Progress In Electromagnetics Research, Vol. 138, 613–627, 2013

A NOVEL 2.45 GHz SWITCHABLE BEAM TEXTILE ANTENNA (SBTA) FOR OUTDOOR WIRELESS BODY AREA NETWORK (WBAN) APPLICATIONS

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Abstract—A novel switchable beam textile antenna (SBTA) for wireless body area network (WBAN) applications is proposed. The SBTA is centrally-fed by a coaxial probe and the power distributed over four circular radiating elements. Four RF switches are integrated through which the SBTA is able to generate beam steering in four directions: 0°, 90°, 180°, and 270°, with a maximum directivity of 6.8 dBi at 0°. Its small size (88 mm × 88 mm) and flexibility enables the structure to be easily integrated into safety jackets, rain coats, etc., for tracking, and search and rescue communication purposes. The structure successfully integrates reconfigurability into a wearable textile antenna.

Received 26 February 2013, Accepted 28 March 2013, Scheduled 12 April 2013

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1. INTRODUCTION

Wearable textile antenna is crucial in providing comfort to users in wireless body area network (WBAN) [1]. Initial applications of WBAN have appeared primarily in the healthcare domain especially for continuous monitoring and logging vital parameters of patients suffering from chronic diseases. On-body communications, which is currently under standardization by IEEE 802.15.6 body area network (BAN) group [2, 3] is aimed for use in various areas such as military, personal recreation, sport equipment etc..

The principal requirement for wearable antennas is the use of flexible materials for ease of integration into clothing [4–8]. The proposed switchable beam textile antenna (SBTA) is designed on textiles to enable flexibility and fulfill this development requirement. This research, to our best knowledge, is the first effort in realizing a combination of such beam-switching feature onto a wearable radiator, which is an intermediate step towards realizing a wearable smart antenna system [9].

Research towards the switchable antenna has gained significant attention among researchers in recent years. Extending this antenna feature to a body-worn implementation needs not only peak gain considerations offered by the designed antennas, but also the coverage distribution around the body [10, 11]. Moreover, it is important to maintain a good outwards-radiating antenna gain throughout most parts of the body to avoid problems with excellent gain over a particular direction as the wearer moves or turns.

A conventional switchable antenna refers to a radiator capable of characteristic reconfiguration, either in terms of operating frequency, radiation patterns, polarizations or directivity through the control of RF switches [12–22]. These RF switches are only a small addition to the hardware requirements to enable this reconfigurable scheme and this research realize the utilization of silver loaded epoxy adhesive is effective in providing a solderless connection between the conductive textiles compared to larger and more complex elements such as phase shifters shown in Figure 1. The use of these small switches is especially practical for implementation on flexible materials and garments [23, 24]. Moreover, the utilized silver conductive epoxy is effective in providing a solderless connection between the conductive textiles and the implemented RF switches.

The four outer circular elements at the antenna's 0°, 90°, 180° and 270° directions are connected by RF switches at its center facilitated beam steering without any external circuitry and simultaneously achieving directivity at each beam-steered directions. The proposed

Figure 1. An array antenna implemented with phase shifter [23].

SBTA sized at 88 mm × 88 mm is relatively small and extremely suitable to be implemented on smart garments.

This paper is organized as follows: the design and RF switch integration procedure for this SBTA is explained in Section 2. The comparative analysis between measurement and simulated result is then presented in the following section. This includes its reflection coefficient, radiation pattern and surface current distribution. Finally, a conclusion is drawn in Section 4.

2. ANTENNA STRUCTURE

The structure of the proposed SBTA is depicted in Figure 2. Four circular patches, each with a radius of 10 mm, are located at 0°, 90°, 180° and 270°. They are connected by four arms to the center patch, which has a radius of 15 mm. Four RF switches are located at the middle of these arms. Theouter circular patches are connected to the central patch using transmission lines with widths of 5 mm. The centers of the four patches are and the longitudinal axes of the transmission lines are located on a circular with the radius of 27 mm. Equal current distribution among the outer circles is achieved by maintaining the line width at 5 mm, producing a 50 Ω input impedance without the use of additional quarter wavelength transformers [25].

