

**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

Contents	v
Abstract	ix
Originality Declaration	xiii
Acknowledgments	xv
Conventions	xix
Abbreviation	xxi
Awards and Scholarships	xxiii
Publications	xxv
List of Figures	xxvii
List of Tables	xliii
Chapter 1. Introduction	1
1.1 Introduction	2
1.2 Objectives	2
1.3 Thesis structure	5
1.4 Original Contributions	8
Chapter 2. Background	13
2.1 Wearable Antennas	14
2.2 Materials for Flexible Antennas	15
2.3 Textile Based Wearable Antennas	23
2.3.1 Clothing Antennas	23
2.3.2 Ultra-Wideband Textile Antennas	24

2.3.3	Resonant Antennas	28
2.3.4	Antenna Arrays	43
2.3.5	Practical aspects	46
2.4	Summary	49
Chapter 3. Connection Strategies		51
3.1	Introduction	52
3.2	Geometry Overview	57
3.3	Simulations	57
3.4	Manufacture	59
3.5	Results	61
3.6	Comparisons	63
3.7	Conclusions	64
Chapter 4. Conformal Ground Planes		65
4.1	Introduction	66
4.2	Vehicular Scenario	67
4.2.1	Monopolar Antenna	67
4.2.2	Ground Plane Effects	68
4.2.3	Curved ground planes	70
4.3	On-Body Scenario	76
4.4	Conclusions	78
Chapter 5. Embroidered Antennas		81
5.1	Introduction	82
5.2	Fabrication	88
5.3	Experimental Method and Considerations	88
5.4	Fabrication Parameter Effects	92
5.4.1	Grid and Stitch Spacing	92
5.4.2	Embroidery Density	94
5.4.3	Embroidery Layout	98
5.5	Modeling and Characterization	103

5.6	Embroidered Antenna Ground Planes	110
5.6.1	Antenna Design	111
5.6.2	Fabrication	114
5.6.3	Experimental Validation	114
5.7	Conclusions	117
Chapter 6. Miniaturized Ultra-High Frequency Antenna		121
6.1	Introduction	122
6.2	Geometry Overview	124
6.3	Design Method	124
6.4	Design Adaptation for Wearable Implementation	130
6.5	Manufacture	135
6.6	Experimental validation	136
6.7	Design variation	142
6.8	Conclusion	144
Chapter 7. Dual-band half-mode substrate-integrated cavity		147
7.1	Introduction	148
7.2	Geometry Overview	152
7.3	Design	154
7.4	Design Adaptation for Wearable Considerations	161
7.5	Manufacture	163
7.6	Experimental validation	165
7.7	Design variation	168
7.8	Conclusions	169
Chapter 8. Detuning Quantification		173
8.1	Introduction	174
8.2	Frequency detuning quantification	174
8.2.1	Simulations	177
8.2.2	Experimental Validation	180
8.3	Conclusions	185

Chapter 9. Multi-Layer Cavity-Backed Broad-Slot Reconfigurable Antenna	187
9.1 Introduction	188
9.2 Reconfigurable Cavity Antenna - Geometry Overview	192
9.3 Design Methodology	192
9.3.1 Cavity Design	192
9.3.2 Incorporation of the Reconfigurability	197
9.3.3 Feeding and Biasing	203
9.3.4 Practical Realization	208
9.3.5 Design Summary	209
9.4 Manufacture	209
9.5 Experimental Validation	211
9.6 Conclusions	213
Chapter 10. Summary and Outlook	217
10.1 Summary	218
10.1.1 Part One - Practical Issues: Summary	218
10.1.2 Part Two - Wearable Cavity Antennas: Summary	219
10.1.3 Part Three - Adaptive Antennas: Summary	220
10.2 Outlook	221
10.3 Concluding statement	223
Bibliography	225

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 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 available 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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Signed

13/07/2018
Date

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Conventions

Typesetting

This document was compiled using $\text{\LaTeX}2_{\epsilon}$. TexStudio was used as the text editor that was interfaced with $\text{\LaTeX}2_{\epsilon}$. 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	Polydimethylsiloxane
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

2014

- 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.

