A Wrist Wearable Dual Port Dual Band Stacked Patch Antenna for Wireless Information and Power Transmission

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***Abstract*—A novel antenna with orthogonally polarized dual ports one of which is dual band is proposed. The dual band performance is achieved by the upper rectangular patch loaded with a U-slot at its edge. It has resonances at 2.41GHz and 2.48GHz covering the advertisement channels of Bluetooth LE standard. It is stacked with an orthogonally polarized rectangular patch which resonates at 2.45GHz. The antenna aims to have good isolation between the ports so that single band port can be used for Wireless Power Transfer (WPT) while the dual band port is used for Communications. The antenna is designed to be used with health monitoring sensors to create a robust and energy efficient wearable which uses WPT as its only source of energy. Therefore it is tested on an arm phantom and the choice of polarization is found to be critical for the WPT range and the performance of the wearable.**

***Index Terms*—antenna, on-body antenna, wrist wearables, stacked patch antenna, U slot, WPT, IoT**

I. INTRODUCTION

A common challenge for IoT sensor networks is to achieve battery free long-term operation. This can be realized by wireless power transfer combined with an energy-efficient sensor design. The SPHERE project is developing sensors for the home to diagnose and help manage health wellbeing conditions [1]. The technology will aid early diagnosis, lifestyle change and independent living.

Its energy efficient sensor design transmits accelerometer data using Bluetooth Low Energy standards. In order to minimize the energy consumption, the advertisement channels are used for data transmission. These channels operate at 2.402 GHz, 2.426 GHz and 2.480 GHz respectively. Considering that the data communication occurs at the two far ends of the 2.4 GHz ISM band, Wireless Power Transfer is proposed to be realized with a continuous single tone signal at 2.45 GHz here. An antenna supporting both data transmission and wireless power transfer is designed.

The stacked patch configuration can be used to have a wider band operation with a shunt connection [2]-[4], or for dual band operation with a series connection [5], or a dual band dual port operation can be realized with two excitations. E shaped patches have been stacked with U slot patches [2], and rectangular patches [4] in the literature however the aim has been achieving wider band operation. [5] proposed a dual layer dual band antenna by stacking a U slotted patch and E shaped patch which again had a single feed point and aimed at wider band operation. Here an antenna is proposed using the third technique with a U slot inserted at the edge of the upper rectangular patch. The dual band is created by the stacked patch configuration and the U-slot is inserted in order to create a notch. The antenna has two orthogonally polarized ports. The upper patch is chosen as the radiator for the data transmission, having two resonances at 2.48 GHz and at 2.41 GHz covering the BLE Ad channels while having a notch at around 22nd Channel (2.45 GHz). It is stacked with a rectangular patch operating at 2.45 GHz fed with the WPT port. An isolation of more than 35 dB is achieved at the ports of the antenna before any further filtering eliminating the need for an additional discrete diplexer.

The antenna is also tested on a human arm phantom. The performance of the antennas have been tested on human body in the literature [6] however limited attention has been paid to the alignment of the antenna according to the arm, namely the effect of the polarization of the wrist wearable [7]. Here it has been shown that the polarization has a greater effect on the efficiency and the gain of the antenna than the separation between the antenna and the wrist considering the fact that one does not have great flexibility in choosing a large separation.

The antenna design is detailed in Section II and the results are demonstrated in Section III. The paper concludes in Section IV.

II. ANTENNA DESIGN

The application requires an antenna with two isolated ports one of which is dual band. Moreover each resonance should be narrow band in order to achieve higher isolation as well as satisfying the additional requirements of wearable antennas e.g. high efficiency, unidirectional radiation comprising a ground plane so that is it isolated from the human body, and small size. Therefore a stacked patch configuration loaded with high permittivity, low loss dielectric material is chosen. The patches are printed on 1.27 mm thick Rogers 6006 and then soldiered together as seen in Fig. 1. The overall size of the antenna is 35 mm by 35 mm by 2.54 mm. Both ports are matched to 50Ω while an SMA connector and a U.FL connector are connected to the WPT port and the communications port respectively.