The SBTA lines and patches are designed and fabricated using Shieldit Super textile as its conductive element. It is 0.17 mm thick, made of polyester base material coated using nickel and copper. This translates to an estimated conductivity of 6.67×10^5 S/m calculated using the equation proposed in [26, 27]. Besides its excellent conductivity and low corrosion, ShieldIt can be easily dimensioned using normal cutting tools. The properly dimensioned ShieldIt is then secured to the felt substrate (with permittivity of 1.22 and thickness of 2 mm) using a non-conductive hot melt adhesive layer on its reverse side, which is activated by ironing at c.a. 130°C. The detailed

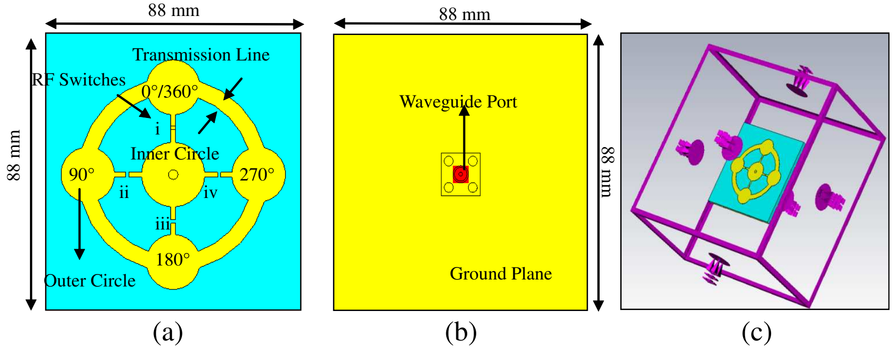

Figure 2. Simulated structure of proposed SBTA: (a) Front view, (b) rear view, (c) perspective view with open boundary conditions.

fabrication procedure is explained in [28]. Polyester-based textiles such as ShieldIt are also more hydrophobic, which reduces proneness to moisture absorption and thus allows for better conservation its electromagnetic properties [29].

The RF switch at the center of each transmission line arm consists of two capacitors and two inductors as shown in Figure 3. Each capacitor allows RF current to flow into a particular outer circular patch while simultaneously blocking the direct current (DC). On the other hand, the inductors act as short circuits to ensure the activation of each RF switch at a particular time. Figure 4 shows the prototype that has been developed fully on textiles, fed using probes with 0.5 mm radius for outdoor measurements at 2.45 GHz WBAN band.

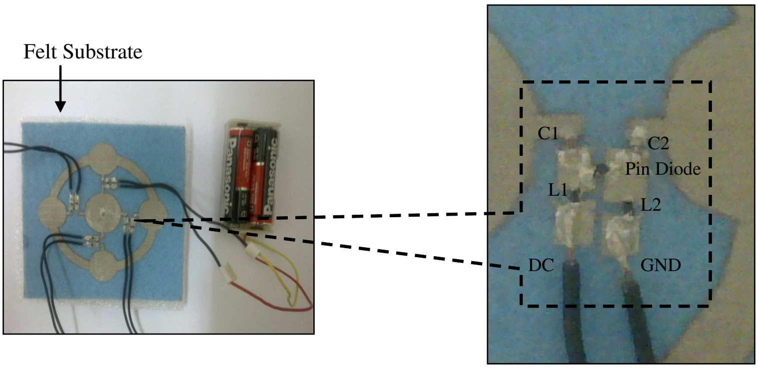

Figure 3. RF switches integration into SBTA structure.

