Paired Snap-On Buttons Connections for Balanced Antennas in Wearable Systems

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Abstract—A pair of commercial snap-on buttons is demonstrated as a detachable radio-frequency (RF) balanced connection between a garment-integrated textile dipole antenna and a passive sensor-enabled radio-frequency identification (RFID) tag in a wearable wireless system. This arrangement offers reliable, low-cost and easily detachable RF coupling and feeding connections for balanced antennas, as conceptualized in simulations and validated through measurements. In addition, a back-to-back balanced transmission line structure has been designed and measured to characterize the RF performance of the proposed snap-on button connection. The resulting S-parameters indicate the good performance of the snap-on buttons as RF connectors for balanced antennas/transmission lines at least up to 5 GHz with insertion loss better than 0.8 dB.

Index Terms—Antenna feeding, textile antennas, balanced transmission line, RFID, wearable electronic system

I. INTRODUCTION

The recent emergence of wearable electronic systems for mobile communications, wireless healthcare monitoring/diagnosing and military applications has lead to increasing demands in body-centric wireless communications components [1]. Healthcare is one of the main fields of application where wearable electronic systems are in demand. Since wearable antennas and sensors are essential to implement wearable applications for healthcare, a significant growth in the relevant research areas has been observed in the last few years [2], [3]. Considering the wearing comfort and ergonomic requirements for these devices, wearable antennas are required to be flexible, low-cost, lightweight and even washable. To fulfil these characteristics, metallic foils [4], conductive inks [5], conductive polymers [6], conductive threads [7] and conductive fabrics [8], [9] are the most promising choices as flexible conductor materials. Generally antennas made from the latter two materials are garment-integratable and washable thus they offer convenience and re-usability for wearable applications. The performance of washable antennas such as gain, reflection coefficient and radiation efficiency have been investigated in [10], [11], where reliable and acceptable antenna performances have been achieved after several washing cycles. However, the connected electronics are not washable in most scenarios, and thus low-cost and easy-to-use solutions of detachable connections for garment-integrated antennas are a significant requirement.

A possible solution is utilizing snap-on buttons as detachable RF connectors. Some dedicated snap connectors designed for wearable RF applications have been reported in [12]. In contrast to specialized solutions, a cheaper and more convenient RF connector solution for a 2.4 GHz probe-fed textile patch antenna has been proposed in [13], by taking advantage of commercial snap-on buttons commonly used in clothing. Despite affecting the antenna resonance frequency and return loss, these buttons still exhibit good performance as RF connectors. Further studies investigating the characteristics of these buttons used as RF connectors in coaxial-to-microstrip transitions [14], [15] and for several plaster microstrip antennas [16] have also been reported. The results have demonstrated that the snap-on button is an appropriate connector for applications up to 3 GHz. Additionally, a successful snap-on-button-based transition between a 2.4 GHz planar inverted-F antenna and an electronic circuit board has also been demonstrated [17]. However, all these research works were performed in conjunction with unbalanced antennas and transmission lines.

In this letter, the use of a pair of commercial snap-on buttons as detachable RF connectors between a balanced wideband textile dipole antenna and a passive sensor-enabled RFID tag in a wearable elderly activity monitoring system is presented. Antenna measurements and investigations of the system indicate excellent performance of the RF connectors for balanced antennas with operating range from 780 MHz to 1030 MHz. The proposed snap-on button pair connection offers not only a solid mechanical connection and detachability but also shows a minimal impact on RF performance. Moreover, an investigation of the characteristics of the snap-on button coupling arrangement for balanced transmission line transitions demonstrates a stable applicability at least up to 5 GHz.

II. THE RFID SYSTEM

The considered application is a wearable RFID system with an operating frequency of 923 MHz, aiming for elderly...
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Fig. 2. A tag with an original rigid dipole antenna.