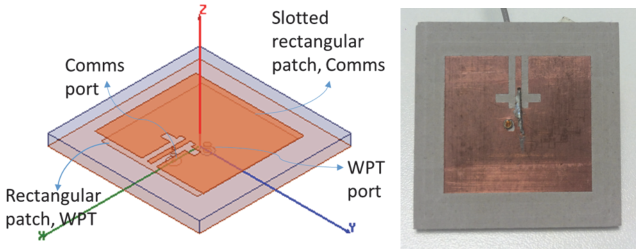

Fig. 1 The proposed antenna: a rectangular patch stacked with a dual band U slot loaded patch

The lower patch is fed by the Wireless Power Transfer port. Its fundamental mode is tuned to 2.45 GHz using the parameters W_{lower} and W_{upper}. Note that W_{upper} is a secondary parameter affecting the effective size of W_{lower} which also shifts the resonance higher in frequency domain as it is decreased. The double resonance that would be created by the higher patch is suppressed because the symmetry is spoiled by the slot on the upper patch therefore there is only a single resonance. Note that the port is matched to 50Ω for ease of measuring. It can also directly be matched to the rectifier by changing the excitation point of the WPT patch.

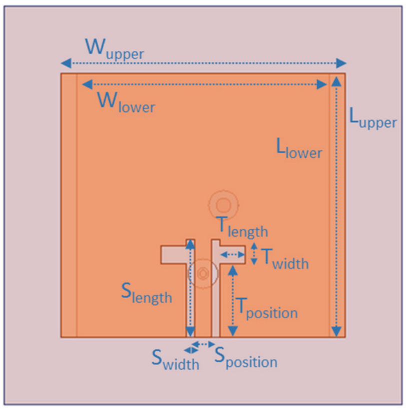

Fig. 2 The design parameters labelled on the top view of the antenna model: W_{upper}: Width of the upper patch, W_{lower}: width of the lower patch, L_{upper}: length of the upper patch, L_{lower}:Length of the lower patch, T_{length}:lenth of the symetrical teeth, T_{width}: width of the teeth, $T_{position}$, position of the teeth, S_{length}: length of the slots, S_{width}: width of the slots

The communications port has two resonances. The lower resonance is the fundamental mode of the higher patch and the higher resonance is due to the lower patch. Both resonances can be tuned by changing L_{upper} and L_{lower}. Both of these parameters affect each other's effective length, therefore they tune both of the resonances. The lower resonance can be matched to 50Ω by changing the position of the feed exciting the upper patch. In addition to the feed position, $S_{position}$ can also be used to match the input impedance of the lower resonance independently from the higher resonance as seen in Fig. 3. Note that the U slot inserted on the edge of the upper patch creates a notch between the two resonances. It also introduces additional degree of freedom for matching purposes. T_{length} can be used to tune the higher resonance as seen in Fig. 4. As T_{length} increases, the higher resonance is shifted down in the frequency domain. In order to achieve good matching, $T_{position}$ and T_{width} should also be optimized.

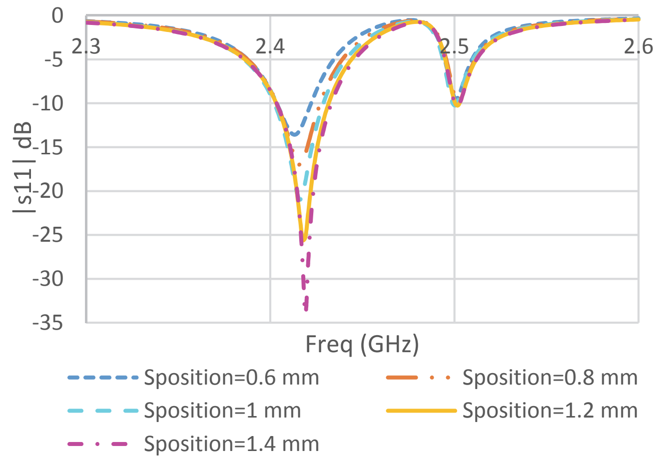

Fig. 3 The effect of Sposition on the frequency response of the Comms port as Sposition is changed from 0.6 mm to 1.4 mm

