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The Design of a Pattern Reconfigurable Antenna Suitable for Smart Glasses

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***Abstract*— A pattern reconfigurable wearable antenna suitable for smart glasses application is designed to operate at the 2.4 GHz ISM band. The antenna consists of two slots that are placed perpendicular to each other and fed with a single stripline feed. The switches that are located directly on the slots are manipulated to activate different polarizations hence provide polarization diversity. The antenna is prototyped and the simulations are validated through measurements. The antenna has been shown to provide two distinct patterns with a correlation coefficient of less than 0.1.**

***Index Terms*— Reconfigurable antennas, Body Area Networks, On-body communications.**

I. INTRODUCTION

In recent years, the amount of wearable devices that are used for the Internet of Health Things (IoHT) applications has been increasing and it is predicted to continue increasing in the coming years [1]. Smart glasses are an example of these wearable devices that form links with an off-body device to transmit information.

The primary problem encountered in wearable antennas is that the nearfield is located in close proximity to the lossy human body that heavily interacts with the antenna. This reduces the overall performance and causes a shift in the resonant frequency [2]. Another challenging aspect of antenna design in wearable devices is the dynamic nature of the human body leading to dynamic propagation channels. Antenna requirements are different and sometimes contradictory for the connections established by different health objects placed at various points in the human body. In order to tackle this challenge, having radiation pattern diversity is a logical step forward [2][3]. However, with small space available on the wearable devices and the limited energy supply, realizing these objectives are difficult since they require complex hardware and intensive calculation.

A wearable antenna that can switch its radiation pattern to provide radiation pattern diversity by directly changing the field distribution on the antenna in an energy efficient way will be a good solution [4]. A limited number of reconfigurable wearable antennas have been proposed before. Raman et al. [3] and Ahyat et al. [5] have proposed antennas that provide two distinct modes on a single plane. Ha et al. has proposed an antenna that can create an omnidirectional and a directional pattern although the proposed antenna is considerably large for a wearable antenna [6]. Masood et al. has also proposed a similar yet smaller wearable antenna [7]. However, none of those proposals including the ones proposed by the second author [8][9] is suitable for smart glasses application. The main reason is the fact that all these antennas include a large ground plane which will limit the transparency of the glass substrate. To the authors' knowledge, a pattern reconfigurable antenna suitable for this application has not been proposed before.

In this paper, a pattern reconfigurable wearable antenna operating at the 2.4 GHz ISM band aimed to be used on smart glasses is presented. The antenna model is explained in Section II and the results are given in Section III. Section IV concludes the work.

II. ANTENNA MODEL

A cavity backed slot antenna is designed in order to achieve the previously defined goal. Two slots are etched onto an L shaped shallow cavity. A single stripline with characteristic impedance of 50 Ohm is used to excite both of the slots. The slots are perpendicular to each other providing polarization diversity hence low coupling. The slots are used in an alternating way. As one of the slots is activated, the other one is shorted by means of switches in the center of each slot.

For the analytical design, the interaction between the cavity modes and the fundamental slot mode can be ignored as the slot resonances are primarily determined by the lengths of the slots rather than the size of the cavity. Note that the cavity is filled with Rogers RO3210 laminate [10] with relative permittivity, ϵ_r of 10.2. If the slots are thin of which lengths are much greater than their widths, then the lowest slot resonance, TE_{10}, will be excited. The length of the slot can be calculated by (1). The guided wavelength, λ_{guided} can be calculated by (2). The permittivity of the substrate cannot be used directly as the fields on the slots are mostly outside of the cavity. However, the effect of the substrate is not negligible. This effect can be calculated taking filling factor, *ff* into account. The effective permittivity can be calculated using (3). If the filling factor is taken as 0.1 which is a

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good estimation for cavity backed slot antennas [11], ϵ_{eff} is calculated to be 1.92, hence λ_{guided} is calculated to be 86 mm at 2.45 GHz which means that the length of the slots should be approximately 43 mm. As a rule of thumb, a thin slot can have a slot width of $\lambda_{guided}/50$ which is approximately 1.7mm.

$$L_{TE10} = \frac{\lambda_{guided}}{2} \qquad (1)$$

$$\lambda_{guided} = \frac{\lambda_{air}}{\sqrt{\epsilon_r}} \qquad (2)$$

$$\epsilon_{eff} = \epsilon_R * ff + (1 - ff) \qquad (3)$$

After calculating the lengths and the widths of the antennas, the feeding should be designed meticulously. In order to understand the whole structure, one should first consider the equivalent circuit for a single shallow cavity backed slot antenna as given in Fig. 1.

