MODIFIED E-SHAPED PIFA ANTENNA FOR WEARABLE SYSTEMS

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Abstract: A new wearable antenna for applications in communication systems used in military and police work has been developed. The proposed modified E-shaped PIFA antenna covers the nominal band of 380–400 MHz, and the functionality is guaranteed independently of the user’s clothing and the presence of lossy materials, such as wet clothing, mud or snow. The design is based on numerical simulations and measured results confirm the superiority of the new antenna with respect to conventional antennas in use in the abovementioned applications.

INTRODUCTION
Wearable antennas have received significant attention lately due to the introduction of wireless communication technology. Personal communication and computer systems are becoming ever smaller in size and mass, evolving into wearable units. Of no less importance are the needs of police and military operations in urban environment (e.g., surveillance and reconnaissance). Communication systems designed in support of these operations use designated frequency bands, which have been carefully chosen to make the functional requirements compatible with radio wave propagation characteristics in urban areas. A wearable antenna is required in the Tetrapol system for undercover operatives. The nominal operating frequency band (380–400 MHz) together with the antenna requirements of i) having a small size, ii) being largely unaffected by the presence of the human body, iii) remaining still operational when covered by wet clothing, iv) being structurally strong to survive near-fight situations, and v) providing a reasonable gain, pose a formidable challenge.

This paper presents the design of a modified E-shaped PIFA solving the problem of the close presence of the human body (which dramatically influences the antenna performance) and of guaranteeing the functionality also in the presence of lossy conductive materials. The designed antenna shows improved electrical performance with respect to the currently used dipole antenna, leading to more efficient radiation of RF power and a larger terrain coverage, thus alleviating the constraints on the overall communication system. The antenna was designed through extensive full-wave electromagnetic simulations, and its performance – in terms of return loss and far-field radiation pattern – was verified and fine-tuned experimentally.

ANTENNA DESIGN
Most currently available wearable antennas are of the resonant type, such as the λ/2 dipole. Antennas of this class have the advantage of having simple structure, light weight and real input impedance but operate well only in a narrow frequency band. Furthermore, if they are used as wearable antenna in the UHF band, they yield large, full-body antennas. A comparably simple – and physically shorter – alternative is the commonly used normal-mode helical antenna. Its dimensions are small in comparison with the wavelength, and the radiation pattern is omnidirectional, i.e., the antenna radiates in all directions normal to the antenna axis. Unfortunately, the input impedance of the helix antenna is very sensitive to changes in frequency, and the bandwidth is narrow. Nevertheless, the normal-mode helix effectively reduces the length of thin-wire-type resonant antennas for personal and mobile communication systems. When employed as wearable antennas, both the half-wavelength dipole and the normal-mode helix exhibit significantly degraded performance due to the immediate proximity of the user’s body, which absorbs energy radiated by the antenna.

To comply with the requirement of a low profile, other types of wearable antennas available at present have been mostly manufactured in the printed-antenna technology. They can be divided into three categories: thick dipoles [1], [2], planar antennas on photonic band-gap substrates [3], and planar inverted-F antennas (PIFAs) [4]–[7]. Thick dipoles have been utilized to increase the operating bandwidth of the thin dipole. However, the technology does not in any way alleviate the problem of gain degradation due to energy absorption by the user’s body.

One of the main operational disadvantages of planar antennas is their narrow frequency bandwidth. To meet requirements of broader bandwidth, methods like increasing the thickness of the substrate are commonly
used. Photonic band-gap materials have been introduced as substrates in planar antennas to increase the useable frequency bandwidth. They have also been utilized in wearable-antenna applications. Their most significant drawback, however, is the requirement of large substrate and ground plane, necessary to induce the band-gap behavior. This effectively excludes the antennas from applications in the UHF band.

In this paper, a wearable antenna based on PIFA technology is presented. Although the nominal specified bandwidth for the antenna is from 380 to 400 MHz, computer simulations assuming a covering layer of (wet) mud led to the conclusion that the antenna had to be designed for a larger frequency band in order to operate with specified parameters over the nominal band in all expected field conditions. The antenna employs two resonant components, in the form of two slightly asymmetric arms supporting two closely spaced yet distinct resonant frequencies (Figure 1). The bandwidth is further increased – at the expense of the antenna gain – by adding a discrete resistor to each radiating arm. The enhanced bandwidth achieved this way allows maintaining the antenna’s low-profile geometry. A low-loss impedance matching is provided by SMD components. The antenna is designed to produce a total field radiation pattern that is nearly omnidirectional in azimuth. The upper metallization of the antenna can be inscribed into a rectangle 14 cm x 22 cm in size, and the ground plane measures 30 cm x 30 cm. The two metallic surfaces are separated by a 2 cm thick layer of Rohacell.

HUMAN BODY AND WET MUD EFFECTS
The aspects to be taken into consideration when the antenna operates in close contact with the human body include a possible degradation of the antenna performance (due to power absorption in the body), and a possible health hazard for the user. Both can be avoided using a ground plane. Simulations have shown that a ground plane of 30 cm x 30 cm is sufficient for this antenna type. The human body effects on the designed antenna are presented in Figure 2. It can be seen that the human body has only a small negative impact on the return loss of the antenna.

The effects of a wet soil layer that in certain field conditions can be expected to cover the antenna have also been studied. A layer of RF absorbent material, such as wet clothing, mud or snow, close to the antenna will alter the antenna’s radiation characteristics. The antenna performance will vary depending on the thickness \( t \) of the dielectric and on the distance \( d \) from the antenna. The general tendency of such a layer is to shift the antenna’s operating frequency band toward lower frequencies, as can be seen in Figure 3. Due to this shift, it was necessary to design the antenna for a larger bandwidth than the nominal. Specifically the bandwidth of the prototype is from 375 to 415 MHz for a 7 dB return loss.

FIELD MEASUREMENTS
A zero-generation breadboard manufactured in the printed-circuit board technology was built and tested. Radiation pattern measurements of the breadboard have been carried out as outdoor far-field measurements, with the antenna under test positioned on a revolving platform at the height of ~1 m and a fixed receiving antenna 220 m away.

The antenna was tested on a plastic tripod, on a phantom (filled with one-percent saline water solution) as well as on a human being. For tests on the phantom and the human body, the antenna was attached to the user’s lumbar region, which was determined to be the most natural and comfortable location to wear the antenna at.

Measured azimuthal radiation pattern exhibits a gain that is by 13 dB higher than that of the conventional body-worn dipole (Figure 4).

CONCLUDING REMARKS
A Wearable E-Shaped Shorted PIFA Antenna for the 400MHz region has been designed. A zero-generation version of the antenna has been developed, built and tested. The antenna operates over the nominal frequency band of 380–400 MHz in a multitude of expected field conditions, for example, when worn under wet clothing, a thick jacket or covered by wet mud. Worst-case measured return loss of the antenna is about 8 dB. Far-field radiation pattern of the antenna in the azimuth plane is almost omnidirectional, with measured gain of about -12 dBd. The gain is by about 13 dB better than that of the existing body-worn dipole.

The next step in the development process is to translate the zero-generation version to a true wearable design, using conductive fabrics and foam materials that are comfortable to wear and compatible with the human body in close contact.
REFERENCES