List of Figures

1.1	The organizational structure of this thesis.	5
<hr/>		
2.1	A vision of what a security orientated body-worn communications scenario will look like where an individual has multiple wireless communication devices integrated into their clothing. Generally these devices will be transmitting information about the status of the user with other devices which are either on or off the body. This image is reproduced from [1].	14
2.2	A highly flexible conductive polymer based meandered dipole. This image is reproduced from [2].	15
2.3	A conductive polymer planar monopole antenna as reproduced from [3].	16
2.4	A typical inkjet printer that can be used in the realization of flexible microwave devices. This image is reproduced from [4].	16
2.5	A periodic ground plane structure realized through inkjet printing technology as reproduced from [5].	17
2.6	A wideband dipole antenna patterned from a conductive fabric. The textile dipole is excited through a balun which has been fabricated from Rogers Duroid 5880.	18
2.7	A textile patch antenna realized from the combination of conductive textiles and textile substrates. This image is reproduced from [6]	18
2.8	A microscopic view of a conductive fabric which shows that such fabrics are made from tightly interwoven bundles of threads.	19
2.9	A computerized embroidery machine that can be used for the realization of textile antennas.	19
2.10	A variety of textile antennas made from computerized embroidery showing the high accuracy that can be achieved through a computerized embroidery machine as reproduced from [7].	20
2.11	Embroidered structures with sub-milimeter precision as adapted from [8].	20
2.12	Dipole antennas integrated into military clothing attire that have been realized through computerized embroidery as reproduced from [8]. . . .	20

List of Figures

2.13	A microscopic view of a conductive yarn which shows a polyester core which is encapsulated by a conductive material. This image is reproduced from [9].	21
2.14	A depiction of a series of multifilament threads and a monofilament thread as reproduced from [10].	22
2.15	A textile substrate integrated waveguide realized through a combination of conductive fabrics, conductive yarns and a foam substrate as reproduced from [11].	23
2.16	A button antenna as reproduced from [12].	24
2.17	A monopole zip antenna as reproduced from [13].	25
2.18	A planar disc UWB monopole antenna as reproduced from [14].	26
2.19	A embroidered UWB spiral antenna as reproduced from [15].	26
2.20	A textile UWB antenna with a full ground plane as reproduced from [16].	27
2.21	Multi-layer textile UWB antenna with full ground plane as reproduced from [17].	28
2.22	A textile bow-tie dipole antenna as reproduced from [18].	29
2.23	Two common variants of a PRS: (a) A metallic sheet with a periodic aperture and (b) A periodic repetition of a metalized geometry.	30
2.24	A visual representation of the partial leakage and reflection of the radiated fields from a patch antenna through a PRS structure. This image is reproduced from [19].	30
2.25	The proposed Fabry-Pérot antenna presented in [20] from which this image has been reproduced.	31
2.26	A textile cavity backed slot antenna as reproduced from [21].	31
2.27	A textile cavity backed slot antenna as reproduced from [22].	33
2.28	A folded cavity backed patch antenna as reproduced from [23].	33
2.29	A textile half-mode substrate-integrated cavity antenna as reproduced from [24].	34
2.30	A textile quarter mode cavity resonator antenna as reproduced from [25].	35
2.31	A dual-band textile antenna exploiting two independently fed radiators with omni-directional and broadside radiation patterns for integration into a military beret as reproduced from [26].	36

2.32	A dual-band slot loaded PIFA for operation at 433 MHz and 2.4 GHz as reproduced from [27].	36
2.33	A dual-band textile patch antenna with resonance frequencies at 2.45 and 5.8 GHz. This image is adapted from [28].	37
2.34	A dual-band quarter-mode cavity antenna as reproduced from [29].	38
2.35	An embroidered multi-band antenna as reproduced from [30].	38
2.36	A model which shows the typically periodic nature of metamaterials. This figure has been adapted from [31] where the text, dashed arrow and dashed red line has been incorporated by the author of this thesis.	39
2.37	A patch antenna with (a) and without (b) a textile soft surface as reproduced from [32].	41
2.38	A patch antenna periodically loaded with a EBG structure for surface wave enhancement as reproduced from [33].	41
2.39	Generic model of a CRLH transmission line as reproduced [34].	42
2.40	Dispersion diagram of a CRLH structure as reproduced [34].	42
2.41	A slotted shorted patch resonator based on the CRLH transmission line as reproduced from [35].	43
2.42	A textile antenna array based on probe fed patches as reproduced from [36].	45
2.43	A self-complementary antenna as reproduced from [36].	45
2.44	From top to bottom: (a) A dipole antenna and (b): the complementary slot antenna on an infinite ground plane.	45
2.45	A semi-textile antenna array at 60 GHz as reproduced from [37].	46
2.46	A textile aperture coupled patch antenna as reproduced from [38].	47
2.47	A textile and copper wire dipole antenna embedded into PDMS as reproduced from [39].	48
<hr/>		
3.1	A textile antenna utilizing conductive epoxy to realize a connection between the feeding element (SMA connector) and the antenna. This image is reproduced from [24].	52