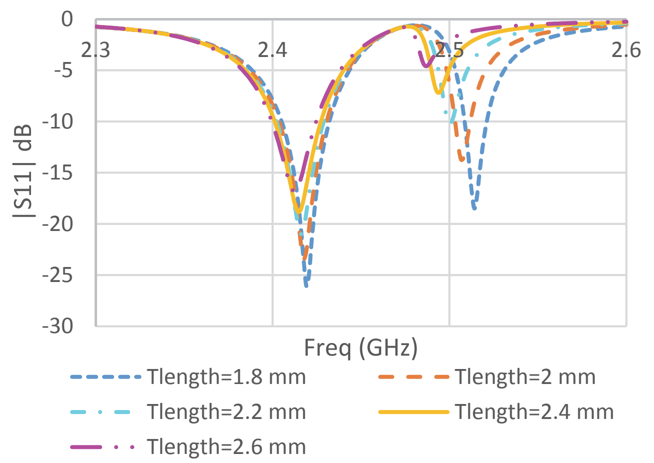

Fig. 4 The effect of Tlength on the frequency response of the Comms port as Tlength is changed from 1.8 mm to 2.4 mm

III. ANTENNA PERFORMANCE

For the optimized values of W_{upper} = 25mm, W_{lower} = 22.2mm, L_{upper} = 23.2mm, L_{lower} = 23.2mm, Tlength = 2.2mm, T_{width} = 1.5mm, $T_{position}$ = 6.5mm, $S_{position}$ = 1.4mm, S_{width} = 0.8mm, S_{length} = 8.6mm, the frequency response of the antenna can be seen in Fig. 5. The isolation is more than 35 dB between the ports throughout the 2.4 GHz ISM band. Communication port is very well matched to the 37th and 38th channels as is the WPT port to the 22nd channel.

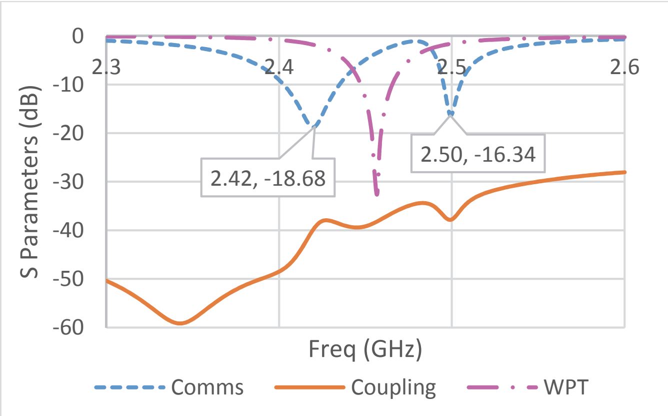

Fig. 5 Simulated frequency responses of the proposed antenna, |s11| (dB), |s22|(dB) and |s21| (dB) vs Frequency (GHz)

Note that the WPT mode of the antenna is required to be directive for the rectifier to receive higher level of energy and operate at its high efficiency region once it is aligned with the transmitter. Fig. 6 shows the directivity pattern and the maximum directivity observed is 4.8 dB. The radiation is Y-polarized and the half power beam width is 110 degrees. The radiation pattern of the Communications port has similar characteristics except that it is X-polarized. The maximum gains in both bands are greater than 4 dB. Simulated efficiency values are satisfactory with figures higher than 80% for both ports when the antenna is in isolation.

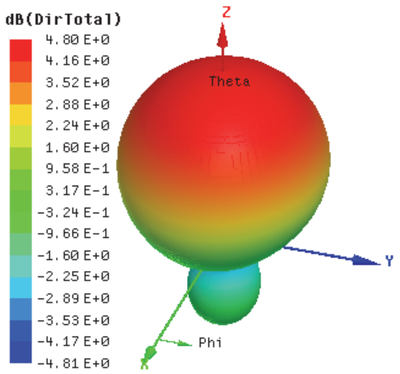

Fig. 6 3D Gain pattern of the antenna at 2.45 GHz for the WPT port.

