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Conductive Fabric-Based Reconfigurable Intelligent Surface

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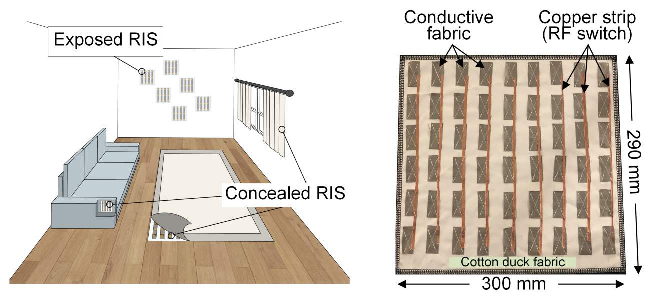
***Abstract*—Reconfigurable intelligent surfaces (RISs) are positioned to be a key enabling technology for next-generation wireless systems. However, for RIS to become pervasive in future systems will require new technologies to unobtrusively integrate them in everyday objects (e.g., carpets, drapes, upholstery) rather than exclusive use of printed circuit boards (PCBs). In this paper, we presented a proof of concept prototype of a fabric-based RIS for internet of thing (IoT) applications. The proposed RIS is a two-dimensional surface with 6 $\times$ 9 conductive fabric elements placed on a non-conductive fabric to operate at 2.4 GHz. Each element acts as a radio frequency (RF) switch to either let the signal through (*i.e.,* "lens") or reflect it (*i.e.,* "mirror") to, for example, enable a legitimate link or impair an eavesdropping link. This concept of the RIS is validated in an indoor test, where the proposed fabric RIS prototype provides a 16 dB decrease in received power when the elements in adjacent columns are electrically connected to reflect the incident waves as compared to the case where the elements are electrically isolated to allow signal transmission.**

***Index Terms*—Conductive fabric, Internet of Things (IoT), reconfigurable intelligent surface (RIS).**

I. Introduction

Recently, research on reconfigurable intelligent surface (RIS) as a new technology to enable next-generation (NextG) network systems (6G, future Wifi, *etc.*) has received significant attention from academia and industry. In essence, a RIS enables us to dynamically control the propagation channel between communicating nodes by deploying a large array of passive electronically tunable reflecting elements in a given environment [1]. Despite their enormous potential benefits, RIS technology faces several challenges to be practically and efficiently integrated into NextG communication systems. Accordingly, only a handful of RISs [2–4] have been prototyped and tested in laboratories to introduce flexibility in the radio frequency (RF) environment. These existing RIS prototypes are built using commercial RF components and conventional printed circuit boards (PCBs), limiting their flexibility and integration in household items (such as wall coverings, upholstery, and carpeting) for indoor IoT deployments.

In this paper, we propose a new kind of RIS that is based on functional fabrics to help enable pervasive and unobtrusive deployment of RIS in indoor IoT networks. The proof-of-concept prototype shown here is composed of 6 $\times$ 9 reflecting elements made of conductive fabric sewn onto a non-conductive fabric. Our performance evaluation in the lab confirms the feasibility of the fabric RIS. Thus, at 2.4 GHz, the proposed RIS achieves a 16 dB decrease in received power between the "ON" and "OFF" states.



(a) (b)

Fig. 1: a) Conceptual mock-up of the IoT network showing the concealed or exposed integration of b) the proposed fabric RIS in household items.

II. Fabric RIS Design and Measurement

Fig. 1(a) illustrates how the use of functional fabrics to realize RIS will allow for the pervasive and unobtrusive deployment of RIS in indoor IoT settings through integration into household items such as upholstery, drapery, and carpets.

A. RIS design

We designed and fabricated a fabric RIS inspired by typical elemental structures [2] by using a combination of conductive and non-conductive fabrics (Fig. 1(b)). The RIS has the form of a rectangular planar array with 6 $\times$ 9 elements made of conductive fabrics. The size of the prototyped fabric RIS is 300 mm $\times$ 290 mm, which also includes copper strips (acting as RF switch) to connect the elements in each column. Each element is $\lambda/4$ long and $\lambda/10$ wide to improve impedance matching and provide better interaction with the EM waves (λ is the wavelength of the signal at 2.4 GHz). The elements in the adjacent columns are $\lambda/10$ apart to prevent grating lobes.