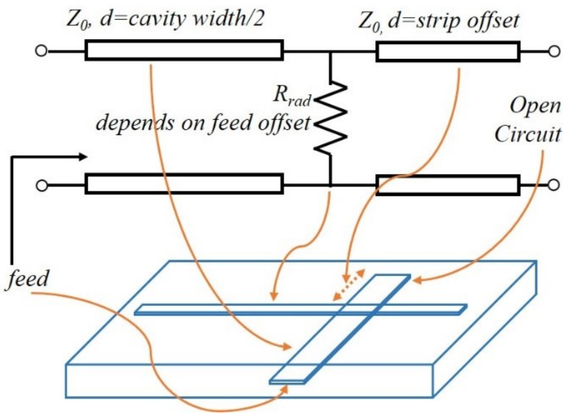


Fig. 1 Equivalent circuit of a single cavity backed slot antenna

There are two different arrangements for the same feed. First, the vertical slot is optimized while the horizontal slot is shorted. In order to match the structure to 50 Ohm, optimum stripline offset and feed offset values are determined empirically. The reason why these parameters are critical in matching the structure can be seen from the equivalent circuit provided in Fig. 1. Once the vertical slot is matched, the horizontal slot is designed with the vertical slot shorted. The horizontal slot is located at the position where the length of the stripline section between the two slots is half a wavelength (impedance repeater) on the stripline at the operating frequency. Note that the guided wavelength is going to be different this time since the filling factor of the substrate is 1 for a closed stripline structure. That is why the physical size of the slot and the stripline section are different while their electrical sizes are the same. This ensures that the impedance value parallel to the radiation resistance of the vertical slot will be repeated at the horizontal slot. Hence the same input impedance value that was obtained for the vertical slot will be obtained if the effect of the shorted vertical slot is ignored as seen in Fig. 2. By using this feeding strategy, both of the slots will be matched to 50 Ohms when they are active.

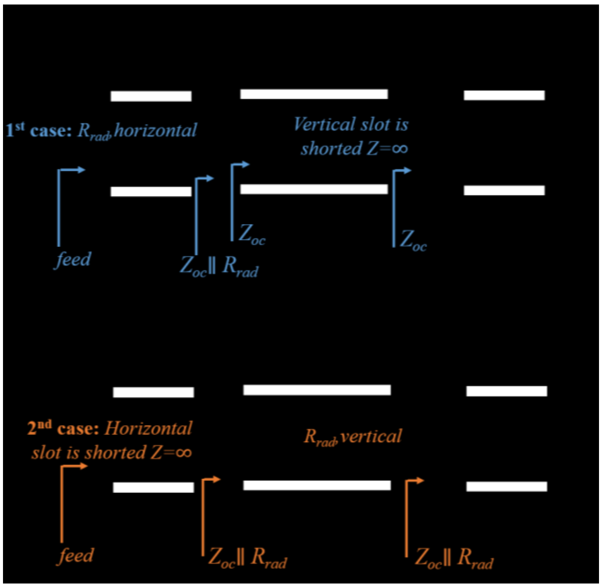
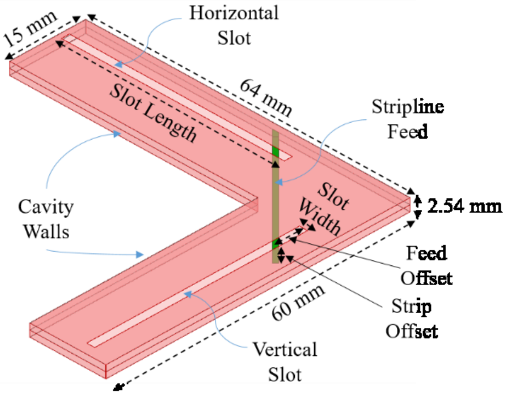
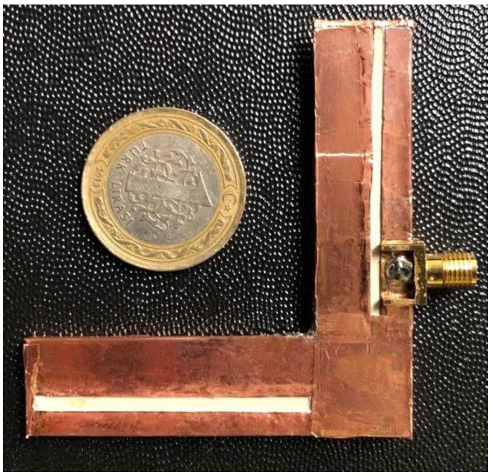


