Magnetic Current Inspired Antennas For Wearable Applications

by

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To those who have put me here today.
Hard work never brings fatigute. It brings satisfaction - Shri Narendra Modi

Contents

Abstract

Since the year 2000 there has been a growing interest in an area known as body-worn communications for diverse applications ranging from healthcare to security. An integral component of body-worn devices are antennas which facilitate transmission of pertinent information about the user such as location. The focus of this thesis is on the antennas, which in the context of body-centric communications are also known as body-worn or wearable antennas.

Prior to designing body-worn antennas there are some subsidiary issues that must be addressed. One of these subsidiary issues is realizing a robust and reliable connection between rigid and flexible devices. This issue must be addressed as textile antennas will be interfaced with rigid electronic devices when viewed from a holistic system perspective. Consequently, this thesis investigates connection strategies and proposes implementations realized solely from textile materials that can connect rigid and flexible devices.

The second subsidiary issue is related to antenna ground planes. Ground planes for wearable antennas are likely to be bent, given the inherent curvature of the human body. In this regard it is important to appreciate the effects of conformal ground planes on the performance of body-worn antennas, which is an issue that is addressed in this thesis.

The final pragmatic issue that must be addressed for wearable antennas is user comfort. The issue of user comfort can best be understood by considering the extent of the ground plane. Generally, to isolate the antenna from the deleterious effect of the human body, a ground plane is used. The most common method of realizing ground planes for body-worn antennas is to use metalized fabrics, which are available with high conductivity. However, conductive fabric ground planes can be uncomfortable, especially if extended ground planes are used to enhance the isolation between the antenna and the human body. Combining conductive fabrics and conductive embroidered structures which are realized through conductive yarns is an attractive option to enhance the wearability of extended ground planes. This hybrid approach is attractive as conductive yarns tend to be less intrusive than conductive fabrics. A challenge in using computerized embroidery however is the accurate characterization and modeling

of conductive embroidered structures. The two aforementioned issues are addressed in this thesis through the use of scattering experiments and introduction of an effective modeling parameter.

Focusing now on the antennas themselves, it is generally accepted that the design of body-worn antennas is a challenging task. Primarily, the design of body-worn antennas is quite demanding as the antenna performance must be insensitive to the effect of the human body, which is a very lossy and complicated propagation medium. An additional consideration is the potential deformation of the antenna geometry which will depend on where the antenna is placed on the human body. To ensure robust performance, the aforementioned factors must be accounted for in the design phase of the antenna.

Consequently, it is vital to select appropriate antenna topologies for body-worn applications. Radiating cavities, or more specifically closed and semi-closed cavity antennas are attractive for wearable applications as they are robust to environmental effects and exhibit high performance with a simple fabrication process. However, closed and semi-closed cavity antennas can be rather large, which can inhibit their deployment for body-worn scenarios. Additionally, realizing dual-band or multi-band closed and semi-closed cavity antennas is challenging as the operating frequency is determined by fixed ratios. In regards to the these challenges, this thesis proposes and validates the following solutions:

1. A new miniaturized low-profile semi-closed UHF cavity antenna is proposed and experimentally validated. This new topology is shown to be robust to the effects of the human body and mechanical deformations. A salient feature of this antenna is the exploitation of computerized embroidery to realize the cavity walls.

2. A new dual-band cavity antenna is realized by the integration of two similar radiating elements operating as equivalent magnetic currents into a single cavity. The antenna is targeted to cover the lower and upper microwave ISM bands. The incorporation of a planar feeding element and a largely independent control of both the lower and upper microwave ISM bands is an attractive feature of this design.

As previously mentioned, obtaining steady performance for body-worn antennas under adverse environmental conditions is a challenging task. One method to deal with

this issue is to utilize frequency reconfigurable antennas. In this context this thesis presents a new proof-of-concept frequency reconfigurable cavity-backed slot antenna. An attractive feature of this antenna is that the reconfiguration elements, i.e varactors, are embedded inside the cavity structure which helps to insulate them from adverse external forces. Additionally, the proposed antenna can be impedance matched through a planar feeding mechanism over a large fractional tuning range of 20% without requiring lumped matching elements.

Overall, this thesis holistically investigates a range of issues related to the realization and utilization of wearable antennas for body-worn applications. Thus the contributions of this thesis lay a strong foundation for future wearable antenna deployment.

Originality Declaration

For a thesis that does contain work already in the public domain.

