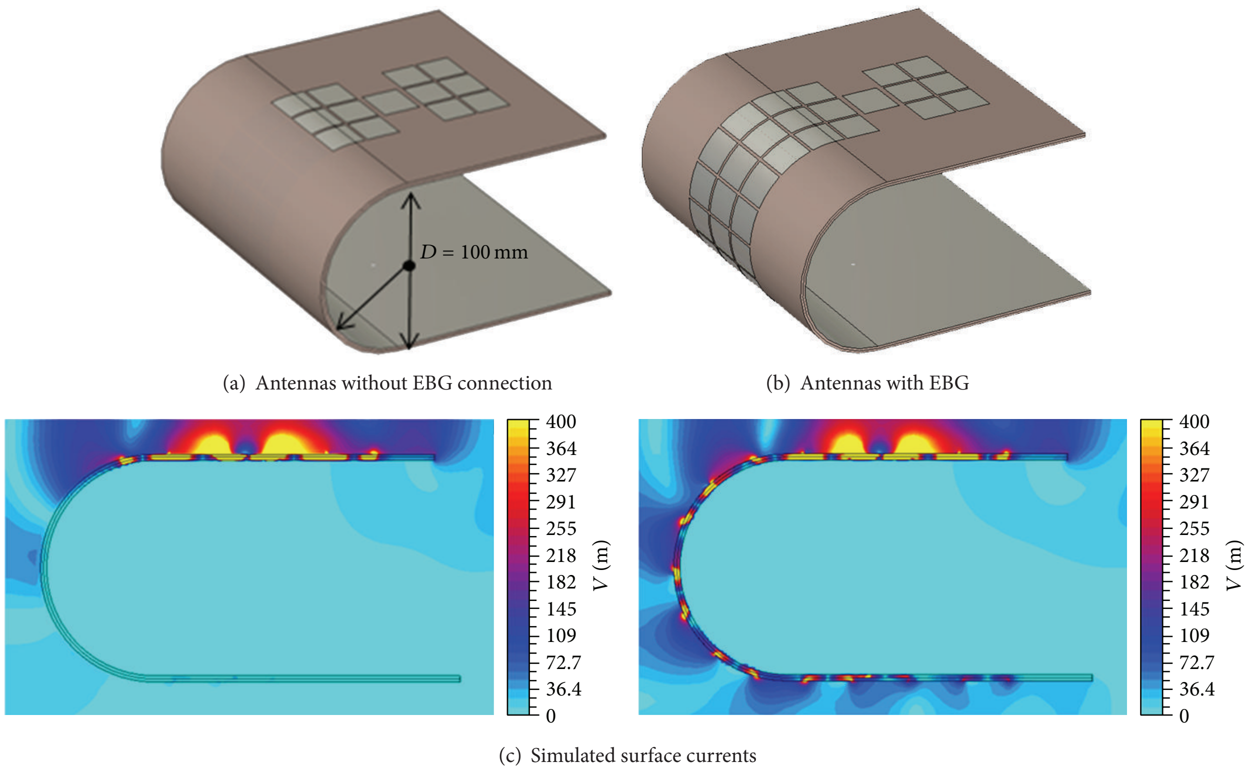


FIGURE 12: Antennas bent on a radius of 100 mm.

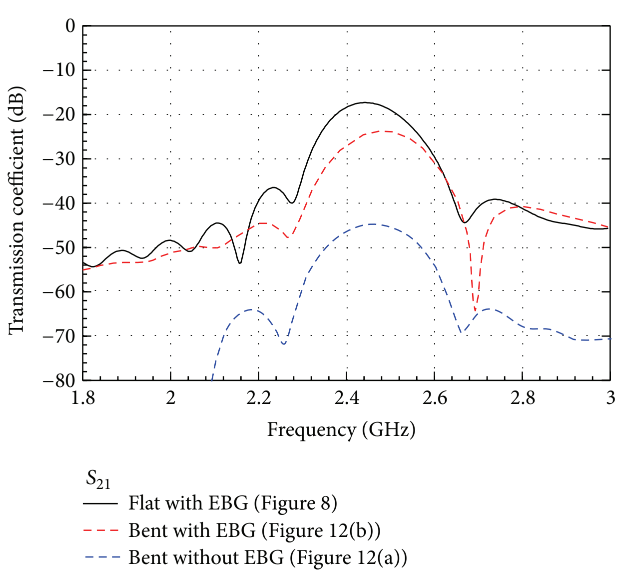


FIGURE 13: Transmission coefficients S_{21} for bent antenna surface.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgment

This work is funded by the UK Engineering and Physical Sciences Research Council (EPSRC) Grant Reference no. EP/G056633.