Fig. 3. Layout of the textile antenna. The design dimensions are \( a = 70 \) mm, \( b = 40 \) mm and \( g = 3.5 \) mm.

monitoring [18], [19]. It consists of at least one battery-free tag with an antenna, a reader with several antennas and back-end systems. A configuration of the system is shown in Fig. 1. The RFID tag is a passive accelerometer-enabled device with an input impedance of \( 78 + 16 \) \( \Omega \), containing a micro-controller unit where a unique identification number is stored. It communicates with a reader through an antenna, where the signal received from the reader is also used as an activating power source. The back-end computer systems collect, analyse and store the data received from the reader and act as a human interface as well. The proposed paired snap-on buttons connection provides a solution to detach the tag from its antenna which can remain integrated with a garment during washing.

III. THE TAG AND ANTENNA

The tag originally comes with a dipole antenna printed on a FR4 substrate [19], as shown in Fig. 2. It is noticeable that the original antenna is not appropriate for wearable applications as it is narrowband and not flexible. Thus an alternative wearable wideband antenna has been designed to improve the wearability and robustness to changing electromagnetic environments. The new antenna is a flexible wideband textile dipole antenna with an impedance bandwidth for matching to 78 \( \Omega \) \((-10 \text{ dB})\) ranging from 780 MHz to 1030 MHz.

To make the antenna flexible and lightweight, a silver-coated nylon RIPSTOP fabric with a sheet resistance of 0.01 \( \Omega / \square \) has been selected as the conductor.

As shown in Fig. 3, the antenna is a planar elliptical dipole which has a major axis \( a = 75 \) mm and a minor axis \( b = 40 \) mm. The elliptical antenna elements offer wideband performances [20] and the ratio of the major and minor axes \( a/b \) determines the taper rate of the slots originating from the feed (between the ellipses) and consequently the impedance bandwidth. The critical parameter to control the antenna input impedance is the feed gap size \( g \) between the two elliptical elements. An optimal gap of \( g = 3.5 \) mm is chosen to set the antenna input impedance to be 78 \( \Omega \) to closely match the tag, as obtained through iterative optimizations in CST Microwave Studio 2014 (CST). In order to have easy detachability without sacrificing the RF performance, commercial snap-on buttons are employed as the RF connector for this replacement flexible antenna.

IV. PAIRED SNAP-ON BUTTONS BALANCED CONNECTION

The snap-on buttons chosen in the present case are of sewn-on type (Fig. 4). As RF connectors, the selected buttons offer excellent mechanical and electrical performance as verified in the following through simulations and experiments.

A. Mechanical Performance

The button dimensions and its 3D model built in CST are shown in Fig. 4. The base diameters of 5.5 mm (male) and 6.2 mm (female) give enough real estate for soldering and sewing while the engaged button height of less than 2.7 mm results in a low-profile connection with negligible obstruction to movement. There is a spring embedded in the female button to clip and hold the male button when engaged. This spring mechanism forms solid and reproducible mechanical and electrical connections, as presented as a pair of metallic thin rods in the CST model. A mechanical test involving a spring scale and a fixture to experimentally test the required force to pull a pair of engaged buttons apart indicates that a force of approximately 3 N is needed. This confirms that the mechanical connection is very solid.

To attach to fabrics and textiles, there are four holes on the base of both male and female buttons for sewing propose. As shown in Fig. 5a) and b), two female buttons are sewed on the textile dipole using conductive threads, while two male buttons are soldered on the tag printed circuit board, one male button being cut to fit the electronics. Consequently the antenna can be easily detached from and reattached to the tag. The mechanical compatibility of these buttons with textile materials and most electronics is clear since they can be sewed or soldered on them respectively.

B. Electrical Performance

The proposed snap-on buttons must have satisfactory electrical performance to be good RF connectors. In order to investigate this aspect, two identical textile elliptical antennas have been fabricated and experimentally characterized with different connection methods. The first one employs the balanced paired snap-on buttons feeding arrangement as shown in Fig. 5 b) while the second one adopts a permanent direct contact method realized with conductive epoxy. For dedicated antenna measurements (i.e. without the tag), a wideband (0.7 GHz - 6 GHz) balun has been adapted from [21], [22]
The experimental results obtained with the balun are in good agreement and confirm the simulated findings: the measured resonance frequency only has a 9 MHz increment from 867 MHz and the impedance bandwidth moves slightly towards the higher frequency end, namely from 773 - 1007 MHz to 805 - 1012 MHz. Hence, with snap-on buttons, the antenna still maintains its bandwidth and matching to the system.