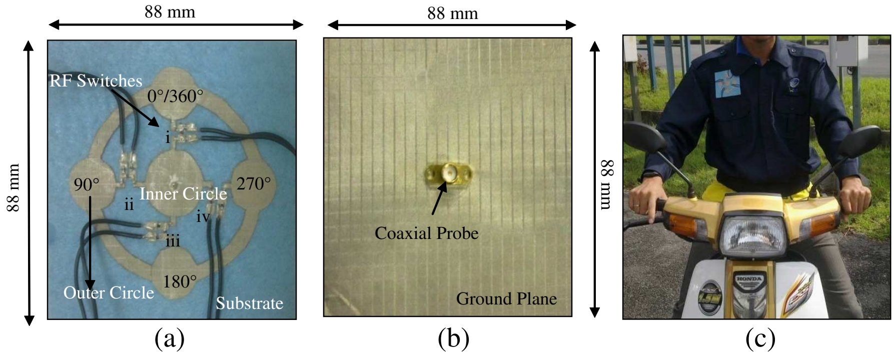

Figure 4. Pictures of the fabricated antenna: (a) Front view and (b) rear view (c) on field testing.

3. RESULTS AND DISCUSSION

The beam switching using the RF switches is successfully achieved, as shown in Figures 5 and 6. The main lobe is directed towards the 180° direction in Figure 5(a) when RF switch (i) is activated, with a directivity of 6.4 dBi. Figure 5(b) shows the main lobe steering towards the 270° direction with a peak directivity of 6.5 dBi and a half-power beamwidth (HPBW) of 86.3° when RF switch (ii) is activated. When switch (iii) is turned on, a directivity of 6.7 dBi and a HPBW of 88° is obtained in the 0° direction, see Figure 5(c). The activation of switch (iv) results in a beam tilting towards the 90° direction with directivity 6.8 dBi and a beamwidth of 86.3°, as shown in Figure 5(d). In summary, the SBTA is able to successfully tilt the beam towards four different directions, each with peak directivity of 6.8 dBi. The measured and simulated patterns are agreeing very well, as summarized in Table 1.

The beam switching and steering of this wearable antenna is efficiently accomplished by this five circular elements structure and the RF switch's sequential activation. It also goes further to prove that the silver loaded epoxy is capable of acting as a reliable solder lead alternative for conductive connection between the switches and the conductive textiles.

The SBTA surface current distributions for each switch at the "ON" state are illustrated in Figure 7. The current is distributed from the 50 Ω SMA feed towards the outer patch for which the switch is "ON". The radiation mechanism of this antenna is very related to this surface current distribution where this current is mainly controlled by the switching configuration. In fact, the direction of main beam