Since the antenna is aimed at wearables, the performance of the antenna is analyzed on the left arm of the Ansys Computational Human Phantom [8]. The antenna is located on high resolution male model's arm as seen in Fig. 7. The separation between the antenna and the wrist is changed from 5 mm to 15 mm in 5 mm steps while the arm is rotated for 90 degrees for each separation as shown in Fig. 7 in order to interrogate the effects of the polarization.

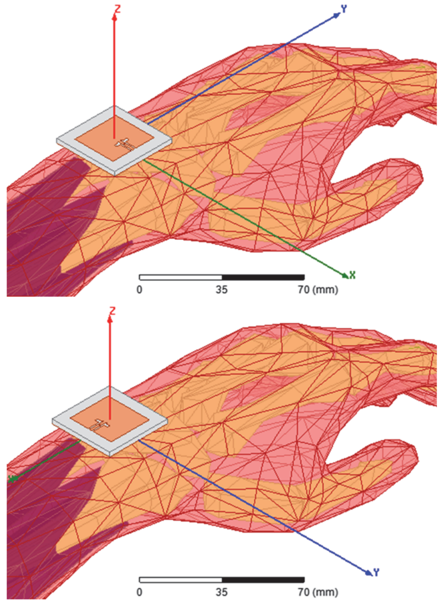

Fig. 7 The antenna located on Ansys Computational Human Phantom, top: the arm has 0° rotation, bottom figure: the arm is rotated for 90°.

Firstly the frequency response of the antenna for these cases are plotted in Fig. 8. It is observed that the detuning is more severe for WPT if there is 0° rotation, and more severe for the Communications port if there is 90° rotation. Namely, if the polarization of the mode (either WPT or Communications) is aligned with the arm, the detuning is stronger.

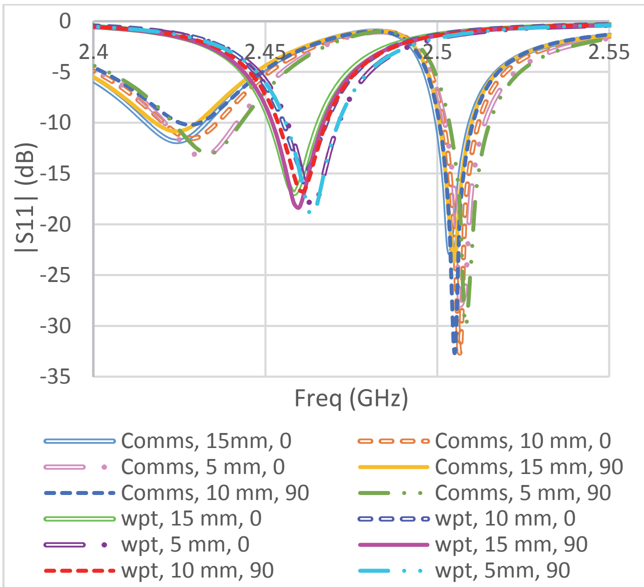

Fig. 8 The frequency response of the antenna once it is located on an arm phantom, the antenna body separation is changed from 5 mm to 15 mm and the antenna is rotated 90 degrees around z axis.

For better demonstration, the magnitude of the current density on the skin surface is plotted in Fig. 9 for the communications port. Note that the maximum and the minimum values plotted are 0.25 A/m and 2*10-4 A/m respectively. The fields are observed to be weakening as the separation increases which is expected. More interestingly, it is observed that stronger surface currents are induced along the arm towards the hand and fingers for 90° rotation as seen in Fig. 9 (b) and (d).