List of Figures

3.2	From left to right (a) Microscopic view of conductive fabric with the application of copper laden solder and (b) Microscopic view of conductive fabric with the application of tin-lead solder. This image is reproduced from [40].	53
3.3	Dedicated snap-on buttons developed for military applications as reproduced from [41].	54
3.4	Commerical snap-on buttons used as a replacement for a SMA connector in a textile microstrip line as reproduced from [42].	55
3.5	Permanent magnets used to secure a textile transmission line structure to a rigid FR-4 substrate as reproduced from [43].	56
3.6	Conductive hook and loop connectors used to bridge a gap in a microstrip line fabricated on a FR-4 substrate as reproduced from [44].	56
3.7	Schematic view of the microstrip line geometry used to evaluate the connection strategies - (a) Side view, (b) Top view. The parameters are $L_S = 60$ mm, $W_S = 50$ mm, $L_T = 37.5$ mm, $D = 2$, $L_W = 7.5$ mm, $H_1 = 1.6$ mm.	58
3.8	Depiction of the proposed connection strategies from left to right: (a) Conductive epoxy, (b) Snap-on buttons, (c) Butterfly clasps, (d) Wing solution. Top row shows the physical structure of each connection strategy and the bottom row shows the approximation of the connection strategy for simulation purposes.	58
3.9	Fabrication procedure for the snap-on buttons connection strategy	60
3.10	Fabrication procedure for the wing connection strategy	61
3.11	Simulated and measured reflection coefficient for connection strategies. Dashed lines are simulations and solid lines are measurements.	62
3.12	Simulated and measured transmission coefficient for connection strategies. Dashed lines are simulations and solid lines are measurements.	63
—————		
4.1	A monopolar antenna integrated onto a metalized helmet for military applications. This image is adapted from [45].	66
4.2	Schematic view of the low-profile monopolar antenna under investigation. $R_{GND} = 175$ mm, $R_I = 33$ mm, $R_C = 37.5$ mm, $R_O = 53$ mm and $H = 25$ mm.	68
4.3	Simulated reflection coefficient of the low-profile monopolar antenna.	68

4.4	Depiction of the far-field radiation patterns when the ground plane is several wavelengths large. It is clearly observed that there is more radiated power in the upper half sphere than to the lower half sphere. The dotted black line represents the antenna ground plane.	69
4.5	The variation of the radiated power ratio in the upper to lower half-space for the monopolar antenna as a function of the ground plane radius. The oscillatory nature of the curves is attributed to the effect of ground plane ripples. The power ratio variation is shown for two frequencies: 0.9 GHz and 2.45 GHz.	71
4.6	Simulated radiation patterns for a ground plane radius of 175 mm and 925 mm at: (a) 0.9 GHz and (b) 2.45 GHz. For both frequencies the arrows show the increasing number of ripples in the radiation patterns as the radius of the ground plane increases.	71
4.7	Cross section of either cylindrical or spherical bending. The bending radius is denoted as R_B . There is also an effective radii denoted as R_{TOTAL}	72
4.8	Simulated variation in the ratio of radiated power in the upper to lower half-space for cylindrical and spherical bending at: (a) 0.9 GHz and (b) 2.45 GHz.	74
4.9	Simulated variation in the end-fire gain for cylindrical and spherical bending at (a): 0.9 GHz and (b) 2.45 GHz.	75
4.10	Radiation patterns showing the realized gain of the monopolar antenna using an electrically large ground plane. From top left to bottom right the radiation patterns at (a) Flat ground plane (0.9 GHz), (b) Cylindrical curvature at $\theta = 180^\circ$ (0.9 GHz), (c) Spherical curvature at $\theta = 180^\circ$ (0.9 GHz), (d) Flat ground plane (2.45 GHz), (e) Cylindrical curvature at $\theta = 180^\circ$ (2.45 GHz) and (f) Spherical curvature at $\theta = 180^\circ$ (2.45 GHz).	76
4.11	Schematic view of the low-profile monopolar antenna under investigation. $R_{GND} = 122$ mm, $R_I = 4$ mm, $R_O = 21$ mm and $H = 5$ mm.	77
4.12	Simulated reflection coefficient for the low-profile monopolar antenna designed to study the effects of a ground plane curvature from a body-worn perspective.	78
4.13	Simulated variation for the body-worn case showing (a) the ratio of radiated power in the upper to lower half space and (b) the end-fire gain.	79