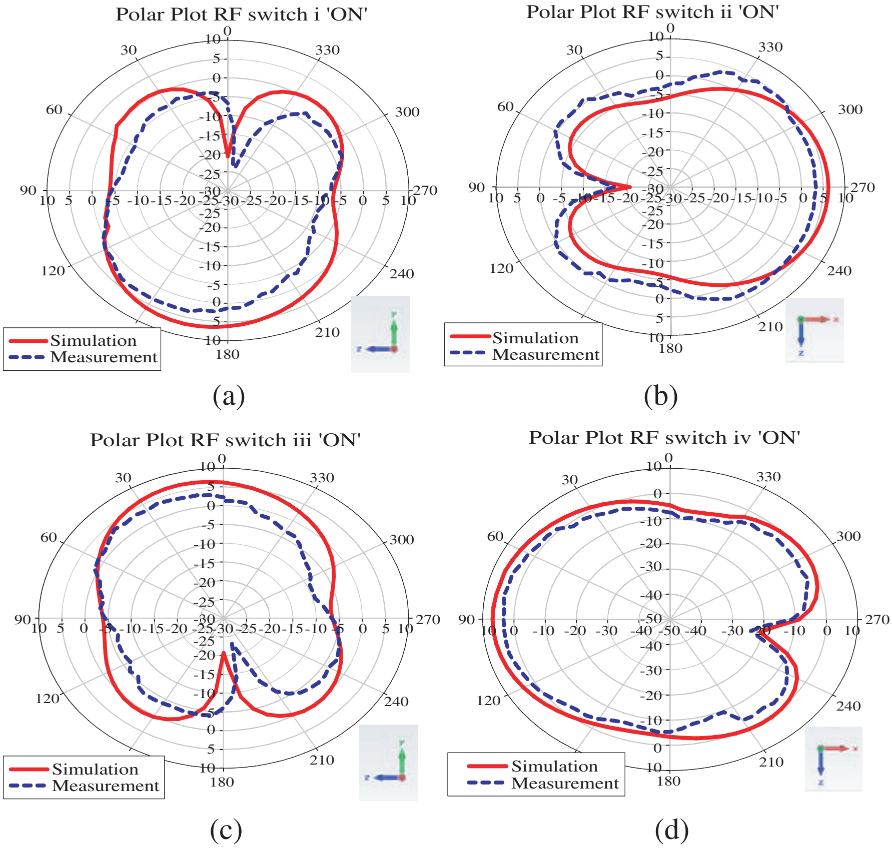

Figure 5. Simulated and measured and radiation patterns of the SBTA. (a) Switch (i) is ON, (b) switch (ii) is ON, (c) switch (iii) is ON, (d) switch (iv) is ON. At each specific "ON" state, all other unmentioned RF switches are in the 'OFF' state.

is dependent on switch configuration. Initially, the RF current is centered at the location of the coaxial port. Then, each of the switch configuration changed the direction of the current flow which is excited from coaxial port. With the switching, main beam could be pulled towards a direction where the current flow is maximum. For instance, when RF switch 'i' ON, majority of the RF current flows toward to 180° angle, hence the main beam is pulled towards 180° angle. Similarly, the current profiles for each switch's "ON" states are depicted in the subsequent Figures 7(a), (c) and (d).

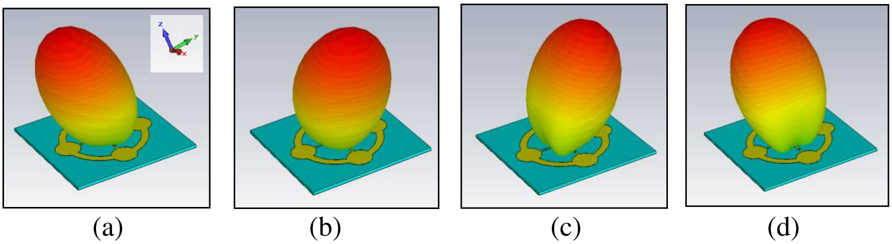

Figure 6. Simulated SBTA radiation patterns at angles: (a) 180°, (b) 270°, (c) 0° and (d) 90°.

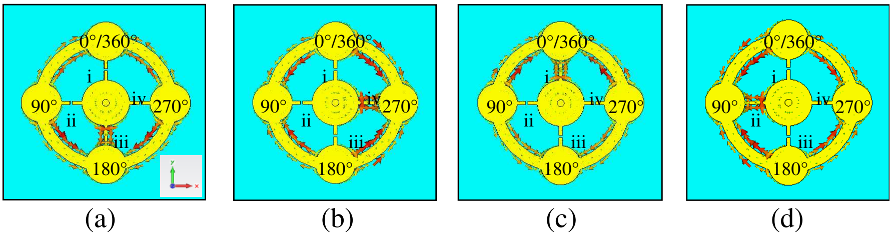

Figure 7. Surface currents generated on the SBTA for each switch in the "ON" state: (a) Switch (i), (b) switch (ii), (c) switch (iii), and (d) switch (iv). At each specific "ON" state, all other unmentioned RF switches are in the 'OFF' state.

3.1. Practical Antenna Measurements

An outdoor practical antenna measurements setup is illustrated in Figure 8(a). The transmitter (T_X) is to be aligned towards the receiver (R_X) to ensure a proper establishment of the point-to-point communication. Therefore, a similar height for the horn and proposed antenna must be maintained for a good line of sight (LOS) as shown in Figure 8(b). The AUT measurement is carried out at five different angles, i.e., +45°, +15°, 0°, −15° and −45°. Each angle is tested from points 1 to 5 with a radial distance of 0.5 m distance as depicted in Figure 8(c).

The U2002A Agilent Power Sensor is deployed as the sensing device to verify the reception of incoming signals transmitted from a commercial horn antenna. The receiving antenna under test (AUT) is connected this power sensor and monitored by a sensor software depicted in Figure 9(a). Transmit signals are fed from a signal generator to the transmitting horn as shown in Figure 9(b), and a sample received power displayed on the analysis software is shown in Figure 9(c).