We used cut and sew techniques to fabricate and combine conductive elements onto a non-conductive cotton duck fabric, without a ground plane. To choose the appropriate conductive fabric for the RIS elements, we measured and compared the DC sheet resistance of several candidate conductive fabrics

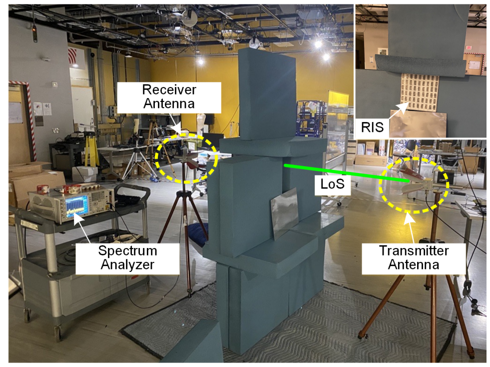
TABLE I: DC sheet resistance data

Material	DC sheet resistance (Ω/sq)
Ag/CuEx/Ni/Acrylic Nylon Woven Fabric	0.375
Ag Plated Nylon/ Elastane Fine Gauge Knit	7.528
Ag/cotton Fine gauge Knit	27.6

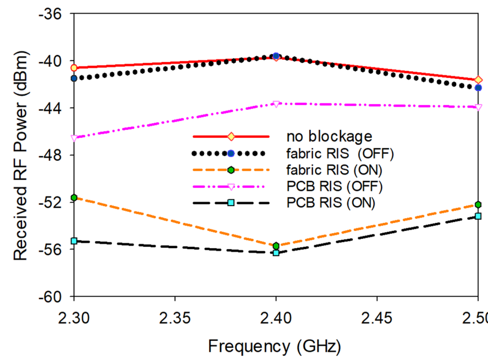
using the two-point probe method, as shown in Table I. The first material demonstrates the lowest DC sheet resistance and thus the highest conductivity, making it the best candidate for the RIS design.

B. Measurement Setup

As previously mentioned, the RIS, in general, can function as an electronically configurable "mirror" or "lens". To partially validate this concept, we conducted a performance evaluation of the fabric RIS in our laboratory by positioning it between a transmitter and a receiver. Relative to the size of our anechoic chamber, the fabric RIS is extremely small. Thus, by having the measurement setup in an anechoic chamber, it will be infeasible to measure the "true" performance of the RIS. For this reason, we built a customized measurement setup shown in Fig. 2(a), which is composed of a "castle-like" EM absorber wall with a small window to create a direct line-of-sight (LoS) between transmitter and receiver horn antennas to maximize the impact of the RIS and minimize the radiation to the surrounding environment. The signal generator and a ridged horn antenna are the main components of the transmitter. The receiver consists of an identical horn antenna and a spectrum analyzer. The transmitter and the receiver are 2 m apart, ensuring far field interaction between the two antennas.



(a)



(b)

Fig. 2: a) Measurement setup and b) measured RF received power *vs.* frequency plot.

III. Results and Discussion

We measured the received signal power through the fabric RIS for different scenarios at the desired frequencies, as shown in Fig. 2(b). The transmitted power is 10 dBm. In the scenario where all the elements in the adjacent columns are connected electrically ("ON" state), the elements become a linear array of half-wave dipoles that interact strongly with the impinging signals to redirect them away from the receiver behind (i.e., "mirror"). Thus, the received power reduces drastically by about 16 dBm compared to the scenario where there is no signal blockage (direct link) between the transmitter and the receiver. Conversely, when the elements of the RIS are electrically isolated from each other ("OFF" state), they weakly interact with the incident energy as the elements by themselves are relatively small. The RIS becomes microwave transparent to let the signal through (i.e., "lens"), which increases the received power significantly closer to the no-blockage scenario. Thus, the proposed fabric RIS achieves a 16 dB reduction in received signal power between the ON and OFF states, which opens the doors to interesting solutions in IoT networks. It should be noted from Fig. 2(b) that the fabric RIS shows similar results to the PCB counterpart.

IV. Conclusion

We presented a fabric RIS prototype as a proof-of-concept for IoT applications. The fabric-based RIS can be constructed using a combination of conductive and non-conductive fabrics that can be integrated with a wide variety of household items (drapes, carpeting, and upholstery) due to its unobtrusiveness. In the future, we will explore production of fabric RIS using scalable, industrial textile manufacturing techniques and integrate RF switch control circuitry to dynamically control them and integrate with real networks.

Acknowledgement

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