Fig. 2 Equivalent circuit of double slotted wearable antenna

Starting from the initial values listed in Table 1, the final optimum values are reached through numerical analysis. After the model is simulated, the assumption of minimum interaction between the cavity modes and the lowest order slot mode is validated. The previously mentioned effect of the shorted vertical slot on the impedance seen at the horizontal slot is found to be reasonably small and adjusted through numerical analysis.



(a)



(b)

Fig. 3 Antenna model and the picture of the prototyped antenna

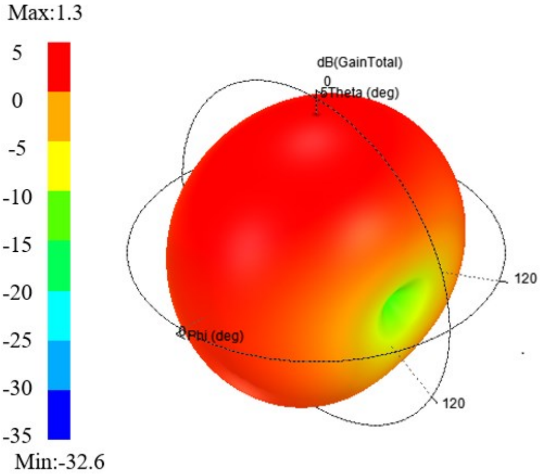
After the simulations, the antenna is prototyped using two layers of Rogers RO3210 substrates. The slots and the stripline feed are printed by dispensing conductive ink on the substrate using Voltera V-one [12]. The conductivity of the ink is 1052632 S/m at DC which is a magnitude smaller than copper. In order to compensate for this difference, the cavity walls are covered with copper tape as seen in Fig. 3(b).

III. ANALYSIS AND RESULTS

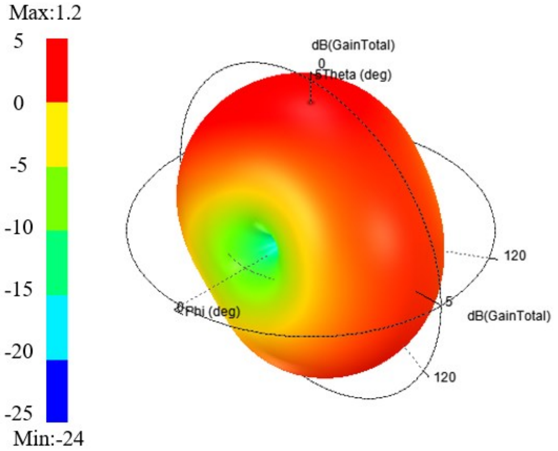
The model is simulated using Ansys HFSS at two steps. The vertical antenna is simulated while the horizontal antenna is physically shorted with a copper strip at its center. The same procedure is repeated for the horizontal slot. With the guidance of the initial values analytically calculated, the results provided in Fig. 5 are obtained. Both of the slots are resonating at 2.44 GHz with a return loss greater than 10 dB. At the resonant frequency, the radiation patterns shown in Fig. 4 are obtained. With maximum gain of 1.3 dBi, the patterns generated are perpendicularly polarized to each other. This ensures that the correlation between the patterns is low, which is calculated to be less than 0.1 at the resonant frequency.

