Wearable Circularly Polarized Antenna for Personal Satellite Communication and Navigation

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***Abstract*—Integrating antennas into fabrics is a potential way for facilitating many applications, such as health monitoring of patients, fire-fighting, rescue work, and space and military personal communications. This paper studies possibilities to construct a flexible, lightweight and mechanically robust textile antenna for dual-band satellite use: Iridium and GPS. Different textile materials were characterized and the most promising materials were used to design, construct, and test a rectangular patch antenna. The gain and axial ratio for both bands is compliant with specifications and relatively stable under most bending conditions. The developed antenna solution allows integration into clothing.**

***Index Terms*—Dual-band patch antenna, circularly polarized antenna, textile antenna, wireless body area network (WBAN).**

I. Introduction

THE number of wireless applications is continuously increasing, while the size of the corresponding devices is decreasing. However, the trend towards miniaturization causes some challenges considering the correct functioning of the antenna and a tradeoff between antenna performance and size and battery life must be performed. Furthermore, one needs to consider the interfering effect of components in close proximity to the antenna.

Integrating wireless electronics into clothing is a potential solution for many applications aiming to increase user safety, awareness, convenience, and operability. These applications include health monitoring of patients [1], fire-fighting [2], rescue work [3], and space and military personal communications [4]. The literature covers both on-body [5]–[7] and off-body [8], [9] solutions.

In satellite communication systems, such as GPS, Galileo, and Iridium, circularly polarized antennas provide up to 3-dB better power levels compared to linearly polarized antennas. However, these antennas are often too large or complex to be implemented as an internal antenna in a mobile phone but can easily be hidden inside a sleeve of a jacket as an external antenna.

Textile antennas can often be implemented without an extreme pressure towards miniaturization while even improving comfort of use and allowing hands-free operation. Also, the use of multiple external antennas is possible, hence improving the overall coverage.

As a textile antenna is meant to be attached to or integrated in user's clothes, it is desirable to make an antenna conformable and as nonobtrusive as possible. When the user moves, the antenna should bend along with the clothes and still maintain its functionality. However, changes in antenna shape are a potential cause for degraded performance [10]. Designing the shape carefully and by positioning the antenna in places with reduced bending, such as the shoulder area, are ways to reduce these problems [11]. Also the selection of textile materials has an influence on both the technical performance and user comfort.

Although noise temperature of the antenna has an effect on the quality of GPS signal and Iridium downlink signal, the effect is estimated to be of second order but would need to be taken into account for further design improvements.

The antenna with conical radiation pattern towards "cold" sky has lower antenna noise temperature and is less sensitive to multipath effects than an omnidirectional antenna.

This paper studies possibilities to construct a flexible and lightweight textile antenna for dual-band use. The antenna should be operational in an outdoor environment, and allow normal activities like walking, running, and sitting. The antenna must function for both Iridium and GPS bands, and preferably maintain right-hand circular polarization even under bending conditions. The feasibility of antenna diversity is examined by determining the coverage area and isolation between two antennas.

II. Antenna Design

In order to achieve an adequate solution for integrating the antenna into clothing, a planar patch-type antenna was selected as the baseline for this research because of its inherent low profile. A ground plane of the patch should also reduce the user's influence on antenna performance. The selected specific geometry was a square ring patch with a polygon-shaped slot due to its demonstrated circular polarization and wide band performance [14]. In this case, the wide band performance is needed in bending conditions when a frequency shift is probable.

When selecting potential fabrics, the following aspects were considered to be of paramount importance. The design driver was the best possible performance, and low loss fabrics were thus preferred. The fabrics should also be mechanically durable and although they should be highly flexible they should show limited stretching and compression. In addition, the fabrics should return to their original form after dimensional deformations. The fabrics should also be nonhygroscopic, and tolerate

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TABLE I
MEASURED ELECTRICAL PARAMETERS OF THE SUBSTRATE MATERIALS

Parameter	Cordura	Ballistic textile
ε_x	1.88	1.46
ε_y	1.91	1.46
ε_z	1.67	1.38
$tan\delta_x$	0.009	0.003
$tan\delta_y$	0.010	0.003
$tan\delta_z$	0.005	0.002

temperatures required for soldering. Out of many materials studied, two substrate textiles, Cordura and another woven fabric, which fulfilled the mechanical qualification requirements, were selected.