List of Figures

4.14	Radiation patterns showing the realized gain of the monopolar antenna using a ground plane radius of 122 mm. The radiation patterns are shown for three cases: (a) Flat, (b) Bending angle of 90° , and (c) Bending angle of 180° . The bottom row shows the ground plane geometry at each of the bending angles.	80
<hr/>		
5.1	Embroidered transmission lines, patch antennas and arrays as reproduced from [46].	82
5.2	An asymmetric slot loaded dipole antenna that has been realized solely from computerized embroidery. This image is reproduced from [47]. . .	83
5.3	Various embroidered ground planes for patch antennas as reproduced from [48].	83
5.4	A variety of dipole antennas realized with different grid spacings reproduced from [49].	84
5.5	An example of an embroidered structure with equal stitch and grid spacing (a) and unequal stitch and grid spacing (b).	85
5.6	An embroidered structure with a grid/stitch spacing of 5 mm that has been prepared for this investigation.	89
5.7	Schematic of the experimental setup. The angle of incidence theta is exaggerated for better representation.	89
5.8	A photo of the experimental setup used to extract the properties of various embroidered surfaces.	90
5.9	Depiction of the three classically defined radar cross section regions for a sphere. Green - Rayleigh region, pink - resonance region and violet - optical region. This image is reproduced from [50]	91
5.10	Measured reflection coefficient for an embroidered structure at a grid/stitch spacing of 1 mm with a sample size of 180 x 180 mm (blue curve) and 170 x 170 mm (red curve) whereas the copper reference was 180 x 180 mm. This graph illustrates the importance of matching the sample size to that of copper reference.	93
5.11	Measured reflection coefficient for the embroidered structures with a grid/stitch spacing of 1, 5 and 10 mm with an embroidery density of 1 under (a) Co-polarized direction and (b) Cross-polarized direction. . .	95

5.12	Microscopic view of the embroidered structure with a grid/stitch spacing of 1 mm showing the two main orientations of the incident electric field relative to the thread direction.	96
5.13	Measured reflection coefficient for the embroidered structures with a grid/stitch spacing of 1 mm and an embroidery density of 1, 4 and 5 (a) Co-polarized direction and (b) Cross-polarized direction. The overlap between the reflection coefficient for an embroidery density of 1 and 4 under the co-polarized direction is attributed to measurement inaccuracies. The mild oscillations which are in the order of 0.2 dB in the reflection coefficient under the co-polarized direction at an embroidery density of 1 are also attributed to measurement inaccuracies.	99
5.14	Measured reflection coefficient for the embroidered structures with a grid/stitch spacing of 5 mm and an embroidery density of 1, 4 and 5 (a) Co-polarized direction and (b) Cross-polarized direction.	100
5.15	Measured reflection coefficient for the embroidered structures with a grid/stitch spacing of 10 mm and an embroidery density of 1, 4 and 5 (a) Co-polarized direction and (b) Cross-polarized direction.	101
5.16	Microscopic view of the embroidered structure with a grid/stitch spacing of 5 mm at an embroidery density of (a) 1 and (b) 5.	102
5.17	Microscopic view of the embroidered structures with a grid/stitch spacing of 1 mm where the conductive threads perpendicular to each other are at an embroidery density of (a) 1 and (b) 2.	102
5.18	Measured reflection coefficient for the meshed embroidered structures at a grid/stitch spacing of 1 mm under the co-polarized and cross-polarized direction for an embroidery density of (a) 1 and (b) 2.	104
5.19	Measured reflection coefficient for the meshed embroidered structures at a grid/stitch spacing of 5 mm under the co-polarized and cross-polarized direction for an embroidery density of (a) 1 and (b) 2.	105
5.20	Measured reflection coefficient for the meshed embroidered structures at a grid/stitch spacing of 10 mm under the co-polarized and cross-polarized direction for an embroidery density of (a) 1 and (b) 2.	106

