# Snap-On Buttons as Detachable Shorting Vias for Wearable Textile Antennas

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***Abstract*** — **This paper demonstrates that commercial snap-on buttons can be utilized as detachable shorting vias for wearable textile antennas. As a consequence, modularity in antenna characteristics can be obtained based on a common initial design. As an illustration, a patch antenna with different configurations of shorting vias is designed and experimentally characterized. In this design, adapted from a recently reported modular snap-on-button-based wearable antenna, four sets of two back-to-back male snap-on buttons affixed within a two-layered substrate are used as detachable patch holders and/or modular shorting vias to the ground plane. By engaging selected male buttons from the ground plane with female buttons to form shorting vias, various antenna patterns can be selected.**

## 1 INTRODUCTION

Numerous novel materials are emerging as conductors for flexible and wearable electronics. This is particularly important for antennas, since conventional metallic materials usually have very limited mechanical resilience. Those materials include conductive textiles [1], conductive inks [2], conductive threads [3] and conductive polymers [4, 5]. In particular, conductive textiles are one of the most promising classes of conductors for wearable applications [6], as they are highly flexible and conductive, light-weight, robust, low-cost and garment-integrable.

A large number of antennas based on conductive textiles including patch antennas [7, 8], ultra-wideband antennas [9, 10], substrate-integrated waveguide (SIW) based antennas [11–13] and a modular antenna [14] have been reported in the literature. Some of these designs require shorting point(s) and shorting wall(s), for example, to create a planar inverted-F antenna (PIFA) structure or form a cavity. To realize these shorts, conductive textiles [15], embroidered vias [16], eyelets [11] and commercial snap-on buttons [14] have been proposed and used due to their compatibility and easy implementation with fabric materials. Especially, snap-on buttons possess an invaluable advantage that can enhance modularity of antenna designs, namely repeated detachability. To further demonstrate this capability, the utilization of snap-on buttons as detacheable shorting vias is presented in this paper. To this end, a modular antenna adapted from [14] with interchangeable beam direction is designed and experimentally characterized.

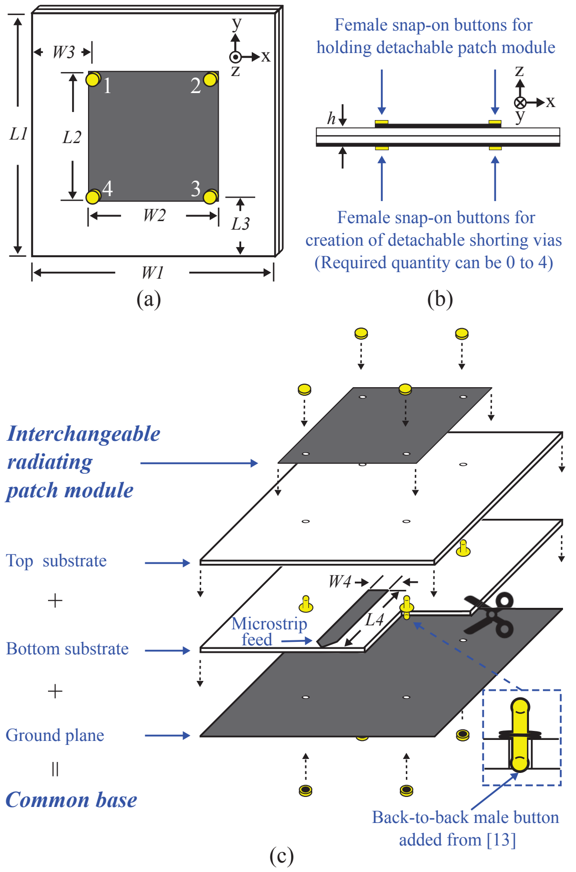


Figure 1: Antenna configuration and dimensions. (a) Top view. (b) Side view. (c) Configuration: the antenna consists of an interchangeable radiating patch module and a common base which contains a two-layered substrate, a ground plane, a microstrip feed and snap-on buttons. Shorting vias are created by engaging female buttons on the back of the ground plane. Dimensions (in mm): $W1 = 40$, $W2 = 19.5$, $W3 = 13$, $W4 = 6.5$, $L1 = 40$, $L2 = 18.5$, $L3 = 13.5$, $L4 = 15$, $h = 3.2$.