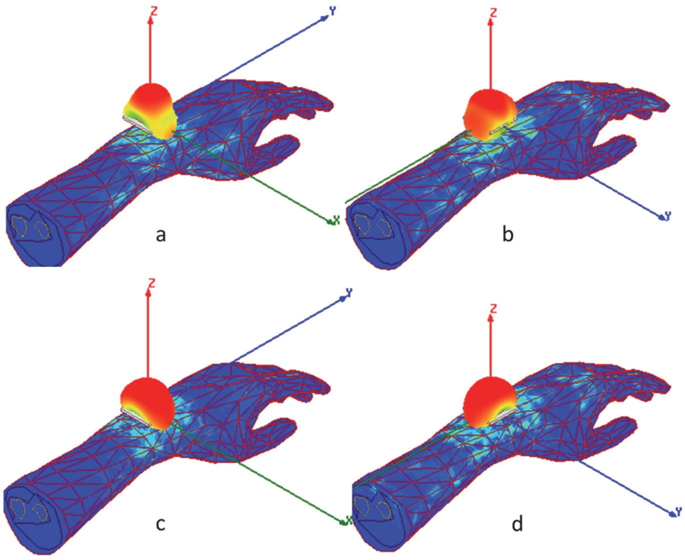

Fig. 9 The gain patterns and the magnitude of the current density, |J|(x,y,z,t), on the skin surface for each antenna body separation at the centre frequency of the lower resonance of the Communications port. The maximum and the minimum values platted are 0.25 A/m and 2*10-4 A/m for the current density. (a): 15mm antenna body separation with 0 degrees rotation, and the maximum gain value is 3 dB; (b): 15 mm, 90°, 4.3 dB; (c): 5 mm, 0°, 1.7 dB; (d): 5 mm, 90°, 1.4 dB.

Fig. 10 shows the efficiency variation as the antenna body separation and the alignment of the antenna according to the arm are changed. The results are building up to the previous results. The efficiency is much lower if the arm is aligned with the polarization of the mode i.e. if the WPT mode is y polarized while the antenna is located along the y axis, more surface currents are excited on the arm, the radiation pattern is distorted and the efficiency is lower than the case where the arm is located along the x axis. The efficiency also decreases as the separation between the antenna and the body decreases if the arm is not aligned with the polarization. Once the surface currents are stronger, it is observed that the monotonic dependence of the efficiency on the antenna body separation does not apply anymore and 10mm separation leads to lower efficiency than 5 mm separation.

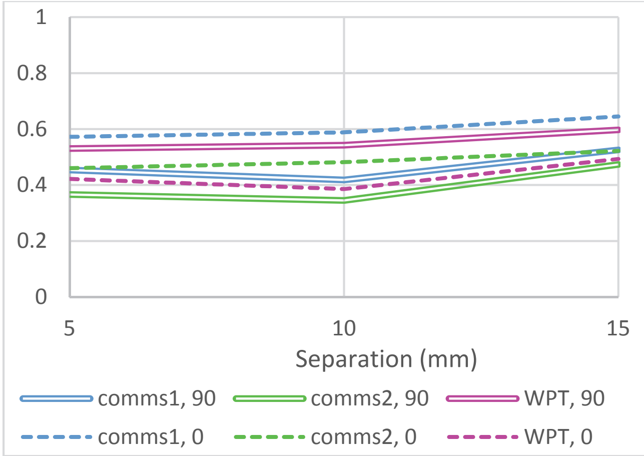

Fig. 10 The efficiency values of each resonance at 5, 10 and 15 mm separation between the human skin and the ground plane of the antenna at the resonant frequencies

Finally the effects of the human body on the radiation characteristics of WPT mode is plotted in Fig. 11. WPT resonance's gain is a critical value in terms of the transfer range. The gain is at its maximum value of 4 dB which is similar to the vacuum case when the rotation angle is 0° and the separation is 15 mm. Note that the efficiency is better for WPT if the rotation degree is 90° however the gain pattern is more important for this case.