References

[1] S. Zhu and R. Langley, "Dual-band wearable textile antenna on an EBG substrate," *IEEE Transactions on Antennas and Propagation*, vol. 57, no. 4, pp. 926–935, 2009.

[2] P. Salonen, K. Jaehoon, and Y. Rahmat-Samii, "Dual-band E-shaped patch wearable textile antenna," in *Proceedings of the IEEE Antennas and Propagation Society International Symposium and USNC/URSI Meeting*, pp. 466–469, July 2005.

[3] M. Klemm, I. Locher, and G. Tröster, "A novel circularly polarized textile antenna for wearable applications," in *Proceedings of the 34th European Microwave Conference*, pp. 137–140, October 2004.

[4] A. R. Chandran and W. G. Scanlon, "Dual-band low profile antennas for body-centric communications," in *Proceedings of the International Workshop on Antenna Technology (iWAT '10)*, pp. 1–4, March 2010.

[5] T. F. Kennedy, P. W. Fink, A. W. Chu, N. J. Champagne II, G. Y. Lin, and M. A. Khayat, "Body-worn E-textile antennas: the good, the low-mass, and the conformal," *IEEE Transactions on Antennas and Propagation*, vol. 57, no. 4, pp. 910–918, 2009.

[6] G. A. Conway and W. G. Scanlon, "Antennas for over-body-surface communication at 2.45 GHz," *IEEE Transactions on Antennas and Propagation*, vol. 57, no. 4, pp. 844–855, 2009.

[7] M. R. Kamarudin, Y. I. Nechayev, and P. S. Hall, "Antennas for on-body communication systems," in *Proceedings of the IEEE International Workshop on Antenna Technology (IWAT '05)*, pp. 17–20, March 2005.

[8] L. Akhoondzadeh-Asl, P. S. Hall, and Y. Nechayev, "Novel conformal surface wave Yagi antenna for on-body communication channel," in *Proceedings of the IEEE International Symposium on Antennas and Propagation (AP-S/URSI '10)*, pp. 1–4, July 2010.

[9] A. R. Chandran, G. A. Conway, and W. G. Scanlon, "Pattern switching compact patch antenna for on-body and off-body communications at 2.45 Ghz," in *Proceedings of the 3rd European Conference on Antennas and Propagation (EuCAP '09)*, pp. 2055–2057, March 2009.

[10] J. Kelly, L. Ford, and R. Langley, "Slotline structure for on/off-body communications at 2.45 GHz," in *Proceedings of the 5th European Conference on Antennas and Propagation (EUCAP '11)*, pp. 525–529, April 2011.