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## 2 THE MODULAR ANTENNA

### 2.1 Antenna configuration

The antenna configuration and dimensions are shown in Fig. 1. The antenna includes an interchangeable radiating patch module tailored for a specific application and a common base which consists of a two-layered substrate. This base supports an open-end microstrip feed, a ground plane and eight commercial snap-on buttons. The 50-Ω microstrip feed enables proximity coupling which permits free-standing interchangeable patch modules. Male snap-on buttons are soldered back to back and embedded in the middle of the two-layered substrate to keep them in a solid and secure position. When engaged to female button counterparts, the top four male buttons serve as holders for patch modules whereas the bottom four can be selected to act as engageable shorting vias to the ground plane. By engaging different male button(s) with female one(s), the patch module can be shorted at different corners and thus resonate in different modes. Therefore modularity in antenna resonance frequency, polarization and beam direction can be achieved on the basis of a common base structure.

### 2.2 Antenna materials

The radiating patch modules, the ground plane and the microstrip feed are made from a highly conductive, flexible, robust and metal-coated nylon RIP-STOP fabric (silver fabric) which has a DC sheet resistance of 0.01 Ω/□ and a 100 $\mu$m thickness. The substrate is based on a highly flexible and low-loss Cuming Microwave C-Foam PF-4 foam with a 1.6-mm thickness, a 1.06 relative permittivity ($\varepsilon_r$) and a 0.0001 loss tangent ($\tan\delta$). The chosen snap-on buttons are suitable for the design, as they have proper physical dimensions and satisfactory mechanical and RF performance [17], while being commercially available at a very low cost.

### 2.3 Configuration with vias

As mentioned, modularity in antenna characteristics can be obtained using various patch modules and different detachable shorting configurations. For instance, the proposed antenna module resonates in the standard half-wave mode with boresight radiation when no shorting vias are engaged. In contrast, when all four vias are engaged, the antenna operates in a planar monopole mode with omnidirectional radiation in the $xy$-plane [18]. These two configurations can be beneficial for wearable applications where either on-body or off-body communications are desired [19]. However, for brevity, only one particular shorting configuration for the patch module is discussed in this paper, namely using shorts at either opposite corners 1 and 3 or 2 and 4 (see Fig. 1-(a)). This configuration leads to the radiation pattern being split into two main beams pointing along the diagonal plane in between $xz$- and $yz$-planes.

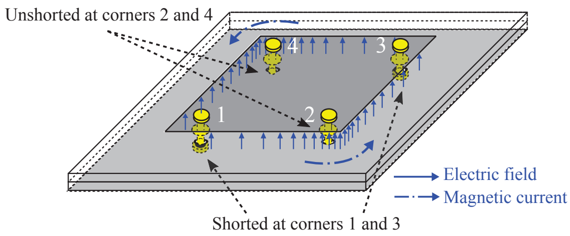


Figure 2: Electric field distribution of the antenna with engaged shorting vias at corners 1 and 3.

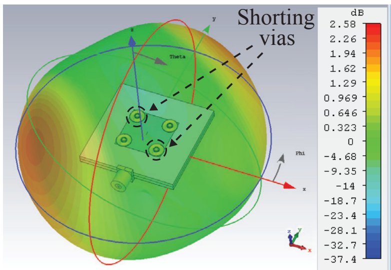


Figure 3: The simulated 3D gain pattern in CST Microwave Studio 2016.

With such shorting vias arrangement as shown in Fig 2, the patch module resonates in a mode similar to a magnetic current loop antenna [20], but with electric field nulls at the two shorted corners, and electric field maximas at the two other corners. Based on the equivalence principle, the antenna can be approximately considered as two antiparallel magnetic currents whose highest amplitudes are at the two ungrounded patch corners. As a result, the antenna possesses two main beams pointing away from these unshorted corners. Therefore, through interchanging the location of the shorted corners, the main beam directions can be rotated by 90°. The 3D radiation patterns simulated in CST Microwave Studio 2016 is depicted in Fig. 3, for the configuration with shorts at corners 1 and 3. It clearly illustrates the expected two main beams. The resonance frequency of this particular design is 3.6 GHz which is determined by the length and width of the patch module. It is worth mentioning that for this demonstration the patch dimension was unchanged from [14], but in principle, the geometry is scalable to achieve other operational frequencies.