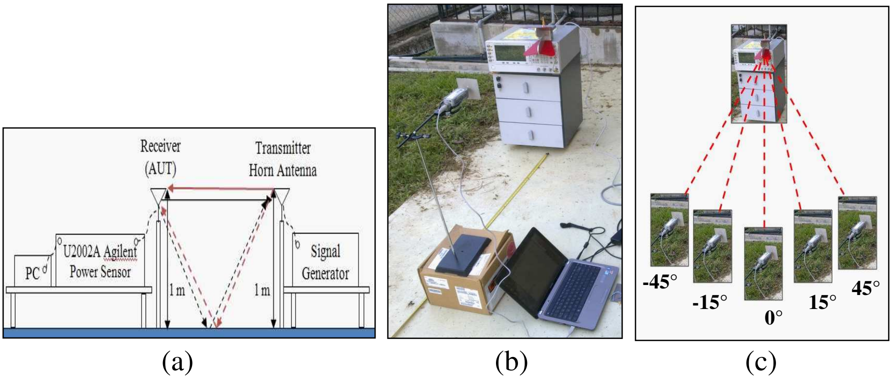

Figure 8. The outdoor practical measurement: (a) Schematic setup, (b) measurement setup, (c) R_x measurement angles.

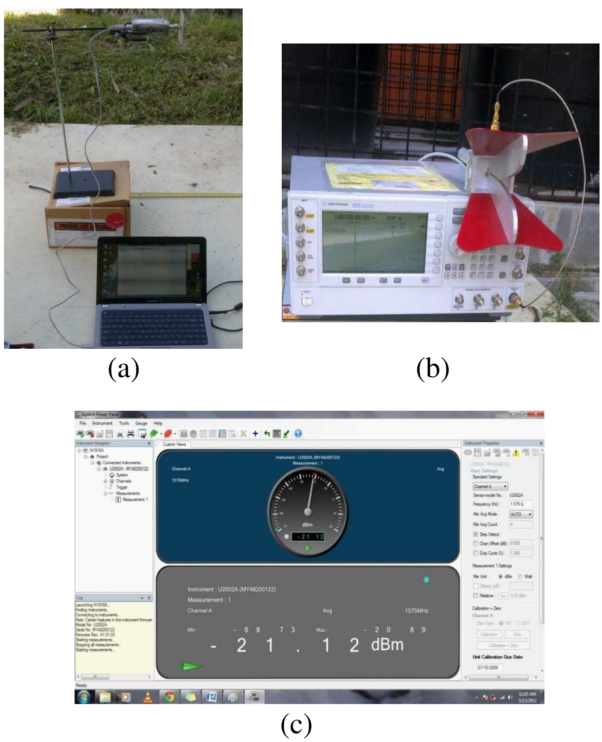

Figure 9. Power measurement setup: (a) At the R_X side, (b) at the T_X side, (c) screenshot of the power analysis software panel.

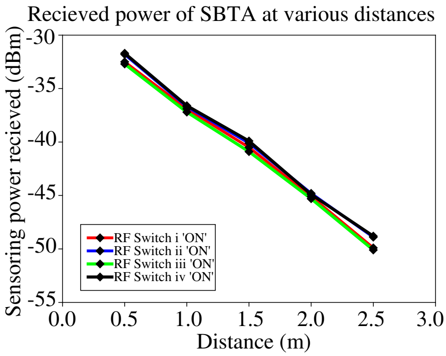

Figure 10. Received power of proposed SBTA at various distances.