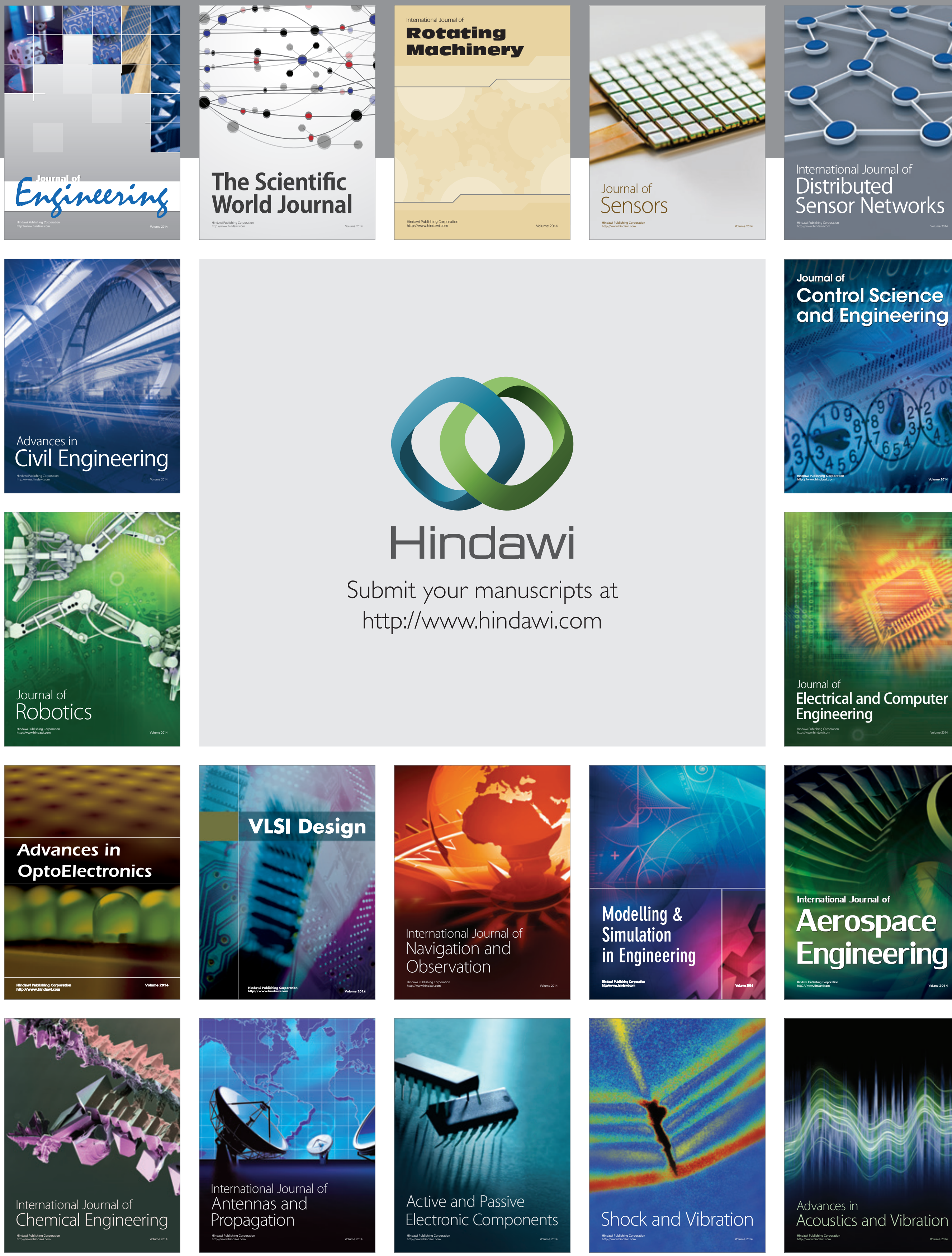
[11] R. J. Langley, K. L. Ford, and Hyung-Joo Lee, "Switchable on/off-body communication at 2.45 GHz using textile microstrip patch antenna on stripline," in *European Conference on Antennas and Propagation (EuCAP '12)*, pp. 728–731, 2012.

[12] P. Salonen and Y. Rahmat-Samii, "Textile antennas: effects of antenna bending on input matching and impedance bandwidth," *IEEE Aerospace and Electronic Systems Magazine*, vol. 22, no. 12, pp. 18–22, 2007.

[13] D. Sievenpiper, L. Zhang, R. F. Jimenez Broas, N. G. Alexöpolous, and E. Yablonovitch, "High-impedance electromagnetic surfaces with a forbidden frequency band," *IEEE Transactions on Microwave Theory and Techniques*, vol. 47, no. 11, pp. 2059–2074, 1999.

[14] F. Yang, A. Aminian, and Y. Rahmat-Samii, "A novel surface-wave antenna design using a thin periodically loaded ground plane," *Microwave and Optical Technology Letters*, vol. 47, no. 3, pp. 240–245, 2005.

[15] R. Khouri, P. Ratajczak, P. Brachat, and R. Staraj, "A thin surface-wave antenna using a via-less EBG structure for 2.45 GHz on-body communication systems," in *Proceedings of the 4th European Conference on Antennas and Propagation (EuCAP '10)*, pp. 1–4, April 2010.


Journal of Engineering
The Scientific World Journal
International Journal of Rotating Machinery
Journal of Sensors
International Journal of Distributed Sensor Networks
Advances in Civil Engineering
Journal of Control Science and Engineering
Hindawi
Submit your manuscripts at
http://www.hindawi.com
Journal of Robotics
Journal of Electrical and Computer Engineering
Advances in OptoElectronics
VLSI Design
International Journal of Navigation and Observation
Modelling & Simulation in Engineering
International Journal of Aerospace Engineering
International Journal of Chemical Engineering
International Journal of Antennas and Propagation
Active and Passive Electronic Components
Shock and Vibration
Advances in Acoustics and Vibration