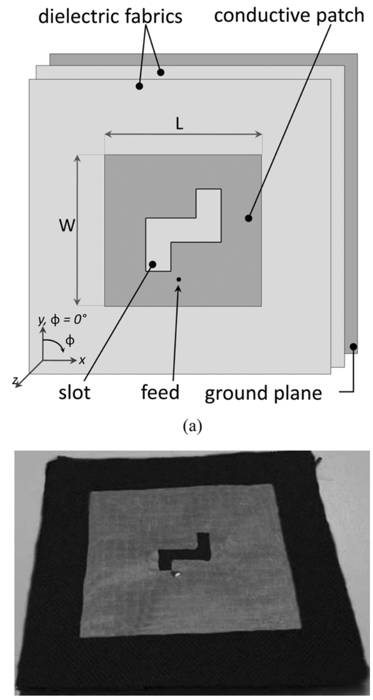
The electrical parameters of these dielectric fabrics were studied to confirm their suitability as antenna substrates. Since these fabrics are woven and thereby anisotropic, their electrical parameters were measured separately in all three orthogonal directions using a cavity resonance method. In Cartesian coordinates, the x- and y-axes are defined as warp and weft directions respectively, while the z-axis is the out-of-plane direction. Measured effective permittivities and loss tangents are presented in Table 1. Both materials have reasonably low losses and qualify to be used as substrates. The uncertainty of the measurements is estimated to be approximately 5% for permittivity values and about 60% for loss tangent. The accuracy of the sample volume is the most significant error source in the measurements. Although low loss values are challenging to measure, the loss is so small that even 60% change in the value does not have significant effect on the antenna performance. The details of the cavity resonance measurement technique, analysis methods, and the measurement results for the other textiles will be presented elsewhere.

In order to achieve an adequate thickness for the antenna to function properly, several fabric layers were stacked. Both measured dielectric fabrics were exploited to get the best possible structure for the antenna.

The ground plane and the patch were woven, silver, and copper plated, low-loss nylon fabric, which surface resistance is less than 0.03 $\Omega/^2$. All the fabric layers were connected by sewing in order to keep the structure as bendable as possible and to avoid extra losses caused by adhesives. The antenna is fed via a SubMiniature version A (SMA) connector, which was punched through the antenna and soldered to the conductive fabrics. The antenna structure is illustrated in Fig. 1 in which the length L and the width W are both 65 mm. The feed point coordinates in millimeters when the origin is located at the center of the antenna are $x = -3$ and $y = -11.5$. The total thickness of the antenna is approximately 3 mm.

The antenna was designed, using CST Microwave Studio software, to simultaneously cover two different frequency bands of 1575 MHz (GPS) and 1621.35–1626.50 MHz (within Iridium). In addition, to assure adequate functioning even when bent, a guard band of some 30 MHz was included.

Some target parameters for the antenna were preset (by the project) as follows. The lower limit for the gain was -2.5 dBi while the upper limit was 7.5 dBi. To assure circular polarization, the highest limit for the axial ratio was 5 dB. The target for the coverage was 85° from the zenith.



(a)

(b)

Fig. 1. (a) The structure and (b) first prototype of the antenna.

III. ANTENNA PERFORMANCE

A circularly polarized wave is very susceptible to distortions in multipath environment wherein arbitrary reflections may degrade the polarization purity of the wave or even change the direction of rotation of the polarization. However, comparative studies in [12] and [13] show that GPS functions also with linearly polarized receiver antennas, thus right-hand circular polarization (RHCP) requirements for GPS, were considered less critical. In the case of a satellite mobile phone, the antenna is not only receiving but also transmitting. As the connection is sustained by an adaptive power control, the quality of the link has an effect on the battery consumption of the phone. In order to secure the connection and to reduce the power consumption, the RHCP requirements were considered to be stricter for Iridium as compared to GPS, and hence the center frequency of the antenna was designed to be closer to the Iridium band.

A. Return Loss

Return loss (S11) measurements were conducted on a prototype textile antenna using a HP8720ES vector network analyzer. The total -10-dB S11 bandwidth was some 80 MHz. Since the prototype antenna resonated at a lower frequency band than the simulated one, another prototype was made and measured to verify the results. After tuning the prototype antennas and using the real measured dimensions in the simulation there remains about 50-MHz difference between simulated and measured values as can be seen in Fig. 2. This is believed to be due