5.21 Measured reflection coefficient for the meshed structure with a grid/stitch spacing of 5 mm at an embroidery density of 1 under both the co-polarized and cross-polarized directions compared against the measured reflection coefficient for the non-meshed structure at the same stitch spacing and embroidery density under the co-polarized direction. 107

5.22 The solid lines show the measured reflection coefficient of the embroidered structures with conductive threads laid parallel to each other at grid/stitch spacings of 5 and 10 mm with an embroidery density of 1. The dashed lines show the simulated reflection coefficient for the samples when modeled as a homogenized sheet with a sheet resistance determined from skin-depth considerations. 108

5.23 From top to bottom: (a) A meshed embroidered structure with a grid/stitch spacing of 10 mm, (b) a homogenized representation of the embroidered structure and (c) a physical representation of the embroidered structure. In the later case the width of the threads and the separation between the threads has been exaggerated for the purposes of illustration. 110

5.24 The measured reflection coefficient for the meshed 5 mm embroidered structure with an embroidery density of 1 and the numerically determined sheet resistance for the sample under two modeling methods: as a homogeneous sheet (MM1) and by approximating the physical layout of the conductive threads (MM2). 111

5.25 From left to right: (a) Top view of patch one and two and (b) Bottom view of patch two. The optimized dimensions are $L = W = 100$ mm, $G_S = 30$ mm, $F_P = 10$ mm, $P_L = 20$ mm, $P_W = 25$ mm. The bottom layer of patch one has a similar structure has patch two but as a purely conductive fabric ground plane with dimensions of $W \times L$ 113

5.26 A patch antenna using the meshed surface with a grid/stitch spacing of 5 mm at an embroidery density of 1 as a partial ground plane. 115

5.27 (a) Simulated and measured reflection coefficient for patch one in free-space and (b) Simulated and measured reflection coefficient for patch two in free-space. 116

5.28	Simulated and measured radiation patterns of both patch antennas in free-space. From top left to bottom right: (a) Patch one in E-Plane, (b) Patch one in H-Plane, (c) Patch two in E-Plane, (d) Patch two in H-Plane, (e) Patch two in E-Plane and (f) Patch two in H-Plane. The simulation results in (c) and (d) are obtained using MM1 whereas the simulation results in (e) and (f) are obtained using MM2.	118
5.29	Simulated and measured radiation patterns of both patch antennas when in close proximity to the human body: (a) Patch one in E-Plane, (b) Patch one in H-Plane, (c) Patch two in E-Plane and (d) Patch two in H-Plane.	119
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6.1	A broadband UHF antenna suitable for on-body operation as reproduced from [51].	122
6.2	A miniaturized UHF antenna for on-body operation realized on a rigid substrate as reproduced from [52].	123
6.3	A narrow band textile UHF antenna with an extended ground plane for isolation from the human body as reproduced from [53].	124
6.4	Geometry of the proposed antenna. The optimized parameters are $G_{EXT} = 10$ mm, $W_C = 60$ mm, $L_C = 100$ mm, $L_E = 10$ mm, $S_L = 52.5$ mm, $S_W = 39$ mm, $A_L = 90$ mm, $A_W = 7$ mm, $W_F = 28$ mm, $W_{CO} = 7$ mm, $W_{CC} = 25$ mm, $G = 12$ mm, $I = 43$ mm, $F_G = 1$ mm, $H_1 = 1.6$ mm, $H_2 = 3.2$ mm. Shaded grey areas represent metallization layers and dotted lines represent embroidered conducting walls. From left to right: (a) 2D layered view, (b) 3D exploded view, (c) cross sectional view of seam compression at the cavity walls.	125
6.5	Evolution of the proposed geometry from: (a) Standard cavity backed slot antenna, (b) Folded cavity backed slot antenna, (c) Multi-layer cavity backed slot antenna.	127
6.6	Electric field across the length of the antenna after cutting the antenna in half.	128
6.7	The modifications to the cavity structure to accommodate the shielded stripline feeding mechanism. For the sake of clarity only the bottom ground plane is shown. The dotted red lines depict the middle layer.	130
6.8	A section of an embroidered wall used to obtain a effective frequency dependent sheet resistance.	131