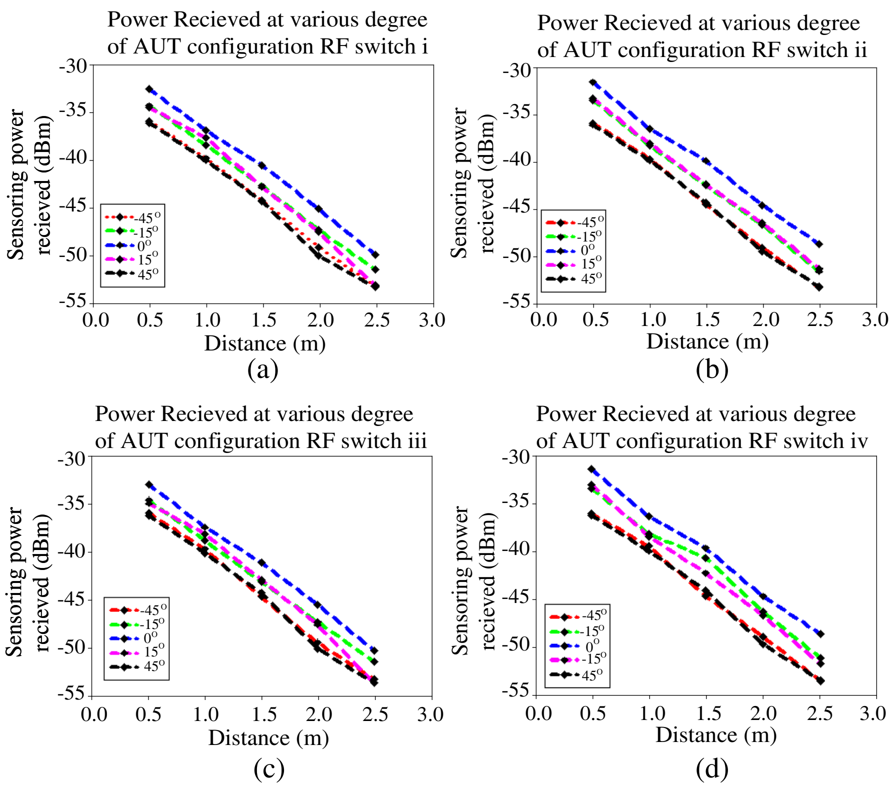

Figure 11. Received power at various AUT angles from the T_X for each "ON" switch state: (a) Switch (i), (b) switch (ii), (c) switch (iii), and (d) switch (iv). At each specific "ON" state, all other unmentioned RF switches are in the 'OFF' state.

The Ground Reflection (Two-Ray) propagation model in [30] is modified by considering additional ground effects to predict the path loss attenuations, as depicted in (1). The floor coefficients for the specified buildings is defined as $T_{\text{floor}} = 13\,\text{dB}$ [31].

$$P_L = 40\log d - (10\log G_t + 10\log G_r + 20\log h_t + 20\log h_r + T_{\text{floor}}) \quad (1)$$

Theoretically, the received signal strength over a large distance from the transmitter can be projected from Equation (2) once the path losses have been determined using Equation (1). In this research, the value of the P_t, G_t, G_r and d are available. The P_t is set to 0 dBm while G_t is 8 dB. The value of G_r is dependent on the degree of steering beam which is (0.9 dBi, 0.8 dBi, 1.1 dBi and 0.8 dBi). Based on Equation (2), the P_r is inversely proportional to the d value. Therefore, the signal