Table 1 Optimized parameters of the model

Parameters	Initial Values	Final Values
Slot length (vertical)	43 mm	42 mm
Slot length (horizontal)	43 mm	44 mm
Slot width (vertical)	1.7 mm	1.6 mm
Slot width (horizontal)	1.7 mm	1.6 mm
Strip offset	-	2.4 mm
Feed offset	-	5.4 mm



(a) Simulated 3D radiation pattern of the horizontal slot



(b) Simulated 3D radiation pattern of the vertical slot

Fig. 4 Radiation patterns at 2.44 GHz

The measured results are although partially agree with the simulations, there is a shift in the resonant frequency with a loss associated to it as seen in Fig. 5. The degradation in the matching has been found to be due to the separation between the two substrates which were meant to be perfectly aligned as well as the conductivity of the conductive ink. In addition to that, in the final prototype, the effective slot length is smaller than the numerically predicted length. This could be due to the effect of slot width on the effective slot length and imperfections during the manufacturing process. In order to clarify this, further simulations are being conducted.

IV. CONCLUSION

A shallow cavity backed slot antenna suitable for smart glasses application is designed to provide radiation pattern diversity through switches located on the slot surface. The switches manipulate the field distribution on the antenna and create two perpendicular polarizations. The antenna is optimized to provide a reasonable return loss at 2.45 GHz. The performance of the antenna has been demonstrated through practical results.

In the future, the antenna is going to be printed on glass substrate. Since the filling factor is low for a cavity backed slot antenna, the design will be subject to minimum changes as the substrate change. Nevertheless, the model will be optimized again for glass substrate and also to operate on a human head phantom. Finally, the antenna will be prototyped and measured on a physical head phantom and various human heads.

ACKNOWLEDGMENT

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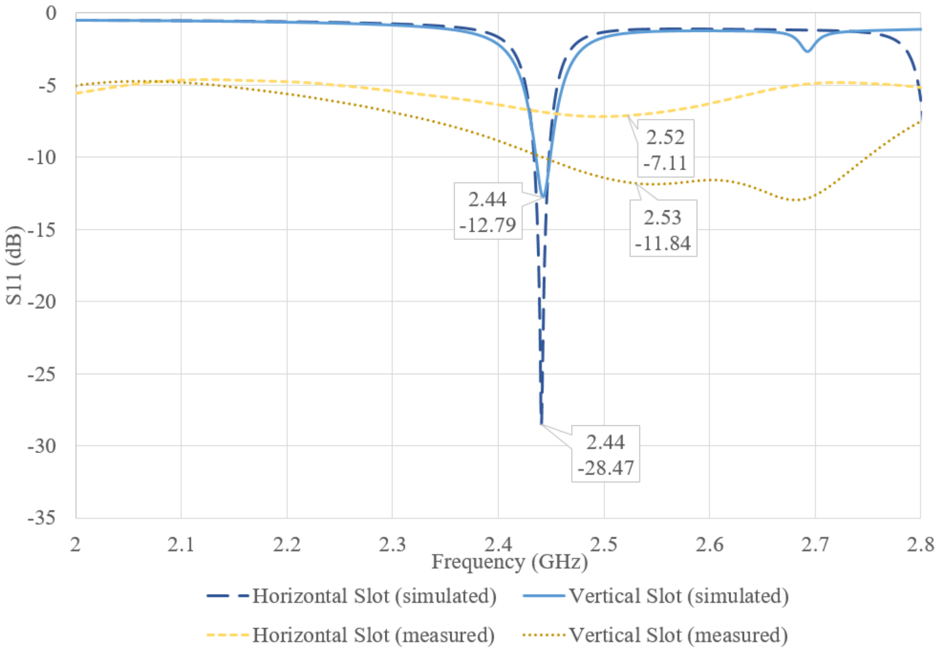

Fig. 5 Simulated and measured ($|S11|$)dB for each slot activated.