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name in any university or tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint award of this degree.

I give permission for the digital version of my thesis to be made avaliable on the web, via the University's digital research repository, the Library Search and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

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	13/07/2018
Signed	Date

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Conventions

Typesetting

This document was compiled using LaTeX 2ε. TexStudio was used as the text editor that was interfaced with LaTeX 2ε. All images have been created using MATLAB and Inkscape.

Spelling

American English spelling conventions have been adopted in this thesis.

Referencing

The Harvard referencing style has been utilized in this thesis.

Units

This thesis has adopted the International System of Units (SI Units).

Abbreviation

MHz	Megahertz
GHz	Gigahertz
EBG	Electromagnetic Bandgap
UWB	Ultra-wide band
PRS	Partially Reflective Surface
GPS	Global Positioning System
ISM	Industrial Scientific and Medical
WLAN	Wireless Local-Area Network
PCS	Personal Communications Services
PIFA	Planar Inverted-F Antenna
CMA	Characteristic Mode Analysis
CRLH	Composite Right/Left Handed
TE	Transverse Electric
TM	Transverse Magnetic
SMA	Subminiature Version A
PDMS	Polydimetylsiloxane
TPU	Thermoplastic Polyurethane
RFID	Radio Frequency Identification
TEM	Transverse Electromagnetic
RCS	Radar Cross Section
MM1	Modeling Method 1
MM2	Modeling Method 2
DC	Direct Current
UHF	Ultra High Frequency
dB	Decibel
PCB	Printed Circuit Board
CRLH-TL	Composite Right/Left-Handed Transmission Line
HIS	High Impedance Surface
HMSIC	Half-Mode Substrate-Integrated Cavity
SIC	Substrate Integrated Cavity

Awards and Scholarships

2016

- IEEE Antennas and Propagation Society Travel Grant Award

2015

- 3 Minute Thesis (3MT) School Finalist
- 3 Minute Thesis (3MT) Faculty Winner

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- Australian Postgraduate Award

Publications

Journal Articles - Organized in reversed chronological order

[1] N. Nguyen-Trong, **S. P. Pinapati,** D. Hall, A. Piotrowski and C. Fumeaux, "Ultra-Low-Profile and Flush-Mounted Monopolar Antennas Integrated into a Metallic Cavity", *IEEE Antennas and Wireless Propagation Letters*, vol. 17, pp. 86-89, 2018

[2] **S.P. Pinapati,** D.C. Ranasinghe and C. Fumeaux, "Textile Multilayer Cavity Slot Monopole For UHF Applications", *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 2542-2545, August. 2017.

[3] **S.P. Pinapati,** T. Kaufmann, D.C. Ranasinghe and C. Fumeaux, "Wearable dual-band stripline-fed half-mode substrate-integrated cavity antenna", *Elec. Letters*, vol. 52, no. 6, pp. 424-426, March. 2016.

Conference Articles - Organized in reversed chronological order

[1] **S.P. Pinapati,** D. C. Ranasinghe and C. Fumeaux, Bandwidth Enhanced Dual-Band Half-Mode Substrate-Integrated Cavity, *Australian Microwave Symposium (AMS)*, 2018. In Print.

[2] **S.P. Pinapati,** S. J. Chen, D. C. Ranasinghe and C. Fumeaux, "Detuning Effects of Wearable Patch Antennas", in *Asia-Pacific Microwave Conference (APMC)*, November. 2017, pp. 162-165. **Finalist for best student paper award.**

[3] **S.P. Pinapati,** N. Nguyen-Trong, A. Piotrowski and C. Fumeaux, "Integration of a Wideband Low-Profile Monopolar Antenna onto Curved Metallic Surfaces", in *International Conference on Electromagnetics in Advanced Applications (ICEAA)*, September. 2016, pp. 203-206.

[4] **S.P. Pinapati,** D. Ranasinghe and C. Fumeaux, "Characterization of conductive textiles for wearable RFID applications", in *International Conference on Electromagnetics in*

Advanced Applications (ICEAA), November. 2016, pp. 341-344. **Winner of Antennas and Propagation Society Travel Grant**

[5] **S.P. Pinapati,** T. Kaufmann, I. Linke, D. Ranasinghe and C. Fumeaux, "Connection strategies for wearable microwave transmission lines and antennas", in *International Symposium on Antennas and Propagation (ISAP)*, November. 2015, pp. 1-4.

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