2) RFID System Performance: A tag attached to a garment-integrated antenna using snap-on buttons and worn by a human subject is shown in Fig. 5 d). In this configuration, one of the most important parameters of the RFID system is the read range, i.e. the maximum distance from the reader antenna at which the RFID tag is activated (i.e. successfully powered) and communication is successful. In the present case, as the operational frequency band of the wearable RFID system is generously covered by the antenna impedance bandwidth for both types of connections (direct and snap-on), similar performances are expected. This is validated in the experiments with a female human subject, where identical read ranges, namely 3.0 m, have been obtained for the tag with direct and snap-on connections to the antenna. It is noted that this read range can be further enlarged with appropriate techniques to isolate the dipole radiation from the human body.

3) Effect of the Gap between Engaged Female and Male Buttons: The presented simulation results have been obtained for the ideal snap-on button connection configuration, which considers the maximum and flattest contact surface for the components connected. However, the thickness of the materials touching both female and male buttons can influence the gap and consequently the capacitance between male and female connector parts. To investigate how this can affect RF performance, a simulation-based study has been conducted. As demonstrated in Fig. 7, the simulated $|S_{11}|$ is not significantly affected when increasing the gap from 10 μm to 550 μm which is the maximum possible gap obtained via empirical observations of the buttons. This confirms the robustness of the snap-on button connection in the proposed design.

**V. INSERTION LOSS**

To characterize the RF performance of the paired snap-on buttons connections in balanced structures up to 5 GHz, a pair of connected back-to-back 125 Ω coplanar strips were used for testing. For reference, a through coplanar strip line with the same length was used. As shown in Fig. 8, both the test and reference structures consist of two baluns and a pair of transmission lines of same length made from silver fabric. The impact on the RF performance from the button

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**Fig. 5.** The snap-on button feeding arrangement. a) A tag with soldered male snap-on buttons, b) Proposed antenna with sewed female snap-on buttons, c) A 50 Ω to 78 Ω impedance balun with soldered male snap-on buttons, d) A tag with proposed antenna worn on human body.

**Fig. 6.** Simulated and measured reflection coefficient $|S_{11}|$ of the proposed antenna. The simulated $|S_{11}|$ parameters for two cases are included: i) the antenna fed with the 50 to 78 Ω balun (with balun); and ii) directly with a 78 Ω port (w/o balun).

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**Fig. 7.** Simulated reflection coefficient $|S_{11}|$ of the proposed antenna with different gaps between female and male snap-on buttons.
connections can be extracted through S-parameters comparison, with time gating used to isolate the impact on the snap-on connections from the parasitic effects of the baluns. Based on these measurements, the resulting transmission coefficients are shown in Fig 9. The test structure holds a slightly lower transmission coefficient than the reference, which demonstrates a good RF performance of the proposed paired snap-on button connection, with insertion losses from 0.29 dB to 0.76 dB up to 5 GHz.

VI. CONCLUSION

A practical and affordable solution using a pair of commercial snap-on buttons as detachable RF connectors has been presented for balanced textile structures. This solution has been applied to connect a wideband elliptical dipole antenna in a 923 MHz wearable RFID system. Two identical antennas have been fabricated using silver fabric, and experimentally characterized to compare direct contact connection to the proposed balanced snap-on connection. The simulated and measured reflection coefficients indicate that only small variations and an insignificant performance degradation are introduced when using the paired snap-on buttons as RF connectors. This is confirmed by a system test where identical read ranges have been obtained when employing these two types of connections. Further results from a simulation-based study indicate that the gap between engaged female and male buttons has negligible impact on the RF performance. Moreover, measurements on a back-to-back balanced transmission line structure suggest that the button connectors are usable for similar applications at least up to 5 GHz. The utilization of low-cost commercial snap-on buttons offers a practical solution for detachable RF connectors without sacrificing the RF performance in balanced configurations.

REFERENCES