List of Figures

6.9	Depiction of seam compression as adapted from [24].	132
6.10	Simulated reflection coefficient in free-space and on-body.	133
6.11	Magnitude of the currents along the cavity length in (a) free-space and (b) on-body.	134
6.12	Simulated reflection coefficient when in proximity to human body tissue.	134
6.13	From left to right: (a) Top ground plane with radiating slot on 1.6 mm thick foam, (b) Middle layer on opposite side of 1.6 mm foam, (c) Front view of final antenna, (d) Bottom view of final antenna.	137
6.14	Simulated and measured reflection coefficient in free-space.	138
6.15	Simulated and measured reflection coefficient on-body.	138
6.16	Measured reflection coefficient of the antenna when bent along the width. The inset shows the opposing phase of the currents on the top ground plane.	139
6.17	Measured reflection coefficient of the antenna when bent along the length.	140
6.18	Simulated and measured radiation patterns: (a) Free-space patterns in ZY plane at 0.93 GHz, (b) Free-space patterns in ZX plane at 0.93 GHz, (c) On-body patterns in ZY plane at 0.93 GHz, (d) On-body in ZX plane at 0.93 GHz.	141
6.19	Measurement setup for the radiation patterns of the antenna when in close proximity to body tissue which is approximated here by a human body phantom.	141
6.20	(a) A top view of the magnitude of the Z component of the instantaneous electric field on the top surface of the middle plate for the multi-layer cavity-backed slot antenna using a SMA connector as the feeding mechanism and (b) A top view of the current distribution on the middle plate. The black dashed lines denote the position where a slot will be cut onto in the middle layer.	142
6.21	The middle layers of both the semi-open (a) and fully closed cavities (b).	144
6.22	Simulated reflection coefficient for the fully-closed cavity antenna with slot in its middle layer under free-space and on-body.	145
<hr/>		
7.1	A typical wearable antenna application scenario where a number of antennas on-body communicate with an off-body node as reproduced from [54].	148

7.2	A heavily miniaturized dual-band antenna based on the composite right-hand/left-hand transmission line (CRLH-TL) as reproduced from [55].	149
7.3	A dual-band coplanar patch antenna with a high impedance surface ground plane for isolation from the body as reproduced from [56].	150
7.4	A dual-band textile complementary antenna as reproduced from [57].	150
7.5	A dual-band textile antenna based on half-mode substrate-integrated cavity (HMSIC) as reproduced from [58].	151
7.6	Electric field distribution of a substrate-integrated cavity when operated in the fundamental TE_{10} mode.	152
7.7	A textile HMSIC antenna as reproduced from [24]	152
7.8	Schematic of the proposed geometry: (a) Top view, (b) Side view. The optimized parameters are $G_{EXT} = 30.5$ mm, $C_B = 4$ mm, $F_E = 2$ mm, $W_T = 12$ mm, $F_S = 20$ mm, $W_C = 81.5$ mm, $L_C = 35.5$ mm, $F_P = 9$ mm, $F_L = 40$ mm, $F_W = 6$ mm, $S_W = 1$ mm, $S_E = 5.2$ mm, $S_P = 18$ mm, $H_1 = 1.6$ mm, $H_2 = 3.2$ mm, $W = 100$ mm, $L = 95$ mm, $S_L = 18$ mm.	153
7.9	A depiction of the electric field developed along the HMSIC aperture. This image is adapted from [24]	154
7.10	A depiction of how the half-mode cavity can be excited through an SMA connector. The black dot represents the position where the inner pin of SMA connector making electrical contact with the top ground plane.	155
7.11	Simulated reflection coefficient of the HMSIC structure operating at the fundamental TE_{10} mode as shown in the inset.	156
7.12	A depiction of how the half-mode cavity is modified by incorporating a slot on the top layer to generate another resonance at 5.8 GHz.	157
7.13	Simulated reflection coefficient of the HMSIC structure with a slot incorporated on the top ground plane. The inset shows the slot mode and the higher order mode of the cavity.	158
7.14	Simulated reflection coefficient of the shielded stripline for a length of 100 mm.	159
7.15	Simulated transmission coefficient of the shielded stripline for a length of 100 mm.	159
7.16	A depiction of how the stripline is short circuited to the bottom ground plane to excite the fundamental TE_{10} mode.	160