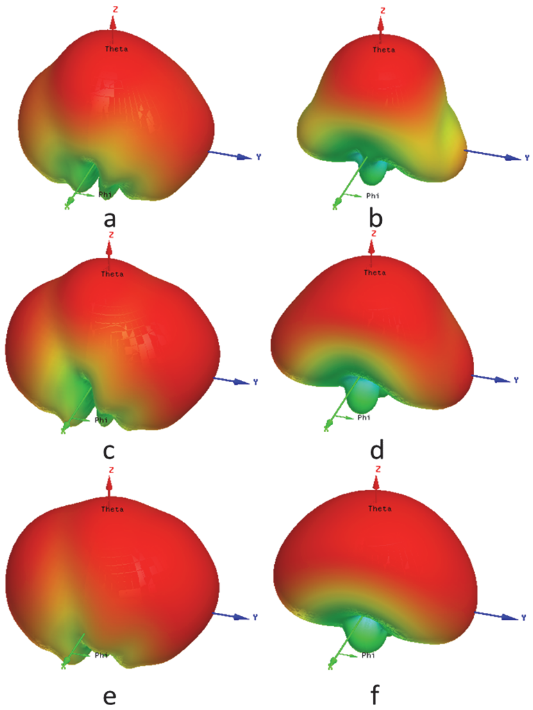

Fig. 11 The Radiation pattern of the WPT mode. (a): 15 mm antenna-body separation, 0 degrees rotation, maximum gain value = 4.0 dB; (b): 15 mm, 90°, 2.8 dB; (c): 10 mm, 0°, 1.5 dB; (d): 10 mm, 90°, 1.1 dB; (e) and 5 mm (e, f) from top to bottom respectively; for 0 degrees rotation left hand side, and 90 degrees rotation right hand side. The maximum gain values for each are as follows: a=4.0 dB, b= 2.8 dB, c=1.5 dB, d=1.1 dB, e=1.4 dB, f=1.4 dB.

The on phantom analysis show that the application is the key factor in choosing the antenna alignment and the antenna body separation. In conclusion 0° degrees rotation is chosen so that higher efficiency values are obtained in the Communications mode and higher directivity can be achieved with the WPT.

IV. Conclusion

A dual port antenna suitable for wireless power and information transfer is designed. The antenna satisfies the requirements of an on-body antenna forming off-body links as well as the requirements of simultaneous power and information transfer with more than 30 dB isolation between the ports. The antenna receives wireless power at 2.45 GHz from more than half a meter range and charges a super capacitor while the wearable can send accelerometer data from the wearable using the Bluetooth advertisement channels simultaneously. Finally the performance of the antenna is analyzed on a human arm phantom and it is shown that the polarization of the antenna is as critical as the antenna body separation. The optimum polarization for each applications is chosen.

Acknowledgment

This project is conducted in collaboration with the SPHERE project. The authors would like to thank their colleagues at University of Bristol for their input.

References

[1] An EPSRC Interdiciplinary Research Calloboration (IRC) http://www.irc-sphere.ac.uk/

[2] Matin, M.A.; Sharif, B.S.; Tsimenidis, C.C., "Probe Fed Stacked Patch Antenna for Wideband Applications," in Antennas and Propagation, IEEE Transactions on , vol.55, no.8, pp.2385-2388, Aug. 2007

[3] Ghannoum, H.; Bories, S.; Roblin, C., "Probe fed stacked patch antenna for UWB," in Ultra-Wideband, 2005. ICU 2005. 2005 IEEE International Conference on , vol., no., pp.97-102, 5-8 Sept. 2005

[4] Ban-Leong Ooi; Shen Qin; Mook-Seng Leong, "Novel design of broad-band stacked patch antenna," in Antennas and Propagation, IEEE Transactions on , vol.50, no.10, pp.1391-1395, Oct 2002

[5] Liu, S.; Wu, W.; Fang, Da-Gang, "Single-Feed Dual-Layer Dual-Band E-Shaped and U-Slot Patch Antenna for Wireless Communication Application," in Antennas and Wireless Propagation Letters, IEEE , vol.PP, no.99, pp.1-1

[6] Paraskevopoulos, A.; Alexandridis, A.; Zervos, T.; Michalopoulou, A.; Lazarakis, F.; Vardaxoglou, J.C.; “Modelling of dynamic on-body channels using different types of wearable antennas” 8th European Conference on Antennas and Propagation (EuCAP), pp. 852- 856, 2014.

[7] Kun Li; Honda, K.; Ogawa, K.; “Experiments of a polarization-controlled active antenna to enhance BAN on-body link in human dynamic channels”, 9th International Symposium on Medical Information and Communication Technology (ISMICT), pp. 117- 120, 2015.

[8] Ansys Human Body Phantom, [Online]. Available http://www.ansys.com/Products/Electronics/ANSYS+HFSS