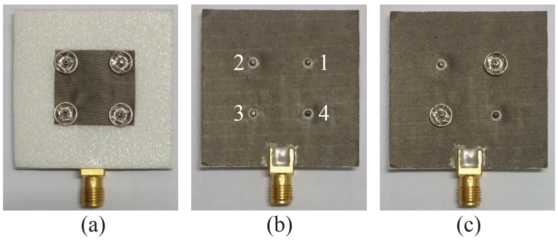


Figure 4: The antenna realization. (a) Top view. (b) Bottom view without female snap-on buttons (no shorts to the ground). (c) Bottom view with engaged female button at corners 1 and 3.

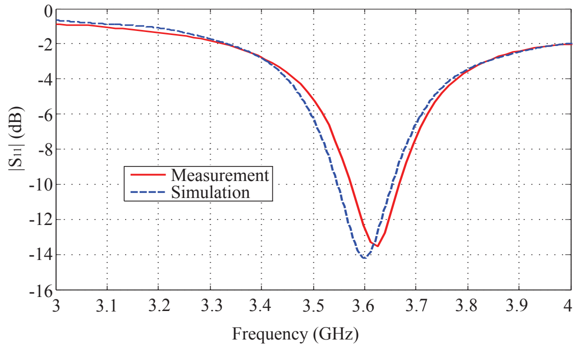


Figure 5: Measured and simulated $|S_{11}|$ of the antenna.

## 3 EXPERIMENTAL RESULTS

To validate the design, a prototype, as shown in Fig 4, has been fabricated and experimentally characterized. Since the proposed design was adapted from [14], one can refer to [14] for general details of the antenna fabrication, and only the two main modifications from that reference are elaborated here. The first modification was soldering one male snap-on button underneath the original ones individually, with precise back-to-back alignment. The second modification was cutting four through holes in the bottom substrate and the ground plane, to accommodate and provide enough clearance from the added male buttons, respectively. To ensure repeatable electrical connection to the ground plane, the holes trimmed in the ground plane should be smaller than the flat contact area of the female buttons.

### 3.1 Reflection coefficient

The simulated and measured reflection coefficients of the antenna with shorts at corner 1 and 3 are demonstrated in Fig 5 and a reasonable agreement is observed. The simulated resonance frequency is 3.6 GHz while the measured value is 3.62 GHz. The small discrepancy can be attributed to the fabrication tolerances.

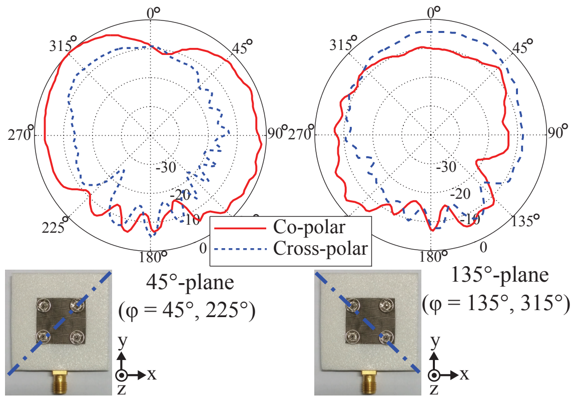


Figure 6: The measured normalized radiation patterns of the antenna in the 45°- and 135°-plane at 3.6 GHz. The diagonal dotted lines on the antenna indicates the 45°- and 135°-planes. Corners 1 and 3 were shorted in this antenna configuration.

### 3.2 Radiation patterns

For the same shorting configuration, the measured antenna radiation patterns at 3.6 GHz in the 45°-plane ($\phi = 45°, 225°$) and 135°-plane ($\phi = 135°, 315°$) in between $xz-$ and $yz-$ planes are shown in Fig. 6. As anticipated, in the 45°-plane, the two main beams are pointing away from the ungrounded patch corners. In contrast, the patterns in the 135°-plane are nearly omnidirectional and with a small amplitude, which again agrees with the expectations of Fig 3. Because of symmetry, the radiation patterns of the configuration with shorts at corners 2 and 4 should be identical, however, with a 90° anti-clockwise rotation.

## 4 CONCLUSION

The concept of utilizing commercial snap-on buttons as detachable shorting vias in wearable textile antennas has been proposed to allow modularity in antenna radiation characteristics. To illustrate the concept, a modular antenna design from [14] has been modified to accommodate various possible configurations of shorting vias, each with different radiation characteristics. The design has been validated through experimental characterization of a dual-beam configuration. The good agreement between simulation and measurement demonstrates the validity of using snap-on buttons as detachable shorting vias. It further suggests a concept where simple manual operations can allow passive reconfiguration of modular textile antenna designs by engaging/disengaging vias.

## 5 ACKNOWLEDGEMENT

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