List of Figures

7.17	Simulated electric field distribution from left to right: (a) 2.45 GHz, (b) 5.8 GHz.	161
7.18	Extracted effective RF sheet resistance for the embroidered walls and silver fabric.	162
7.19	Simulated reflection coefficient of the seam compressed antenna with material losses. Dashed lines denote the bands to be covered.	163
7.20	Selected steps of the fabrication process: (a) Computerized embroidery of the feedline, (b) Final structure after bonding both substrates and performing computerized embroidery to realize cavity walls.	165
7.21	Simulated and measured reflection coefficient in free-space and on-body. Dashed lines are simulations and solid lines are measurements.	166
7.22	Measured reflection coefficient of the antenna when bent along the width (ZX plane).	167
7.23	Measured reflection coefficient of the antenna when bent along the length (ZY plane).	167
7.24	Simulated and measured radiation patterns: (a) ZY plane at 2.47 GHz, (b) ZX plane at 2.47 GHz, (c) ZY plane at 5.74 GHz, (d) ZX plane at 5.74 GHz.	169
7.25	Schematic of the proposed design variation where the new aperture slot is shown in a red outline.	170
7.26	Simulated reflection coefficient of the nominal antenna and the antenna with a slot near the HMSIC aperture for bandwidth enhancement.	171
7.27	Simulated radiation patterns for two cases: The nominal design and the design variation incorporating the additional aperture slot. Dashed red lines correspond to the nominal design and dashed blue lines correspond to the design variation with the aperture slot. From top left to bottom right: (a) ZY plane at 2.45 GHz, (b) ZX plane at 2.45 GHz, (c) ZY plane at 5.8 GHz, (d) ZX Plane at 5.8 GHz.	172
<hr/>		
8.1	A fully flexible wearable frequency reconfigurable antenna as reproduced from [59]	174

8.2	A general depiction of the effects of detuning on the operation frequency of a wearable antenna. The solid blue line represents the operation frequency that an antenna can be designed for. The dashed red lines with the corresponding insets demonstrate the potential undesired variations in operating frequency due to water absorption, bending and dielectric loading by human body tissue.	175
8.3	A schematic of the modular patch antenna that is used to quantify the variations in operation frequency (a) and a prototype of the antenna which is used in this investigation (b).	176
8.4	Simulation results for the top metalized layer of the modular patch antenna embedded in a homogeneous layer of water with varying thickness.	178
8.5	Simulation results for (a) the antenna bent along the width and (b) the antenna bent along the length. In both cases the antenna is cylindrically bent around a bending radius of R	179
8.6	(a) Simulation results for the antenna in free-space and when placed above a human body tissue model by 1 mm and (b) Simulation results for the antenna in free-space and when a human finger is placed above the antenna at two different separations, namely 3 and 5 mm.	181
8.7	Simulated electric field distribution of the patch antenna when placed below a cylindrical three layer human body model.	182
8.8	(a) Measured results for the top layer of the patch sprayed with water at a close distance where the inset shows the moisture on the top layer of the antenna and (b) Measured results after allowing the top layer of the patch to dry for 300 seconds.	184
8.9	The measured results when the antenna is <i>placed below</i> a human finger for two spacings: 3 and 5 mm. The inset shows the measurement setup.	185
—————		
9.1	A rigid frequency reconfigurable half-mode substrate-integrated cavity antenna based on the concept of stub loading. This image is adapted from [60].	189
9.2	A frequency reconfigurable cavity-backed slot antenna with a fractional tuning range of 67% implemented in rigid substrate-integrated waveguide technology. This image is reproduced from [61].	190