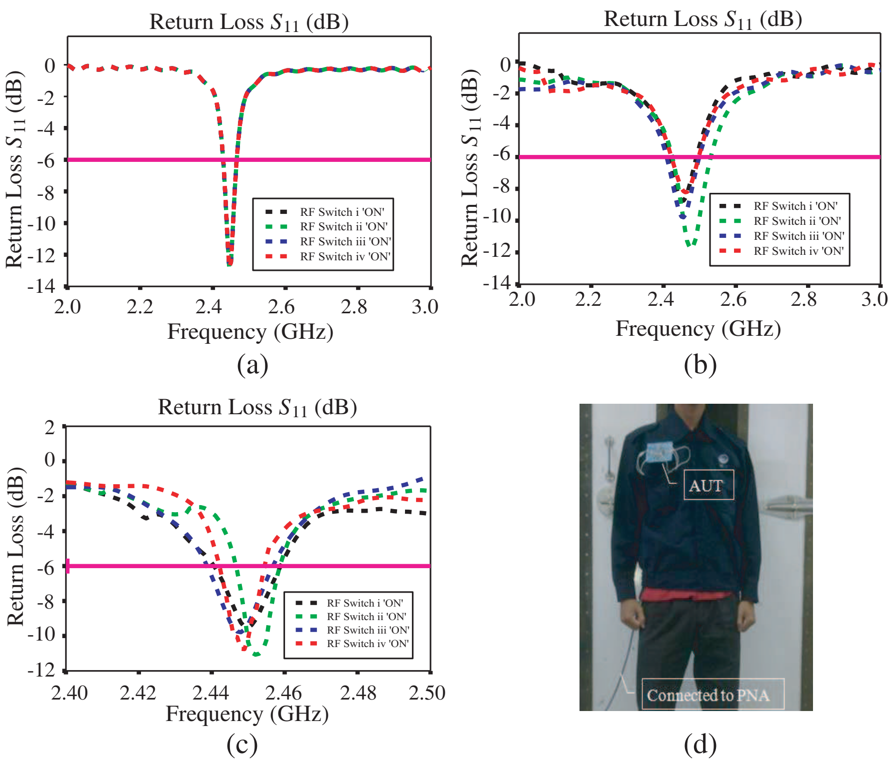

Figure 12. Return losses of the SBTA: (a) Simulated result, (b) measurement result, (c) on-body result, (d) on-body S_{11} measurement setup.

strength reduces when travelling farther.

$$P_R = P_T + G_T + G_R - P_L \tag{2}$$

where;

P_R = received power (W)
P_T = transmitted power (W)
G_T = gain of the transmitting antenna (dBm)
G_R = gain of the receiving antenna (dBm)
P_L = path loss

Received power measurements are measured at various distances, i.e., 0.5 m and 2.5 m away from the T_X, as shown in Figure 10. Different RF switch configurations show similar patterns plot. Conforming to conventional theory, increasing the AUT distance from the T_X results in a decrease of received power received due to polarization.

The received power measurements are performed at frequencies of 2.45 GHz with switchable beam. The AUT are placed at particular angles of +45°, +15°, 0°, −15° and −45° from the T_X. AUT located at 0° enables the best LOS whereas other angles are at non-line-of-sight (NLOS) positions. As depicted in Figures 11(a) to (d), the descending lines indicate a decreasing received power for all RF switch configurations. Meanwhile, the optimum received power of −31.8 dBm is achieved with the best LOS (AUT at 0° face T_X) than other

Table 1. SBTA performance for different RF switch configurations.

Parameter	RF Switch Status			
	i	ii	iii	iv
	On	Off	Off	Off
	Off	On	Off	Off
	Off	Off	On	Off
	Off	Off	Off	On
Simulated Directivity (dBi)	6.5	6.2	6.8	6.7
Simulated Degree of Directivity	180°	270°	10°	90°
Measured Directivity (dBi)	6.4	6.15	6.69	6.45
Measured Degree Directivity	170°	270°	15°	80°
S_{11} Simulated (dB) at 2.45 GHz	−12.24	−12.26	−12.26	−12.26
S_{11} Measured (dB) at 2.45 GHz	−9.5	−11.8	−9.8	−8
Measured Gain (dBi)	0.9	0.8	1.1	0.8

NLOS angles. On the other hand, a comparison among the NLOS measurements indicate that the power received at ±15° and ±45° functions properly. Ideally, placement of AUT in good LOS records better received power from U2002A Agilent Power sensor.

The simulated and measured return losses (S_{11}) are shown in Figure 12, which indicate a satisfactory agreement in the 2.45 GHz band. The acceptable return loss in wireless communication is -6 dB, which corresponds to a maximum reflection of 30%. Simulations and measurements are also summarized in Table 1.

4. CONCLUSION

A novel textile antenna design with beam steering capabilities, the SBTA, is proposed for WBAN applications. Four RF switches are integrated in a symmetrical design. The SBTA is able to achieve beam steering in four directions: 0°, 90°, 180° and 270°, with peak simulated and measured directivities of 6.8 dBi and 6.69 dBi, respectively. The antenna maintains an input impedance around 50 Ω at 2.45 GHz. It has an area of $88 \times 88\,\mathrm{mm}^2$, which means that it is compact enough to be integrated in clothing for WBAN applications.

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