9.3	A frequency reconfigurable inflexible cavity-backed slot antenna obtained by loading the radiating slot with a varactor. This image is reproduced from [62].	190
9.4	An inflexible frequency reconfigurable antenna with a very wide tuning range of 67% using two disconnected patches that are individually fed with microstrip lines. This image is reproduced from [63].	191
9.5	Layered view of the proposed antenna. From left to right: (a) Top layer which contains a broad radiating slot, (b) Middle layer which contains the feeding elements and varactors, (c) Bottom layer which contains the ground plane. Behind the ground plane is a small substrate which contains the bias network. The optimized parameters are: $W_C = 40$ mm, $L_C = 30.5$ mm, $S_W = 20$ mm, $S_L = 34$ mm, $W_F = 20$ mm, $P_W = 1.0$ mm, $P_L = 1.5$ mm, $V_P = 2$ mm, $V_G = 1$ mm, $I_{SW} = 5$ mm, $I_{SL} = 8$ mm, $F_G = 0.5$ mm, $F_{LW} = 5.0$ mm, $F_L = 11.25$ mm, $G = 4$ mm, $L_{CW} = 5$ mm, $C_S = 3$ mm, $L_E = 10$ mm, $B_{CW} = 1.5$ mm.	193
9.6	Top ground plane of the standard cavity-backed slot antenna (a) and bottom ground plane of the standard cavity-backed slot antenna (b). . .	194
9.7	A depiction of how the cavity topology is modified as a consequence of the “folding” operations. From left to right: (a) Standard cavity, (b) Folded cavity and (c) Multi-layer cavity.	195
9.8	Variation in the resonance frequency as a function of the capacitive gap between the middle layer and the cavity walls when the standard cavity-backed slot antenna is transformed into a square multi-layer cavity. The inset shows the topology of the antenna.	196
9.9	A schematic view of how the top layer of the cavity for each of the aforementioned solutions. From left to right: (a) Solution One, (b) Solution Two and (c) Solution Three.	196
9.10	The topology of the middle layer after the inclusion of the varactor pads.	197
9.11	Variation in the resonance frequency as a function of varactor capacitance for three different values of cavity and slot dimensions described previously as: Solution one, Solution two and Solution Three.	199
9.12	A zoomed in version of Fig. 9.11 over the capacitance range of approximately 1.0 - 10 pF. This range has been chosen as it represents a region where there is a large variation in the operating frequency.	200

9.13	Variation in the resonance frequency and radiation efficiency as a function of varactor capacitance for solution one.	201
9.14	Variation in the resonance frequency and radiation efficiency as a function of varactor capacitance for solution two.	201
9.15	Variation in the resonance frequency and radiation efficiency as a function of varactor capacitance for solution three.	202
9.16	Variation in the resonance frequency and radiation efficiency for solution three using three varactors.	203
9.17	A zoomed in version of the variation in the resonance frequency as a function of varactor capacitance for solution three using three varactors. Three regions known as Region 1, Region 2 and Region 3 corresponding to a capacitance range from 0.1 - 0.4 pF, 0.4 - 1.6 pF and 1.6 - 6.4 pF are shown. In all three regions the ratio of maximum to minimum capacitance is 4:1.	204
9.18	Two potential planar feeding mechanisms: (a) Shielded stripline and (b) Capacitively excited CPW.	205
9.19	Modifications to the cavity structure to accommodate the planar CPW feeding mechanism. The top substrate has been omitted as there is no variation in the topology. The solid red lines depict the middle layer. From left to right (a) Extending the bottom substrate, (b) introducing a width-wise cut in one of the cavity walls, (c) Introducing two length-wise cavity walls from the position of the aforementioned width-wise cut and (d) Introducing the microstripline - CPW feeding mechanism.	206
9.20	A depiction of the middle layer which shows the introduction of shorting rods on the varactor pads for the purposes of biasing.	207
9.21	The topology of the biasing board which is realized from Rogers Duroid 5880.	208
9.22	Variation in the resonance frequency and radiation efficiency for the antenna.	210
9.23	Top view of the top and bottom substrates.	211
9.24	Topology of the cavity walls which are realized from a 3.2 mm thick section of brass.	211
9.25	The top layer (a) and bottom layer (b) of the fabricated antenna.	212

List of Figures

9.26	Simulated and measured variation in the resonance frequency of the antenna as a function of varactor capacitance.	212
9.27	(a) Simulated and measured results for a varactor capacitance of 0.63 pF and (b) simulated and measured results for a varactor capacitance of 0.95 pF. In both cases the simulation results are presented for an varactor resistance of 0.8 Ω and 1.5 Ω	214
9.28	Simulated and measured radiation patterns for 0.63 pF.	215
9.29	Simulated and measured radiation patterns for 0.95 pF.	215

List of Tables

- 2.1 The advantages and disadvantages of using the aforementioned materials to realize wearable antennas. 22

- 5.1 Numerically determined sheet resistance for the embroidered structures using MM1. 112

- 6.1 Simulated peak realized gain variations as a function of ground plane extension G_{EXT} under various conditions. 135